

**DIVERSITY OF PLANKTON AND ICHTHYOFAUNA IN RELATION  
TO LIMNOCHEMISTRY OF RIVER TEESTA AND RELLI IN  
THE DARJEELING HIMALAYA OF WEST BENGAL**

**A Thesis Submitted to the University of North Bengal**

**For the award of**

**Doctor of Philosophy**

**In**

**Department of Zoology**

**By**

**Manik Lal Acharjee**

**SUPERVISOR**

**Dr. Sudip Barat**

**Professor**

**Department of Zoology**

**University of North Bengal**

**Dist. Darjeeling**

**West Bengal, India**

**734013**

**August, 2013.**



# UNIVERSITY OF NORTH BENGAL

**DEPARTMENT OF ZOOLOGY**

DST-FIST & UGC-SAP Sponsored



P.O. North Bengal University,  
Raja Rammohunpur, Dt. Darjeeling,  
West Bengal, India, PIN - 734 013

*From*  
*Dr. Sudip Barat*  
*Professor*

## CERTIFICATE

This is to certify that Mr. Manik Lal Acharjee, M.Sc., has prepared the thesis entitled '**Diversity of Plankton and Ichthyofauna in Relation to Limnochemistry of River Teesta and Relli in the Darjeeling Himalaya of West Bengal**', for the award of Ph.D Degree in Zoology of the University of North Bengal, under my guidance. He has carried out the work at the Department of Zoology, University of North Bengal.

Date: 8<sup>th</sup> August, 2013

(S. Barat)



## **DECLARATION**

I declare that the thesis entitled '**Diversity of Plankton and Ichthyofauna in Relation to Limnochemistry of River Teesta and Relli in the Darjeeling Himalaya of West Bengal**' has been prepared by me under the guidance of Dr. Sudip Barat, Professor, Department of Zoology, University of North Bengal. No part of the thesis has formed the basis for the award of any Degree or Fellowship previously.

Date:

**(Manik Lal Acharjee)**

Aquaculture and Limnology Research Unit  
Department of Zoology  
University of North Bengal



# DEDICATED

To my mother, Alo Acharjee, who encouraged my interests in diversity of life and to the memory of my grandfather, Raj Kumar Acharjee, who introduced me to the world of fish while fishing together in my early teenage at the riverside.



# *Acknowledgements*

---

*At first, it is a pleasure for me to implore reverting gratitude and indebtedness to my cogent, perspicacious and reverend supervisor of the present research work, Dr. Sudip Barat, Professor, Department of Zoology, University of North Bengal for unequivocal motivation, benevolent guidance, affectionate encouragement and constant supervision during the entire period of investigation and preparation of manuscript. His indefatigable spirit shall always my panacea.*

*It is a glorifying pleasure for me to record my thanks to the Honourable Vice-Chancellor, University of North Bengal, Dean, Registrar and other officials of the University for the academic and administrative facilities extended to me.*

*It is my pleasure to express my sincere thanks to the Head, Department of Zoology, University of North Bengal for providing me all the necessary facilities to carry out the research work.*

*I express deep gratitude to my respected teachers Prof. B. C. Pal, Prof. A. K. Chakravarty, Prof. D. C. Deb, Prof. J. Pal, Prof. Ananda Mukherjee and Prof. T. K. Chaudhuri for their useful suggestion, cooperation and constructive ideas throughout the pursuit of present work. Further, I extend my sincere thanks to all the staff members of Zoology Department, University of North Bengal for their kind cooperation.*

*Words cannot express heartfelt gratitude towards Dr. M. Bahadur, Dr. S. Bhattacharjee, for their useful suggestion, cooperation and constructive ideas throughout the pursuit of present work.*

*A note of thanks to my research colleagues Arindam Das, P. Jha, D. Saha, Debashree Mondal, Bishu Singh, Mayukh Sarkar, Deepa Barman, Pritam Goswami, Chandan Chakraborty, Rudra Prasad Roy, Soma Banerjee, Rakesh Bhagat, Ruksa Nur of Department of Zoology, North Bengal University for their cooperative support at all stages of the work.*

*I am deeply indebted to our Principal Dr. R. P. Dhakal and all staff of Kalimpong College, especially Mr. B. B. Sharma, Dr. D.C. Roy, Mr. M. N. Bhattacharya, Mr. Pravat Roy, Mr. N. Das, Dr. J. Pradhan, Dr. S. Mukherjee, Mr. D. D. Rai, Dr. S. Mondal, Mr. S. Saha for their unstinted support, cooperation, and encouragement during the study.*

*The author also likes to record his thanks to Mr. Gopal Chandra Mondal, Assistant Professor in Economics, Kalimpong College, who tirelessly helped me in statistical analyses. I am also grateful to the Chairman, Alipurduar Nature Club, and Mr. Soven Sanyal, Mr. Sumilan Ghosh, Mr. Sajal Mitra, Mr. Bipul Mazumder, Dr. Debasis Dutta for their support and help.*

*I would like to express my sincere thank to Mr. Suraj Rai, Kanchha Monger, Nabin Gupta, Gopal Chhetri, Krishna Pradhan, Shanti Rai, Bhim Bahadur Chhetri, Sangay Sherpa, Purna Bahadur Rai for their kind cooperation during field visit and sampling.*

*The author also expresses his sense of deep gratitude to Dr. Mrinal Mukherjee, of CIFRI, Barrackpore, Prof. A.P.Das, Department of Botany, University Of North Bengal, Dr. U. C. Pal, Principal, L. N. Khan Womens' College, Prof. D. N. Das for their valuable suggestion and encouragements during the course of the study.*

*I am indebted to my entire family members; Specially I would like to thank my wife Shruti, son Udvas, daughter Sampriti and uncle Anil Acharjee for their unending understanding and support.*

*I also like to thank to those well wishers who helped me knowingly or unknowingly during the period of present study.*

*Raja Rammohunpur*

*Manik Lal Acharjee*

*Dated-*

## *Abstract*

---

Largest **glacier-fed** river Teesta and its **spring-fed** tributary hill-stream Relli in the Darjeeling Himalaya were studied from March 2007 to February 2009 for assessing some selected physico-chemical parameters of water quality, density and diversity of phytoplankton, zooplankton and ichthyofauna through space and time. The present study evaluated the hypothesis that the tropical seasonality of this sub-tropical region affects the physico-chemical water quality of glacier-fed river and spring-fed hill-stream in different styles. This as a far-reaching consequence alters the density and diversity of phytoplankton, zooplankton and ichthyofauna in a predictable manner. The objective of the study was to compare diversity of plankton and ichthyofauna and their relationship with water quality in the glacier-fed river Teesta and its spring-fed tributary hill-stream Relli. The mean values of water temperature, pH, specific conductance, dissolved oxygen, free carbon dioxide and chloride in Teesta river water were found lower than those of the hill-stream Relli. But, the mean values of water velocity, total alkalinity, total hardness,  $\text{NH}_4\text{-N}$ ,  $\text{NO}_2\text{-N}$ ,  $\text{NO}_3\text{-N}$  and  $\text{PO}_4\text{-P}$  were found higher in Teesta river than those of the Relli. Water Quality parameters of both the streams showed strong seasonal dynamics, significant correlation and altitudinal variations, all pointing towards a unique pattern. Principal Component Analysis (PCA) reduced all the physico-chemical variables to two sets of uncorrelated transformed variables in the river Teesta (PC-I and PC-II) and three variables in the stream Relli (PC-I, PC-II and PC-III).

A total of 47 genera of phytoplankton found in the river Teesta was higher than 34 genera observed in Relli. Both the streams were dominated by Bacillariophyceae followed by Chlorophyceae, Cyanophyceae and Euglenophyceae. Value of similarity Index of phytoplankton between two streams was 0.84. The average values of density, number of genera, Shannon-Wiener Diversity Index and Margalef's Richness Index of phytoplankton in the Teesta were higher than those of Relli. On the contrary, mean value of Evenness Index in Teesta was slightly lower than that of Relli. Interestingly, same mean value of Index of Dominance of phytoplankton were observed in both the streams.

A total of 22 genera of zooplankton found in Teesta were higher than 18 genera observed in Relli. The river Teesta was dominated by Rotifera followed by Cladocera, Protozoa, and Copepoda. But in Relli zooplankton community was dominated by Rotifera followed by Protozoa, Copepoda and Cladocera. Value of similarity Index of zooplankton

between two streams was 0.80. Average values of density, number of genera, Shannon-Wiener diversity index, Evenness Index and Margalef's richness index in Teesta were higher than those of Relli. On the contrary, mean value of Dominance Index of zooplankton in Teesta was lower than that of Relli.

A total of 65 species of fish belonging to 3 orders, 10 families and 39 genera found in Teesta were higher than 25 species of fish belonging to 5 families and 15 genera observed in Relli. Maximum number of rheophilic, cold water hill stream species belong to the order Cypriniformes followed by Siluriformes in both the streams. Value of Similarity Index of ichthyofauna between two streams was 0.56. Among these fishes 10 species are endemic to India and about 55% fish species are threatened. Mean values of Fish Catch Per Unit Effort (CPUE), estimated population size, Number of Fish Species, Shannon-Wiener Species Diversity Index and Margalef's Species Richness Index in Teesta were higher than that of the Relli. On the contrary, mean values of Evenness Index and Dominance Index of ichthyofauna in Teesta were lower than those of Relli.

Abundance and diversity indices of phytoplankton, zooplankton and ichthyofaunal community in both the streams showed strong seasonal dynamics, strong altitudinal variations, weak annual dynamics and significant correlation amongst themselves and with water quality parameters, all pointing towards a unique pattern. Regression analysis showed causal relationship between the principal components of physico-chemical parameters and density and diversity indices of phytoplankton, zooplankton and ichthyofaunal community. Seasonality driven physical factors such as water velocity and water temperature were responsible for more mineralization of stream water by dissolving inorganic ions and nutrients which in turn regulating dynamics of density and diversity of plankton and ichthyofauna in a predictable fashion year after year until a big natural calamity. The study provides baseline data which may be helpful for conservation and management of the streams, biodiversity and also formulating new fishery policy.

**Key words:** *Darjeeling Himalaya, Ichthyodiversity, Teesta River, Hill-Stream Relli, Physico-Chemical Parameters, Zooplankton, Phytoplankton, Population Density, Catch Per Unit Effort, Population Size, Diversity Indices, Pearson's Correlation, PCA, Regression analysis.*

# *Preface*

---

*“Rivers are like mothers for the country and mountains like the father. This father is magnanimous thoughtful resolute archaic man and the rivers are conscious liberators, swift and source of knowledge. When clouds which roam free in the open sky spend themselves at the bedstead of the horizon after creating a commotion, then mother Earth conceives that life giving man with the halo through its river in arteries. These water-filled streams fill the earth with the power of procreation and energy. It is these streams flowing on the landmass which act as the blood-pumping arteries in the body”.*

*Kalidasa in Raghuvansham  
(Bharati, 2004)*

The Himalaya is often called the “Water Tower of India” as it is the source of the three largest rivers. These rivers have perennial flow throughout the year and operate as essential lifeline of the people on the flood plain and the downstream nation. The Ganga and The Brahmaputra drained Eastern Himalaya is considered as ‘biodiversity hotspot’ and also as ‘fresh water biodiversity hot spot’. Huge varieties of Cold water fish species, plankton, periphyton, macrobenthic invertebrates and other peculiar vertebrates constitute unique riverine biodiversity which is largely influenced by the physico-chemical characteristics of river water. But, the rich biodiversity and high level of endemism in Himalayan riverine waters especially in eastern Himalaya are under immediate threat of species extinction and habitat loss due to tremendous pressure from demotechnic growth. Himalayan riverine waters and biodiversity constitute a valuable natural resource, in economic, cultural, aesthetic, scientific and educational terms. Their conservation and management are critical to the interests of all humans, nations and governments. Yet this precious heritage is in crisis. Conservation of Himalayan riverine ecosystem is hamstrung by a lack of information. Information on biota, diversity, key-species, physico-chemical characteristics, spatio-temporal dynamics, interaction, influence etc is urgently needed.

Darjeeling, ‘the queen of hill stations’ fosters many perennial rivers which flow through deep gorges. A complicated pattern of drainage has evolved amidst the myriad of interlacing ridges and ramifying spurs of Darjeeling Himalaya. Rivers of this region belong either to the Ganga river system or to the Brahmaputra river system. The ‘Teesta’ or ‘Tista’ is the biggest and by far most turbulent glacier-fed river of Darjeeling district. Interestingly, the river was the part of the Ganga river system and shifted to the Brahmaputra river system in

the year 1787. The ichthyodiversity of this region is unique from the zoogeographical point of view. Major threats to riverine biodiversity of this region may be grouped under five interacting categories: over-exploitation; water pollution; flow modification; destruction or degradation of habitat; and invasion by exotic species, with global scale environmental changes being superimposed upon all of them. Two hydro-electric projects namely Teesta Low Dam Project-III and IV (TLDP-III and IV) are being constructed on river Teesta in this region by National Hydro Power Corporation (NHPC). Six other dams are in progress on the river in Sikkim and further downstream a mighty barrage without fish ladder at Gajoldoba in Jalpaiguri district already exists. A group of environmentalists are of opinion that dancing and roaring Teesta will be silenced and rich biodiversity will be lost if the dam building on the Teesta is completed. The Telegraph reported 'Fish vanish from Teesta' (**Lakhotia, 2003**), it wrote 'Going...going...gone'.

Many eminent workers collected fish from the Darjeeling Himalaya for taxonomic work but almost no work has been done on the distribution, abundance and diversity of plankton and ichthyofauna in relation to water quality either in the river Teesta or in its tributaries. The present work is intended to partially compensate the paucity of comprehensive and authentic information on the riverine ecosystem of Darjeeling Himalaya. Scientific understanding of diversity of Phytoplankton, zooplankton and ichthyofauna in relation to limnochemistry of glacier-fed river Teesta and its tributary hill-stream Relli in the Darjeeling Himalaya will help to understand the health of riverine system and also help in generation of constructive alternatives to meet the challenges of sustainable equitable development and utilization of the Teesta river system.

Manik Lal Acharjee

# Contents

Chapter No.	PARTICULARS	Page No.
<b>1.</b>	<b>INTRODUCTION</b>	1
	1.1. Background	1
	1.2. Rationale of the study	4
	1.3. Aims and Objectives	6
<b>2.</b>	<b>REVIEW OF LITERATURE</b>	7
	2.1. Lotic Ecosystem	7
	2.2. Himalayan River	8
	2.2.1. Water Quality Parameters	9
	2.2.1.1. Temperature	9
	2.2.1.2. Flow	11
	2.2.1.3. Chemistry	11
	2.2.1.3.1. Specific Conductance	12
	2.2.1.3.2. pH	12
	2.2.1.3.3. Dissolved Oxygen	14
	2.2.1.3.4. Free Carbon dioxide	14
	2.2.1.3.5. Total Alkalinity	15
	2.2.1.3.6. Chloride	16
	2.2.1.3.7. Total Hardness	17
	2.2.1.4. Nutrients	18
	2.2.1.4.1. Ammonium Nitrogen	19
	2.2.1.4.2. Nitrite Nitrogen	19
	2.2.1.4.3. Nitrate Nitrogen	20
	2.2.1.4.4. Phosphate Phosphorus	21
	2.2.2. Phytoplankton Community	21
	2.2.2.1. Taxonomic Diversity and Relative Abundance	22
	2.2.2.2. Density and Diversity Indices	24
	2.2.3. Zooplankton Community	26
	2.2.3.1. Taxonomic Diversity and Relative Abundance	27
	2.2.3.2. Density and Diversity Indices	28
	2.2.4. Ichthyofauna	30
	2.2.4.1. Taxonomic Diversity	31
	2.2.3.2. Density and Diversity Indices	34
<b>3.</b>	<b>MATERIALS AND METHODS</b>	36
	<b>3.1. Study area.</b>	36
	3.1.1. River system.	36
	3.1.1.1. River Teesta.	36
	3.1.1.2. Hill stream Relli.	37
	3.1.2. Teesta river basin.	38
	3.1.2.1. Physical and Geomorphic features.	38
	3.1.2.2. Physiography.	38
	3.1.2.3. Geological set up.	39
	3.1.2.4. Soil.	40
	3.1.2.5. Forest.	40
	3.1.2.6. Climate and Seasons.	41
	3.1.2.7. Population and Land use pattern.	42
	3.1.3. Sampling Sites.	43
	3.1.3.1. Descriptions of sampling Sites in the river Teesta.	43

3.1.3.2. Descriptions of sampling Sites in the Relli.	43
<b>3.2. Examination Procedure</b>	48
3.2.1. Collection of water sample for water quality analyses.	48
3.2.2. Methods for water analyses.	48
3.2.2.1. Air and water analyses.	48
3.2.2.2. Water velocity.	48
3.2.2.3. pH and electrical conductivity.	48
3.2.2.4. Dissolved Oxygen (DO), Free Carbon dioxide (Free CO <sub>2</sub> ), Total alkalinity, Total hardness and Chloride.	48
3.2.2.5. Phosphate-P (PO <sub>4</sub> -P), Ammonium-N (NH <sub>4</sub> -N), Nitrite-N (NO <sub>2</sub> -N) and Nitrate-N (NO <sub>3</sub> -N).	51
3.2.3. Qualitative and Quantitative Estimation of Plankton	51
3.2.3.1. Collection of Phytoplankton and Counting technique	51
3.2.3.2. Collection of Zooplankton and Counting technique	52
3.2.4. Qualitative and Quantitative Estimation of Ichthyofauna	52
3.2.5. Measurement of Diversity	54
3.2.5.1. Shannon – Wiener Species Diversity Index	54
3.2.5.2. Evenness Index	54
3.2.5.3. Species Richness Index	55
3.2.5.4. Index of dominance	55
3.2.5.5. Similarity index	55
3.2.6. Statistical analyses	56
3.2.6.1. Fisher t test	56
3.2.6.2. Karl Pearson's Correlation	56
3.2.6.3. Principal Component Analysis (PCA)	56
3.2.6.4. Simple Linear Regression	57
<b>4. RESULTS</b>	
<b>4.1. Water Quality of the river Teesta</b>	58
4.1.1. Monthly Variations of Water Quality Parameters	58
4.1.1.1. Air temperature	58
4.1.1.2. Water temperature	58
4.1.1.3. Water velocity	58
4.1.1.4. pH	61
4.1.1.5. Specific conductance	61
4.1.1.6. Dissolved oxygen	61
4.1.1.7. Free carbon dioxide	61
4.1.1.8. Total alkalinity	61
4.1.1.9. Chloride	62
4.1.1.10. Total hardness	62
4.1.1.11. Ammonium-N	62
4.1.1.12. Nitrite-N	62
4.1.1.13. Nitrate-N	64
4.1.1.14. Phosphate-P	64
4.1.2. Seasonal Variations of Water Quality Parameters	64
4.1.3. Annual Variations of Water Quality Parameters	68
4.1.4. Altitudinal Variations of Water Quality Parameters	68
4.1.5. Correlation and Principal Component Analysis.	70
4.1.5.1. Principal Component-I	70
4.1.5.2. Principal Component-II	71

<b>4.2. Water Quality of the hill-stream Relli.</b>	74
4.2.1. Monthly Variations of Water Quality Parameters	74
4.2.1.1. Air temperature.	74
4.2.1.2. Water temperature.	74
4.2.1.3. Water velocity.	74
4.2.1.4. pH	76
4.2.1.5. Specific conductance.	76
4.2.1.6. Dissolved oxygen.	76
4.2.1.7. Free carbon dioxide.	76
4.2.1.8. Total alkalinity.	76
4.2.1.9. Chloride.	76
4.2.1.10. Total hardness.	77
4.2.1.11. Ammonium-N.	77
4.2.1.12. Nitrite-N.	77
4.2.1.13. Nitrate-N.	77
4.2.1.14. Phosphate-P.	77
4.2.2. Seasonal Variations of Water Quality Parameters	83
4.2.3. Annual Variations of Water Quality Parameters	83
4.2.4. Altitudinal Variations of Water Quality Parameters	84
4.2.5. Correlation and Principal Component Analysis	84
4.2.5.1. Principal Component-I	86
4.2.5.2. Principal Component-II	86
4.2.5.3. Principal Component-III	86
<b>4.3. Diversity of Phytoplankton in the river Teesta</b>	90
4.3.1. Taxonomic diversity and Relative abundance	90
4.3.2. Monthly Variations of Density and diversity indices	90
4.3.2.1. Phytoplankton Density	90
4.3.2.2. Number of phytoplankton genera	92
4.3.2.3. Shannon-Wiener Species Diversity Index	92
4.3.2.4. Phytoplankton Evenness Index	92
4.3.2.5. Margalef's Richness Index	92
4.3.2.6. Index of Dominance	92
4.3.3. Similarity Index of phytoplankton	95
4.3.4. Seasonal Variations of Density and diversity indices	95
4.3.5. Annual Variations of Density and diversity indices	96
4.3.6. Altitudinal Variations of Density and diversity indices	96
4.3.7. Density and Diversity Indices of Phytoplankton and Water Quality	96
4.3.7.1. Density of Phytoplankton	99
4.3.7.2. Number of Phytoplankton genera	99
4.3.7.3. Shannon-Wiener Diversity Index of Phytoplankton.	100
4.3.7.4. Evenness Index of Phytoplankton.	100
4.3.7.5. Richness Index of Phytoplankton.	101
4.3.7.6. Dominance Index of Phytoplankton.	101
<b>4.4. Diversity of Phytoplankton in the hill-stream Relli</b>	104
4.4.1. Taxonomic diversity and Relative abundance	104
4.4.2. Monthly Variations of Density and diversity indices	104
4.4.2.1. Phytoplankton Density	104
4.4.2.2. Number of phytoplankton genera	108
4.4.2.3. Shannon-Wiener Species Diversity Index	108
4.4.2.4. Phytoplankton Evenness Index	108
4.4.2.5. Margalef's Richness Index	108
4.4.2.6. Index of Dominance	108

4.4.3. Similarity Index of phytoplankton	109
4.4.4. Seasonal Variations of Density and diversity indices	109
4.4.5. Annual Variations of Density and diversity indices	110
4.4.6. Altitudinal Variations of Density and diversity indices	110
4.4.7. Density and Diversity Indices of Phytoplankton and Water Quality	110
4.4.7.1. Density of Phytoplankton	113
4.4.7.2. Number of Phytoplankton genera	113
4.4.7.3. Shannon-Wiener Diversity Index of Phytoplankton.	114
4.4.7.4. Evenness Index of Phytoplankton.	114
4.4.7.5. Richness Index of Phytoplankton.	115
4.4.7.6. Dominance Index of Phytoplankton.	115
<b>4.5. Diversity of Zooplankton in the River Teesta.</b>	<b>118</b>
4.5.1. Taxonomic Diversity and Relative Abundance.	118
4.5.2. Monthly Variations of Density and Diversity indices	118
4.5.2.1. Zooplankton Density	118
4.5.2.2. Number of Zooplankton Genera	118
4.5.2.3. Shannon-Wiener Diversity Index	122
4.5.2.4. Zooplankton Evenness Index	122
4.5.2.5. Margalef's Richness Index	122
4.5.2.6. Index of Dominance.	122
4.5.3. Similarity Index of zooplankton.	123
4.5.4. Seasonal Variations of Density and Diversity Indices	123
4.5.5. Annual Variations of Density and Diversity Indices	123
4.5.6. Altitudinal Variations of Density and Diversity Indices	124
4.5.7. Density and Diversity Indices of Zooplankton and Water Quality	124
4.5.7.1. Density of Zooplankton	127
4.5.7.2. Number of Zooplankton genera	127
4.5.7.3. Shannon-Wiener Diversity Index of Zooplankton.	128
4.5.7.4. Evenness Index of Zooplankton.	128
4.5.7.5. Margalef's Richness Index of Zooplankton.	128
4.5.7.6. Dominance Index of Zooplankton.	129
<b>4.6. Diversity of Zooplankton in the hill-stream Relli.</b>	<b>132</b>
4.6.1. Taxonomic Diversity and Relative Abundance.	132
4.6.2. Monthly Variations of Density and Diversity indices	132
4.6.2.1. Zooplankton Density	132
4.6.2.2. Number of Zooplankton Genera	132
4.6.2.3. Shannon-Wiener Diversity Index	136
4.6.2.4. Zooplankton Evenness Index	136
4.6.2.5. Margalef's Richness Index	136
4.6.2.6. Index of Dominance.	136
4.6.3. Similarity Index of zooplankton.	137
4.6.4. Seasonal Variations of Density and Diversity Indices	137
4.6.5. Annual Variations of Density and Diversity Indices	138
4.6.6. Altitudinal Variations of Density and Diversity Indices	138
4.6.7. Density and Diversity Indices of Zooplankton and Water Quality	139
4.6.7.1. Density of Zooplankton	140
4.6.7.2. Number of Zooplankton genera	141
4.6.7.3. Shannon-Wiener Diversity Index of Zooplankton.	142
4.6.7.4. Evenness Index of Zooplankton.	142
4.6.7.5. Margalef's Richness Index of Zooplankton.	143
4.6.7.6. Dominance Index of Zooplankton.	143

<b>4.7. Ichthyodiversity in the river Teesta.</b>	146
4.7.1. Taxonomic diversity and Relative abundance	146
4.7.2. Monthly Variations of Density and diversity indices	147
4.7.2.1. Catch per Unit Effort	147
4.7.2.2. Estimated fish population size	147
4.7.2.3. Number of fish species	147
4.7.2.4. Shannon-Wiener Species Diversity Index	147
4.7.2.5. Ichthyofaunal Evenness Index	148
4.7.2.6. . Ichthyofaunal Species Richness Index	148
4.7.2.7. Index of Dominance	148
4.7.3. Similarity Index	148
4.7.4. Seasonal Variations of Density and Diversity Indices	149
4.7.5. Annual Variations of Density and Diversity Indices	153
4.7.6. Altitudinal Variations of Density and Diversity Indices	153
4.7.7. Density and Diversity Indices of Ichthyofauna and Water Quality	154
4.7.7.1. Catch Per Unit Effort (CPUE)	154
4.7.7.2. Estimated Population Size	157
4.7.7.3. Number of Fish Species	157
4.7.7.3. Shannon-Wiener Species Diversity Index	158
4.7.7.4. Ichthyofaunal Evenness Index	158
4.7.7.5. Ichthyofaunal Species Richness Index	158
4.7.7.6. Ichthyofaunal Dominance Index	159
<b>4.8. Ichthyodiversity in the hill-stream Relli.</b>	162
4.8.1. Taxonomic diversity and Relative abundance	162
4.8.2. Monthly Variations of Density and diversity indices	162
4.8.2.1. Catch per Unit Effort (CPUE)	162
4.8.2.2. Estimated fish population size	165
4.8.2.3. Number of fish species	165
4.8.2.4. Shannon-Wiener Species Diversity Index	165
4.8.2.5. Ichthyofaunal Evenness Index	167
4.8.2.6. Ichthyofaunal Species Richness Index	167
4.8.2.7. Index of Dominance	167
4.8.3. Similarity Index	167
4.8.4. Seasonal Variations of Density and Diversity Indices	167
4.8.5. Annual Variations of Density and Diversity Indices	168
4.8.6. Altitudinal Variations of Density and Diversity Indices	171
4.8.7. Density and Diversity Indices of Ichthyofauna and Water Quality	171
4.8.7.1. Catch Per Unit Effort (CPUE)	171
4.8.7.2. Estimated Fish Population Size	172
4.8.7.3. Number of Fish Species	172
4.8.7.3. Shannon-Wiener Species Diversity Index	173
4.8.7.4. Ichthyofaunal Evenness Index	173
4.8.7.5. Ichthyofaunal Species Richness Index	173
4.8.7.6. Ichthyofaunal Dominance Index	174
<b>5. DISCUSSION</b>	
5.1. Water Quality	177
5.1.1. Water Colour	177
5.1.2. Water Flavour	177
5.1.3. Air Temperature	178
5.1.4. Water Temperature	178
5.1.5. Water Velocity	179
5.1.6. pH of water	180
5.1.7. Specific Conductance	181

5.1.8. Dissolved Oxygen	181
5.1.9. Free Carbon dioxide	182
5.1.10. Total Alkalinity	182
5.1.11. Chloride	183
5.1.12. Total Hardness	184
5.1.13. Ammonium Nitrogen	185
5.1.14. Nitrite Nitrogen	185
5.1.15. Nitrate Nitrogen	186
5.1.16. Phosphate phosphorus	187
5.1.17. Principal Component Analysis of Physico-Chemical Variables	187
5.1.17.1. PCA of Water Quality of the Hill-Stream Relli	188
5.1.17.1.1. PC-I; More Physical/Nutrients and Less Chemicals	188
5.1.17.1.2. PC-II; More Nutrients and Less Physical	188
5.1.17.1.3. PC-III; More Chemicals	188
5.1.17.2. PCA of Water Quality of the River Teesta	189
5.1.17.2.1. PC-I; More Physical/Nutrients and Less Chemicals	189
5.1.17.2.2. PC-II; More Chemicals and Less Physical	189
5.2. Phytoplankton Diversity	190
5.2.1. Taxonomic Diversity	190
5.2.2. Density and Diversity Indices	192
5.2.3. Altitudinal Variations of Density and Diversity Indices	197
5.2.4. Annual Variations of Density and Diversity Indices	198
5.2.5. Phytoplankton Diversity in Relation to Water Quality	198
5.3. Zooplankton Diversity	201
5.3.1. Taxonomic Diversity	201
5.3.2. Density and Diversity Indices	202
5.3.3. Altitudinal Variations of Density and Diversity Indices	206
5.3.4. Annual Variations of Density and Diversity Indices	207
5.3.5. Zooplankton Diversity in Relation to Water Quality	208
5.4. Ichthyodiversity	211
5.4.1. Taxonomic Diversity	211
5.3.2. Density and Diversity Indices	214
5.3.3. Seasonal Variations of Density and Diversity Indices	217
5.3.3. Altitudinal Variations of Density and Diversity Indices	218
5.3.4. Annual Variations of Density and Diversity Indices	219
5.3.5. Ichthyodiversity in Relation to Water Quality	219
<b>6. SUMMARY</b>	<b>223</b>
<b>7. BIBLIOGRAPHY</b>	<b>227</b>

## List of Tables

Table No.	TITLE	Page No.
Table 3-1	Range (maximum and minimum) and Average temperature ( $^{\circ}\text{C}$ ) at study area during study period.	44
Table 3-2	Range (maximum and minimum) and average of relative humidity at study area during study period.	44
Table 3-3	Rainfall data (mm.) and number of rainy days at study area during study period.	44
Table 3-4	Physical characteristics, location, and channel morphology in the sampling sites of the river Teesta.	47
Table 3-5	Physical characteristics and channel morphology in the sampling sites of the hill stream Relli.	44
Table 3-6	Water quality parameters estimated and the method applied for estimation of water quality during the survey.	49
Table 4.1-1	Summary of the Water Quality Parameters (range, average, standard deviation) in the River Teesta (n=96) during two Years of Study Period.	59
Table 4.1-2	Results of Test of Significance for Difference in Means (Fisher's t) of Seasonal Values of Physico-Chemical Parameters of Water Quality of the River Teesta During the Study Period (March 2007 to February 2009).	67
Table 4.1-3	Mean Values ( $\pm$ standard deviation) of Physico-Chemical Parameters of Water Quality along the Altitudinal Gradient (n=24) of Teesta and Comparisons of Mean ( $\pm$ standard deviation) Annual Values (n=48) During the two years of Study Period.	69
Table 4.1-4	Statistical Descriptive and Kolmogorov–Smirnov Normality Tests for the Physico-Chemical Variables Analysed.	69
Table 4.1-5	KMO and Bartlett's Test of the Data Set	71
Table 4.1-6	Interpretation and Eigenvalues of the Components, Component Loadings of the Variables and extracted communalities. (Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization).	71
Table 4.1-7	Pearson's Correlation Coefficient Matrix for Physico-Chemical Water Quality of the River Teesta (n=96, d.f. 94).	73
Table 4.2-1	Summary of the Water Quality Parameters (range, average, standard deviation) in the hill stream Relli (n=72) During Two Years of the Study Period.	75
Table 4.2-2	Results of Test of Significance for Difference in Means (Fisher's t) of Seasonal Values of Physico-Chemical Parameters of Water Quality of the hill stream Relli During the Study Period (March 2007 to February 2009).	82
Table 4.2-3	Mean Values ( $\pm$ standard deviation) of Physico-Chemical Parameters of Water Quality along the Altitudinal Gradient (n=24) of Relli and Comparisons of Mean ( $\pm$ standard deviation) Annual Values (n=36) During the two years of Study Period.	85
Table 4.2-4	Statistical Descriptive and Kolmogorov–Smirnov Normality Tests for the Physico-Chemical Variables Analysed.	85
Table 4.2-5	KMO and Bartlett's Test of the Data Set	85
Table 4.2-6	Interpretation and Eigenvalues of the Components, Component Loadings of the Variables and Extracted Communalities.	88
Table 4.2-7	Pearson's Correlation Coefficients Matrix for Physico-Chemical Parameters of Water Quality of the Hill-Stream Relli at the three Sites.	89
Table 4.3-1	Taxonomic Diversity and Relative Abundance of Phytoplankton in four sampling sites of river Teesta during the study period.	91
Table 4.3-2	Percent Composition of Phytoplankton Groups in four sampling sites of river Teesta during the study period.	93
Table 4.3-3	Summary of Phytoplankton Density and Diversity Indices of (showing the Range and Mean $\pm$ Standard Deviation) of the river Teesta (n=96) during the study period.	93

Table 4.3-4	Similarity Index Variations at Different Sampling Sites in Teesta river during the Study Period.	98
Table 4.3-5	Results of Test of Significance for Difference in Means (Fisher's t) of Seasonal Values of Density and Diversity Indices of Phytoplankton in the hill stream Relli During the Study Period (March 2007 to February 2009).	98
Table 4.3-6	Mean Values ( $\pm$ standard deviation) of Density and Diversity Indices of Phytoplankton along the Altitudinal Gradient (n=24) of Teesta and Comparisons of Mean ( $\pm$ standard deviation) Annual Values (n=48) During the two years of Study Period.	98
Table 4.3-7	Physico-Chemical Water Quality Determinants of phytoplankton diversity: OLS Estimation.	102
Table 4.3-8	Pearson's Correlation Coefficients Matrix for Phytoplankton Density and Diversity Indices and Water Quality Parameters of the river Teesta.	103
Table 4.4-1	Taxonomic Diversity and Relative Abundance of Phytoplankton in three sampling sites of the hill stream Relli during the study period.	105
Table 4.4-2	Percent Composition of Phytoplankton Groups in three sampling sites of the hill stream Relli during the study period.	106
Table 4.4-3	Summary of Phytoplankton Density and Diversity Indices (showing the Range and Mean $\pm$ Standard Deviation) of the hill stream Relli (n=72) during the study period.	106
Table 4.4-4	Values of Similarity Index of Phytoplankton between different sampling sites in the hill stream during two years of study period.	112
Table 4.4-5	Results of Test of Significance for Difference in Means (Fisher's t) of Seasonal Values of density and diversity indices of phytoplankton in the hill stream Relli During the Study Period (March 2007 to February 2009).	112
Table 4.4-6	Mean Values ( $\pm$ standard deviation) of Density and Diversity Indices of Phytoplankton along the Altitudinal Gradient (n=24) of Relli and Comparisons of Mean ( $\pm$ standard deviation) Annual Values (n=36) During the two years of Study Period.	112
Table 4.4-7	Pearson's Correlation Coefficients Matrix for Phytoplankton Density and Diversity Indices and Water Quality of the river Relli.	116
Table 4.4-8	Physico-chemical Water Quality Determinants of phytoplankton diversity: OLS Estimation.	117
Table 4.5-1	Taxonomic Diversity and Relative Abundance of Zooplankton in four sampling sites of the river Teesta during the study period.	119
Table 4.5-2	Percent Composition of Zooplankton Groups in four sampling sites of river Teesta during the study period.	120
Table 4.5-3	Summary of Zooplankton Density and Diversity Indices of (showing the Range and Mean $\pm$ Standard Deviation) of the River Teesta (n=96) during the study period.	120
Table 4.5-4	Similarity Index Variations at Different Sampling Sites in Teesta river during the Study Period.	120
Table 4.5-5	Results of Test of Significance for Difference in Means (Fisher's t) of Seasonal Values of Density and Diversity Indices of Zooplankton in the river Teesta During the Study Period (March 2007 to February 2009).	126
Table 4.3-6	Mean Values ( $\pm$ standard deviation) of Density and Diversity Indices of Zooplankton along the Altitudinal Gradient (n=24) of Teesta river and Comparisons of Mean ( $\pm$ standard deviation) Annual Values (n=48) During the two years of Study Period.	126
Table 4.5-7	Physico-Chemical Determinants of Zooplankton Diversity in Teesta River: OLS Estimation.	130
Table 4.5-8	Pearson's Correlation Coefficients Matrix for Zooplankton Density and Diversity Indices and Water Quality of the river Teesta.	131
Table 4.6-1	Taxonomic Diversity and Relative Abundance of Zooplankton in three sampling sites of the hill stream Relli during the study period.	133
Table 4.6-2	Percent Composition of Zooplankton Groups in three sampling sites of the hill-stream Relli during the study period.	133

Table 4.6-3	Summary of Zooplankton Density and Diversity Indices of (showing the Range and Mean $\pm$ Standard Deviation) of the hill stream Relli (n=72) during the study period.	134
Table 4.6-4	Similarity Index Variations at Different Sampling Sites in Relli river during the Study Period.	134
Table 4.6-5	Results of Test of Significance for Difference in Means (Fisher's t) of Seasonal Values of density and diversity indices of zooplankton in the hill stream Relli During the Study Period (March 2007 to February 2009).	139
Table 4.6-6	Mean Values ( $\pm$ standard deviation) of Density and Diversity Indices of zooplankton along the Altitudinal Gradient (n=24) of Relli and Comparisons of Mean ( $\pm$ standard deviation) Annual Values (n=36) During the two years of Study Period.	139
Table 4.6-7	Physico-Chemical Determinants of Zooplankton Diversity: OLS Estimation.	144
Table 4.6-8	Pearson's Correlation Coefficients Matrix for Zooplankton Density and Diversity Indices and Water Quality of the river Relli.	145
Table 4.7-1	Occurrence, Distribution and Relative Abundance of Fish Species at all the Sampling Sites of the River Teesta During the Study Period.	155
Table 4.7-2	Percent Composition of Fish Groups in Four Sampling Sites of River Teesta During the Study Period.	149
Table 4.7-3	Summary of Ichthyofaunal Density and Diversity Indices of (showing the Range and Mean $\pm$ Standard Deviation) of the River Teesta (n=96) During the Study Period.	150
Table 4.7-4	Similarity Index Variations at Different Sampling Sites in Teesta river during the Study Period.	150
Table 4.7-5	Results of Test of Significance for Difference in Means (Fisher's t) of Seasonal Values of Density and Diversity Indices of Ichthyofauna in the river Teesta During the Study Period (March 2007 to February 2009).	156
Table 4.7-6	Mean Values ( $\pm$ standard deviation) of Density and Diversity Indices of Ichthyofauna along the Altitudinal Gradient (n=24) of Teesta river and Comparisons of Mean ( $\pm$ standard deviation) Annual Values (n=48) During the two years of Study Period.	156
Table 4.7-7	Physico-Chemical Determinants of Ichthyodiversity in Teesta: OLS Estimation.	160
Table 4.7-8	Pearson's Correlation Coefficients Matrix for Ichthyofaunal Density and Diversity Indices and Water Quality of the river Teesta.	161
Table 4.8-1	Occurrence, Distribution and Relative Abundance of Fish Species at the Sampling Sites of Relli River During the Study Period.	163
Table 4.8-2	Percent Composition of Fish Groups in Three Sampling Sites of River Relli During the Study Period.	163
Table 4.8-3	Summary of Ichthyofaunal Density and Diversity Indices of (showing the Range and Mean $\pm$ Standard Deviation) of the Hill Stream Relli (n=72) During the Study Period.	164
Table 4.8-4	Similarity Index Variations at Different Sampling Sites in the Hill-Stream Relli during the Study Period.	164
Table 4.8-5	Results of Test of Significance for Difference in Means (Fisher's t) of Seasonal Values of Density and Diversity Indices of Ichthyofauna in the hill stream Relli During the Study Period (March 2007 to February 2009).	170
Table 4.8-6	Mean Values ( $\pm$ standard deviation) of Density and Diversity Indices of Ichthyofauna along the Altitudinal Gradient (n=24) of Relli and Comparisons of Mean ( $\pm$ standard deviation) Annual Values (n=36) During the two years of Study Period.	170
Table 4.8-7	Physico-Chemical Determinants of Ichthyodiversity: OLS Estimation.	175
Table 4.6-8	Pearson's Correlation Coefficients Matrix for Ichthyofaunal Density and Diversity Indices and Water Quality of the hill-stream Relli	176



# List of Figures

Figure No.	Title	Page No.
<b>Figure 3-1</b>	Map showing study area and sampling sites in the river Teesta and hill-stream Relli.	<b>45</b>
<b>Figure 3-2</b>	Map showing study area and sampling sites in the river Teesta and hill-stream Relli.	<b>45</b>
<b>Figure 3-3</b>	Satellite images of sampling sites (courtesy Google Earth) and photo of author at the river side.	<b>46</b>
<b>Figure 3-3a</b>	Slope gradient and sampling sites in Teesta river (a) and Relli (b) in Darjeeling Himalaya.	<b>47</b>
<b>Figure 3-4</b>	The fish population (N) estimate using simple linear regression and determining the x-intercept for the cumulative catch.	<b>50</b>
<b>Figure 4.1-1</b>	Monthly variations of air (a) and water (b) temperature during first and second year of the study period (March 2007-February 2009).	<b>59</b>
<b>Figure 4.1-2</b>	Monthly variations of water velocity (a) and pH (b) of the hill stream water during first and second year of the study period (March 2007-February 2009).	<b>60</b>
<b>Figure 4.1-3</b>	Monthly variations of specific conductance (a) and dissolved oxygen (b) of the hill stream water during first and second year of the study period (March 2007-February 2009).	<b>60</b>
<b>Figure 4.1-4</b>	Monthly variations of free CO <sub>2</sub> (a) and total alkalinity (b) of the hill stream water during first and second year of the study period (March 2007-February 2009).	<b>60</b>
<b>Figure 4.1-5</b>	Monthly variations of chloride (a) and total hardness (b) of the hill stream water first and second year of during the study period (March 2007-February 2009).	<b>63</b>
<b>Figure 4.1-6</b>	Monthly variations of ammonium nitrogen (a) and nitrite nitrogen (b) of the hill stream water first and second year of during the study period (March 2007-February 2009).	<b>63</b>
<b>Figure 4.1-7</b>	Monthly variations of nitrate nitrogen (a) and phosphate phosphorus (b) of the hill stream water during first and second year of the study period (March 2007-February 2009).	<b>63</b>
<b>Figure 4.1-8</b>	Seasonal variations of air temperature (a), water temperature (b), water velocity (c), pH (d), specific conductance (e) and dissolved oxygen (f) in the three sampling sites of the Teesta river water during the study period (March 2007-February 2009).	<b>65</b>
<b>Figure 4.1-9</b>	Seasonal variations of free Carbon dioxide (g), total alkalinity (h) Chloride (i) total hardness (j), Ammonium-N (k) and nitrite-N (l) in the three sampling sites of the hill stream water during the study period (March 2007-February 2009).	<b>66</b>
<b>Figure 4.1-10</b>	Seasonal variations of Nitrate-N (m) and phosphate-P (n) in the three sampling sites of the hill stream water during the study period (March 2007-February 2009).	<b>67</b>

<b>Figure 4.1-11</b>	PCA ordination for physico-chemical factors of Teesta on main factor plane.	<b>72</b>
<b>Figure 4.2-1</b>	Monthly variations of air (a) and water (b) temperature during first and second year of the study period (March 2007-February 2009).	<b>75</b>
<b>Figure 4.2-2</b>	Monthly variations of water velocity (a) and pH (b) of the hill stream water during first and second year of the study period (March 2007-February 2009).	<b>75</b>
<b>Figure 4.2-3</b>	Monthly variations of specific conductance (a) and dissolved oxygen (b) of the hill stream water during first and second year of the study period (March 2007-February 2009).	<b>78</b>
<b>Figure 4.2-4</b>	Monthly variations of free CO <sub>2</sub> (a) and total alkalinity (b) of the hill stream water during first and second year of the study period (March 2007-February 2009).	<b>78</b>
<b>Figure 4.2-5</b>	Monthly variations of chloride (a) and total hardness (b) of the hill stream water first and second year of during the study period (March 2007-February 2009).	<b>78</b>
<b>Figure 4.2-6</b>	Monthly variations of ammonium nitrogen (a) and nitrite nitrogen (b) of the hill stream water first and second year of during the study period (March 2007-February 2009).	<b>79</b>
<b>Figure 4.2-7</b>	Monthly variations of nitrate nitrogen (a) and phosphate phosphorus (b) of the hill stream water during first and second year of the study period (March 2007-February 2009).	<b>79</b>
<b>Figure 4.2-8</b>	Seasonal variations of air temperature (a), water temperature (b), water velocity (c), pH (d), specific conductance (e) and dissolved oxygen (f) in the three sampling sites of the hill stream water during the study period (March 2007-February 2009).	<b>80</b>
<b>Figure 4.2-9</b>	Seasonal variations of free Carbon dioxide (g), total alkalinity (h) Chloride (i) total hardness (j), Ammonium-N (k) and nitrite-N (l) in the three sampling sites of the hill stream water during the study period (March 2007-February 2009).	<b>81</b>
<b>Figure 4.2-10</b>	Seasonal variations of Nitrate-N (m) and phosphate-P (n) in the three sampling sites of the hill stream water during the study period (March 2007-February 2009).	<b>82</b>
<b>Figure 4.2-11</b>	PCA ordination for physico-chemical factors of Relli on main factor plane.	<b>87</b>
<b>Figure 4.3-1</b>	Percent Composition of different Phytoplankton Groups in the River Teesta.	<b>93</b>
<b>Figure 4.3-2</b>	Monthly variations of phytoplankton density (a) and number of genera (b) river Teesta during the study period.	<b>94</b>
<b>Figure 4.3-3</b>	Monthly variations of Shannon-Wiener Diversity Index (a) and Evenness Index (b) of phytoplankton in the river Teesta during the study period.	<b>94</b>
<b>Figure 4.3-4</b>	Monthly variations of Margalef's Richness Index (a) and Dominance Index (b) of phytoplankton in the river Teesta during the study period.	<b>94</b>
<b>Figure 4.3-5</b>	Seasonal variations of phytoplankton density (a) and number of genera (b) in the four sampling sites of the river Teesta during the study period.	<b>97</b>

<b>Figure 4.3-6</b>	Seasonal variations of Shannon-Wiener Diversity Index (a) and Evenness Index (b) of phytoplankton in the four sampling sites of the river Teesta during the study period.	<b>97</b>
<b>Figure 4.3-7</b>	Seasonal variations of Margalef's Richness Index (a) and Dominance Index (b) of phytoplankton in the four sampling sites of the river Teesta during the study period.	<b>97</b>
<b>Figure 4.4-1</b>	Percent Composition of Phytoplankton Groups in the hill-stream Relli.	<b>106</b>
<b>Figure 4.4-2</b>	Monthly variations of phytoplankton density (a) and number of genera (b) hill stream Relli during the study period.	<b>107</b>
<b>Figure 4.4-3</b>	Monthly variations of Shannon-Wiener Diversity Index (a) and Evenness (b) of phytoplankton in the hill stream Relli during the study period.	<b>107</b>
<b>Figure 4.4-4</b>	Monthly variations of Margalef's Richness Index (a) and Dominance Index of phytoplankton in the hill stream Relli during the study period.	<b>107</b>
<b>Figure 4.4-5</b>	Seasonal variations of phytoplankton density (a) and number of genera (b) in the three sampling sites of the hill stream water during the study period.	<b>111</b>
<b>Figure 4.4-6</b>	Seasonal variations of Shannon-Wiener diversity Index (a) and Evenness Index (b) of phytoplankton in the three sampling sites of the hill stream water during the study period.	<b>111</b>
<b>Figure 4.4-7</b>	Seasonal variations of Margalef's Richness Index (a) and Index of Dominance (b) of phytoplankton in the three sampling sites of the hill stream water during the study period.	<b>111</b>
<b>Figure 4.5-1</b>	Percent Composition of Zooplankton Groups in the river Teesta.	<b>119</b>
<b>Figure 4.5-2</b>	Monthly variations of zooplankton density (a) and number of genera (b) in the river Teesta during the study period.	<b>121</b>
<b>Figure 4.5-3</b>	Monthly variations of Shannon-Wiener Diversity Index (a) and Evenness Index (b) of zooplankton in the river Teesta during the study period.	<b>121</b>
<b>Figure 4.5-4</b>	Monthly variations of Margalef's Richness Index (a) and Dominance Index (b) of zooplankton in the river Teesta during the study period.	<b>121</b>
<b>Figure 4.5-5</b>	Seasonal variations of zooplankton density (a) and number of genera (b) in the four sampling sites of the river Teesta during the study period.	<b>125</b>
<b>Figure 4.5-6</b>	Seasonal variations of Shannon-Wiener Diversity Index (a) and Evenness Index (b) of zooplankton in the four sampling sites of the river Teesta during the study period.	<b>125</b>
<b>Figure 4.5-7</b>	Seasonal variations of Margalef's Richness Index (a) and Dominance Index (b) of zooplankton in the four sampling sites of the river Teesta during the study period.	<b>125</b>
<b>Figure 4.6-1</b>	Percent Composition of Zooplankton Groups in the hill-stream Relli.	<b>134</b>
<b>Figure 4.6-2</b>	Monthly variations of zooplankton density (a) and number of genera (b) in the hill stream Relli during the study period.	<b>135</b>
<b>Figure 4.6-3</b>	Monthly variations of Shannon-Wiener Diversity Index (a) and Evenness Index (b) of zooplankton in the hill stream Relli during the study period.	<b>135</b>
<b>Figure 4.6-4</b>	Monthly variations of Margalef's Richness Index (a) and Dominance Index (b) of zooplankton in the hill stream Relli during the study period.	<b>135</b>
<b>Figure 4.6-5</b>	Seasonal variations of zooplankton density (a) and number of genera (b) in the three sampling sites of the hill stream water during the study period.	<b>140</b>

<b>Figure 4.6-6</b>	Seasonal variations of Shannon-Wiener diversity Index (a) and Evenness Index (b) of zooplankton in the three sampling sites of the hill stream during the study period.	<b>140</b>
<b>Figure 4.6-7</b>	Seasonal variations of Margalef's Richness Index (a) and Index of Dominance (b) of zooplankton in the three sampling sites of the hill stream water during the study period.	<b>140</b>
<b>Figure 4.7-1</b>	Percent Composition of Fish Families of Teesta.	<b>149</b>
<b>Figure 4.7-2</b>	Monthly variations of Ichthyofaunal CPUE (a) and Population Size (b) in the river Teesta during the study period.	<b>150</b>
<b>Figure 4.7-3</b>	Monthly variations of Number of Fish Species (a) and Species Diversity Index (b) in the river Teesta during the study period.	<b>151</b>
<b>Figure 4.7-4</b>	Monthly Variations of Ichthyofaunal Evenness Index (a) and Species Richness Index (b) in the river Teesta during the study period.	<b>151</b>
<b>Figure 4.7-5</b>	Monthly variations of Ichthyofaunal Dominance Index (a) and Seasonal Variations of CPUE (b) in the river Teesta during the study period.	<b>151</b>
<b>Figure 4.7-6</b>	Seasonal variations of Ichthyofaunal Population Size (a) and Number of Species (b) in the three sampling sites of the river water during the study period.	<b>152</b>
<b>Figure 4.7-7</b>	Seasonal variations of Ichthyofaunal Species Diversity Index (a) and Evenness Index (b) in the three sampling sites of the river water during the study period.	<b>152</b>
<b>Figure 4.7-8</b>	Seasonal variations of Ichthyofaunal Species Richness Index (a) and Species Dominance Index (b) in the three sampling sites of the river water during the study period.	<b>152</b>
<b>Figure 4.8-1</b>	Percent Composition of Ichthyofaunal Orders (a) and Families (b) in the hill-stream Relli.	<b>164</b>
<b>Figure 4.8-2</b>	Monthly variations of Ichthyofaunal CPUE (a) and Population Size (b) in the hill stream Relli during the study period.	<b>166</b>
<b>Figure 4.8-3</b>	Monthly variations of Number of Fish Species (a) and Species Diversity Index (b) in the hill stream Relli during the study period.	<b>166</b>
<b>Figure 4.8-4</b>	Monthly Variations of Ichthyofaunal Evenness Index (a) and Species Richness Index (b) in the hill stream Relli during the study period.	<b>166</b>
<b>Figure 4.8-5</b>	Monthly variations of Ichthyofaunal Dominance Index (a) and Seasonal Variations of CPUE (b) in the hill stream Relli during the study period.	<b>169</b>
<b>Figure 4.8-6</b>	Seasonal variations of Ichthyofaunal Population Size (a) and Number of Species (b) in the three sampling sites of the hill stream water during the study period.	<b>169</b>
<b>Figure 4.8-7</b>	Seasonal variations of Ichthyofaunal Species Diversity Index (a) and Evenness Index (b) in the three sampling sites of the hill stream water during the study period.	<b>169</b>
<b>Figure 4.8-8</b>	Seasonal variations of Ichthyofaunal Species Richness Index (a) and Species Dominance Index (b) in the three sampling sites of the hill stream water during the study period.	<b>170</b>

## List of Plates

Serial No.	Title	Plate No.
1.	Camera Lucida Drawings of Phytoplankton Genera found during the present study	Plate 1
2.	Images of Some Important Phytoplankton Genera found during the present study.	Plate 2
3.	Images of Some Important Phytoplankton Genera found during the present study	Plate 3
4.	Images of Some Important Phytoplankton Genera found during the present study.	Plate 4
5.	Camera Lucida Drawings of Zooplankton Genera found during the present study	Plate 5
6.	Images of Some Important Zooplankton Genera found during the present study.	Plate 6
7.	Images of Some Important Zooplankton Genera found during the present study.	Plate 7
8.	Images of Fish Species found during the present study.	Plate 8
9.	Images of Fish Species found during the present study.	Plate 9
10.	Images of Fish Species found during the present study.	Plate 10
11.	Images of Fish Species found during the present study.	Plate 11
12.	Images of Fish Species found during the present study.	Plate 12
13.	Images of Fish Species found during the present study.	Plate 13
14.	Images of Fish Species found during the present study.	Plate 14
15.	Some Images of Teesta and Relli	Plate 15
16.	Images of Some Important Fishing Methods and Gears Used in the Hill-Stream.	Plate 16



## List of Appendices

Appendix No.	Title	Page No.
Appendix A	<b>Salient Features of the River Teesta</b>	266
Appendix B	<b>Salient Features of the hill-stream Relli</b>	267
Appendix C	<b>List of Fish, Distribution, Relative Abundance, Conservation and Other Status of Fish Fauna from the Teesta River in Darjeeling Himalaya</b>	268
Appendix D	<b>List of Fish, Distribution, Relative Abundance, Conservation and Other Status of Fish Fauna from the Hill-Stream Relli in Darjeeling Himalaya.</b>	272
Appendix E	<b>Pearson's Correlation Coefficients Matrix for Density and Diversity Indices of Phytoplankton, Zooplankton and Ichthyofana in the Hill-Stream Relli at the three Sites.</b>	274
Appendix F	<b>Pearson's Correlation Coefficients Matrix for Density and Diversity Indices of Phytoplankton, Zooplankton and Ichthyofana in the River Teesta .</b>	275



# *List of Abbreviations*

---

asl	Above Sea Level
APHA	American Public Health Association
cm	Centimeter
CL	Chloride
CPUE	Catch per Unit Effort
$^{\circ}\text{C}$	Degree Celsius
df	Degree of Freedom
DO	Dissolved Oxygen
EDTA	Ethylenediaminetetraacetic acid
$\text{FCO}_2$	Free Carbon dioxide
g	Gram
IUCN	International Union for Conservation of Nature and Natural Resources
KMO	Kaiser Meyer Olkin measure of sample adequacy
$\text{km}^2$	Square Kilometer
m	Meter
$\text{m}^2$	Square Meter
$\text{msec}^{-1}$	Meter per Second
msl	Mean Sea Level
mg	Milligram
$\text{mgL}^{-1}$	Milligram per Litre
mL	Millilitre
mmhos	Millimhos
msl	Mean Sea Level
$\mu\text{Scm}^{-1}$	Micro Siemens per Centimeter

NHPC	National Hydro Power Corporation
OLS	Ordinary Least Square
Org L <sup>-1</sup>	Organisms per Litre
pH	Hydrogen Ion Concentration
PCA	Principal Component Analysis
PC	Principal Component
p	Probability
r	Simple Correlaton or Regression
RR	Sampling Site in Relli
SPSS	Statistical Package for the Social Sciences
TR	Sampling Site in Teesta
TLDP-III	Teesta Low Dam Project Stage III
TLDP-IV	Teesta Low Dam Project Stage IV
Unit L <sup>-1</sup>	Unit per Litre
vers.	Version

# *Chapter 1*



## *Introduction*

# ***1. Introduction***

---

## **1.1. Background of the study**

River is simply defined as a dynamic body of water, which flows from higher ground elevation, like hills and mountains, towards lower levels, like the sea. But, rivers are not so simple linear features delimited by the bed and banks of the main channel, and dominated by downstream transfer of water. Currently, rivers are explained as dynamic, three dimensional systems dependent upon longitudinal, lateral and vertical transfers of material, energy and biota. Their physical, chemical and biological characteristics depend upon the interactions of hydrological, geomorphological and biological processes over a range of time scales (**Calow and Petts, 1992; Petts and Amoros, 1996**). The structure and function of river ecosystem are determined by the interactions between five elements, physical structure, water quality and quantity, condition of riparian zone and floodplain, and the diversity and population of plants and animals living in streams (**Rutherford *et al.*, 2000**). Any change in one of these elements can have significant impact upon other parts of the system.

Only a miniscule proportion (0.006%) of the world's freshwater is present in streams and rivers at any one time (**Shiklomanov, 1993**), but this statistic belies the significance of lotic system in human kind and the biosphere. River laid the foundation for human civilization more than ten thousand years ago when human started cultivating crops on the flood plains, and later expanded it away from the rivers by carrying river water through an extensive network of canals. This initial step of water withdrawal from rivers gradually led to elaborate river regulation involving storage and transfer, and channelization of flow by constructing embankments. These activities picked up pace only about a century ago. Soon, the impacts of river regulation became evident in the decline of biodiversity especially fisheries and the concern against dams was expressed as early as 1940s (**Gopal, 2003**). Running water provide a plethora of utilities for human kind including source of water for domestic, industrial and agricultural use, waste disposal, routes for navigation, and locations for the pursuit of leisure activities. Thus, from time immemorial, rivers are meeting the multifarious demands of society at the expense of its own health. Many types of river ecosystem have been lost and population of many riverine species have become highly fragmented due to human intervention (**Dynesius and Nilsson, 1994; Bunn and Arthington, 2002**). The human activities damaging river system includes; i) supra catchment effects such

as inter basin transfer of water, acid deposition, climate change, ii) catchment land use change, iii) river corridor ‘engineering’ and, iv) in stream impacts (**Arthington and Welcomme, 1995; Junk, 2002**). **Wetzel (2001)** explained that the impending environmental problem are not only the result of population growth but the result also from technological growth, both directly in the sense of increased per capita production and consumption and indirectly in that technology has furthered the growth of population and urbanization. This is termed as demotechnic concept of growth and is currently most evident in tropical countries, where most global biodiversity resides and where rapidly expanding human population and increasing exploitation of natural resources can exert great pressure on river ecosystems (**Farley and Daly, 2004; Agostinho et al., 2005; Schindler, 2007**).

India is a tropical country with about 29,000 kilometres of river systems and comprises the Himalayan rivers Indus, Ganges, and Brahmaputra traversing thousands of kilometres in upland forming a very rich and dynamic resource of high altitude fisheries, where cold water fishes abound (**Kamal, 2006**). The eastern Himalaya drained by the Brahmaputra has greater diversity of cold water fish than western Himalayan drainage (**Sehgal, 1999**). Eastern Himalaya is considered as one of the hotspots of freshwater biodiversity in the world (Kottelat and Whitten, 1996). Over the years uncontrolled and often indiscriminate fishing in the largely unmanaged Himalayan rivers and streams has resulted in a sharp decline in catches of the important subsistence and sports fish (**Sehgal, 1999**). The increasing use of river water for irrigation, hydropower production, municipal and industrial purposes, and the inputs of pollutants, have all affected fish stocks. But there is hardly any information on the ecology and fisheries of rivers of the eastern Himalayas (**FAO, 2002**). Darjeeling Himalaya, being an integral of the eastern Himalaya, is regarded as one of the two biodiversity hot spots of India.

The hilly and Himalayan part of the northernmost Darjeeling district of Indian state of West Bengal is popularly known as ‘Darjeeling Himalaya’. The district lies between latitude  $27^{\circ}13'05''$  and  $26^{\circ}17'10''$  North and between longitude  $88^{\circ}53'00''$  and  $87^{\circ}59'30''$  East and fosters many perennial rivers and streams which flow through deep gorges. The district has 3398 km of riverine resources, which belongs to the Himalayan river system (**Ghoshal, 2002**). The rivers of this group are glacier-fed, spring-fed, and rain-fed, originating from the Himalayas to traverse great alluvial Indo-Gangetic plains. Some rivers of this region belong to Ganga river system (for example, Mahananda and Balason) others like Teesta and Jaldhaka belong to the Brahmaputra river system. The glacier-fed river Teesta is the largest river in

this region and the river flows through deep mountainous gorge known as Sevoke-Gola pass. The river below the confluence with the Great Rangit flows entirely through the Darjeeling district for about 29 km before it debouches into the flood plains of North Bengal. Thus, it forms a kind of ecotone through which migratory fishes move upland and to the down. The altitude varies from about 300m above msl at Melli Bazar to about 145 m above msl near Sevoke. In this stretch, the river Teesta receives a number of tributaries on both of its bank, among which the spring fed river Relli is an important left bank tributary. Darjeeling Himalaya with rich biodiversity and high level of endemism is under immediate threat of species extinction and habitat destruction mainly due to tremendous pressure from demotechnic growth and also because of natural environmental changes. Lotic waters are perhaps the most impacted ecosystem of the region.

Records revealed that neotectonic activity coupled with high level of flush flood caused massive shifting of Teesta River from Ganga river system to Brahmaputra in the year 1787 and floods during subsequent years caused bank failures, meandering, widening and elevating the river bed (**Anon, 2001**). In September 1899, the entire well stocked big-fishes of the Teesta, the Great Rangit, Little Rangit and Rammam were either killed or carried off to sea due to devastating cyclone (**Malley, 1907**). In the year 1968, unprecedented cloud burst caused havoc land slides into the river, the Teesta and its tributaries ran wild. Bridges were swept away, mud and debris poured into the rivers and streams. Fishes were swept away and died in thousands. Rivers and streams became fishless (**Sen and Biswas, 2006**). Reports are also coming that glaciers are receding in Sikkim Himalaya. Zemu-glacier in Sikkim retreated 440m during the period from 1909 to 1965 (**Joshi, 1990**). Glacier retreat and global warming is affecting rainfall pattern, temperature regime, and wild life distribution.

Two hydro-electric projects namely Teesta Low Dam Project-III and IV (TLDP-III and IV) are being constructed on river Teesta in this region by National Hydro Power Corporation (NHPC). Six other dams are in progress on the river in Sikkim and further downstream a mighty barrage without fish ladder at Gajoldoba in Jalpaiguri district already exists. A group of environmentalist are of the opinion that dancing and roaring Teesta will be silenced and rich biodiversity will be lost if the dam building on the Teesta is completed. The Teesta and its tributaries are also impacted because of high population growth, construction of highways, roads, bridges, destruction of riparian vegetation and watershed forest cover, denudation causing high siltation, boulders and sand-lifting, landslides, rampant fishing,

disposal of untreated sewages, indiscriminate use of pesticides and fertilizers in agricultural practices, altered land use pattern and so on.

Rivers are not simply dynamic body of water or vector of water resources. They constitute living environments that harbour highly varied organisms (for example, Phytoplankton, Periphyton, Zooplankton, Benthos, fishes, and so on.) in great quantity and quality and linked among themselves by nutritional relationships. The basic structure of riverine food chain is Phytoplankton – Zooplankton – Fishes. According to **Faurie et al. (2001)**, the biological structure maintains its quality and productivity to the extent that it has a high degree of diversity (large number of species in complementary roles) and density (large number of individuals ensuring assimilation and transformation of inputs). Rivers like Teesta within its drainage basin is central to surface water ecosystems. The hydrological, chemical, and biological characteristics of river reflect the climate, geology, disturbances and vegetational cover of the drainage basin (**Wetzel, 2001**). The ultimate aim of ecology is to study the interaction of organisms with their environment and the other organisms living in it (**Wilson, 1992; Krebs, 2001**). The interactions actually determine the distribution and abundance of organisms (**Krebs, 1985**).

Phytoplankton is the primary producer of organic matter in riverine ecosystem and constitutes the first trophic level in the pelagic food-web and through the process of photosynthesis provides food and oxygen to other organisms and can be used as indicator of the trophic phase of the water body (**Verma and Datta Munshi, 1987; Bohra and Kumar, 1999**). The quality and quantity of phytoplankton population in a biotope is altered by any change in the prevailing environmental conditions and biotic variables. The zooplankton forms a vital link in the food-chain between the phytoplankton and the higher trophic levels in riverine ecosystem. Its diversity is a good indicator of the health of an aquatic ecosystem (**Cozar et al., 2003**). Physico-chemical variables such as temperature, pH and dissolved oxygen also regulate the density and diversity of zooplankton (**Berjins and Pejler, 1987, 1989**). River fish which provide a major source of food and recreation is also useful for characterizing environmental conditions in streams and rivers. A stream ecosystem has to have a healthy and diverse fish community (**Cowx, 1998**).

## **1.2. Rationale of the study**

The mountain fluvial ecosystem is unique as well as distinct in all aspect, especially in the tropics. Stretch of largest glacier-fed river Teesta in the Darjeeling Himalaya forms a

link between Himalayan mountainous part and flood plains of North Bengal. Thus, it portrays a kind of ecotone, an excellent riverine ecosystem in the eastern Himalayan Hotspot. The region with rich biodiversity and high level of endemism is under immediate threat of species extinction and habitat destruction mainly due to tremendous pressure from demotechnic growth and also because of natural environmental changes. Its left hand tributary Relli represents typical ecosystem of a Himalayan spring-fed hill-stream. Though lying in the sub-tropical latitudes, both of them are functioning under the influence of tropical seasonality. Rivers within their drainage basins are central to surface water ecosystems. The hydrological, chemical, and biological characteristics of a river reflect the climate, geology, and vegetational cover of the drainage basin. Diversity of basic food chain that is, phytoplankton, zooplankton and ichthyofauna is a good indicator of the health of an aquatic ecosystem. The diversity of plankton and fish enable a synthetic and complete assessment of the quality of the water and aquatic environment by means of diversity indices. The diversity of species found in the environment is the surest guide to the fight against water pollution (**Faurie *et al.*, 2001**). Biodiversity is thus, one of the potential and essential characteristics of life for proper functioning of fluvial ecosystem and a means of coping natural and anthropogenic environmental changes. Thus, diversity of plankton and fish fauna in relation to the physico-chemical water quality will be good indicator of the health of the river and its drainage basin. It will also unveil the mystery of regulatory mechanism of diversity dynamics prior to loss of fine tune of riverine ecosystem due to anthropogenic activity. Scientific understanding of diversity of phytoplankton, zooplankton and ichthyofauna in relation to limnochemistry of river Teesta and Relli in the Darjeeling Himalaya will help in generation of constructive alternatives to meet the challenges of sustainable equitable development and utilization of the Teesta river system, especially for future capture fishery.

### **1.3. Aims and Objectives**

The nucleus of the present study was therefore, to compare population density, diversity index, evenness, richness and dominance of phytoplankton, zooplankton and ichthyofauna in relation to physico-chemical water quality of the glacier-fed river Teesta and the spring-fed hill-stream Relli in the Darjeeling Himalaya. The present work evaluates the hypothesis that tropical seasonality of this sub-tropical region affects the physico-chemical water quality of glacier-fed river and spring-fed hill-stream in different styles. This as a far-reaching consequence alters the density and diversity of phytoplankton, zooplankton and ichthyofauna in a predictable manner.

Therefore, with the above background, the present study entitled “**Diversity of plankton and ichthyofauna in relation to limnochemistry of river Teesta and Relli in the Darjeeling Himalaya**” has been executed for a period of two years (March 2007 to February 2009) and consisted of the following objectives.

- I. To study some physico-chemical parameters of both the rivers and make a comparative account.
- II. To determine the meso- and macroplankton diversity, evenness, and species richness in the two different types of river.
- III. To study the ichthyofaunal diversity of both the rivers.
- IV. To determine the relationship between physico-chemical factors and biota (plankton and fish) of both the rivers.
- V. To suggest some suitable steps for better management of the water bodies.

# *Chapter 2*



## *Review of Literature*

## 2. Review of Literature

---

### 2.1. Lotic Ecosystem

Flowing freshwater environments are called *lotic ecosystems* for obvious reason of unidirectional water movements along a slope in response to gravity (**Wetzel, 2001**). A lotic ecosystem is the ecosystem of a river, stream or spring. The main characteristics of river and stream ecosystem have been summarized by **Wetzel (2001)**, as i) unidirectional flow; ii) linear form that occupies little of the total drainage basin area; iii) unstable and constantly changing channel substrata and morphology; iv) having most of the biotic metabolism supported by organic matter originally from external allochthonous sources that is imported to the stream or river; e) high spatial heterogeneity that changes rapidly and frequently; v) high variability and individuality of physical, chemical and biological characteristics. River systems can be described in five dimensions (**Lenders and Knippenberg, 2005**). The three physical dimensions (longitudinal, transversal and vertical) are key features of river systems (**Ward et al., 2002; Van der Velde et al., 2004**). The temporal or fourth dimension (**Ripl et al., 1994; Boon, 1998; Poudevigne et al., 2002; Lenders and Knippenberg, 2005**) represents short- and long term changes and is usually elaborated in terms of physical river system processes, such as hydro- and morphodynamics, and accompanying phenomena such as succession and rejuvenation. Finally, the social or fifth dimension includes socio-economic activities as well as issues like cultural identity and various positions humans may hold towards nature (**Lenders and Knippenberg, 2005**). The ecosystem concept is sometimes applied to streams and rivers, referring to them as *flowing water ecosystems*.

The combination of disciplines within freshwater science was expressed in the classic monograph on *lac leman* (Lake Geneva) by Swiss **Forel (1892-1904)**. His term *limnologie* (limnology, the science of lakes) was later extended non-etymologically to include running waters. **Welch (1952)** defined Limnology as the branch of science which deals with biological productivity of inland waters and with all the causal influences which determine it. But later, **Wetzel (2001)** explained it as the study of the structural and functional interrelationships of organisms of inland waters as they are affected by their dynamic physical, chemical and biotic environments. The origins of limnology date back many centuries but, no significant contributions of a strictly limnological nature were made for at least, nineteen hundred years after the time of **Aristotle (384-322 B.C)**. The development of stream ecology or stream limnology as a discipline analogous to Lake Limnology grew out of initiatives that began in the 1950s and 1960s. **Hynes' 1970** book *The Ecology of Running*

*Waters* is usually regarded as the first book on stream ecology. The limnology of running waters was reviewed masterfully by **Hynes (1970)**, but much new information and understanding has emerged since then. **Wetzel (2001)** summarized characteristics of running waters and compare them to those of standing water in his book *Limnology Lake and River Ecosystems*. **Dodds (2002)** discussed fresh water biology in his book *Freshwater Ecology Concepts and Environmental Applications*. **Gordon et al., (2004)** wrote a beautiful book named *Stream Hydrology An Introduction for Ecologists*. **Lampert and Sommer (2007)** described various aspects of the ecology of Lakes and Streams in their book *Limnoecology*. **Allan and Castillo (2007)** explained elaborately the structure and function of running waters in their book *Stream Ecology*. **Hauer and Lamberti (2007)** explained different techniques used to understand running waters in their book *Methods in Stream Ecology*. **Dudgeon (2008)** discussed characteristics of tropical stream and compared with the temperate counterparts in his edited book *Tropical Stream Ecology*. In India, **Gopal and Zutshi (1998)**, gave an overview of the developments in hydrobiological studies in India of fifty years, and links them with a historical perspective of the pre-independence studies.

## **2.2. Himalayan River**

“**Abode of snow**”, the **Himalaya** which forms a great mountain wall to the north of India. The Himalaya is often called the “Water Tower of India” as it is the source of the three largest rivers. These rivers have perennial flow throughout the year and operate as essential lifeline of the people on the flood plain and the downstream nations. The major river system of India on the basis of drainage can be divided into two-(i) Himalayan river system (Ganga, Indus and Brahmaputra), and (ii) Peninsular river system (East coast and West coast river system).The world’s highest streams are located in the Himalayas (**Ormerold et al., 1994; Brewin et al., 1995**), but even the southernmost part of this region has pronounced seasonal climate and lies north of the tropical belt. The glacier-fed rivers originating in the Himalaya mountain ranges comprise the largest river run-off from any single location in the world (**UNEP/GRID-Arendal 2007**). The rivers provide drinking water, food, income, transport, power, and jobs for millions of people; the Ganga- Brahmaputra alone sustains the highest population density in the world (**WATCH, 2010**).The Himalayas are drained by 19 major rivers, of which the Indus and the Brahmaputra are the longest (Trans-Himalayan). Of the remaining 17 rivers five belong to the Indus system; nine rivers belongs to the Ganga river system; and three belong to the Brahmaputra system. Most of these rivers flow in deep valleys until they exit the mountains. The Himalayan or extra- peninsular rivers are snow-fed, spring-fed, or rain-fed, originating from the Himalayas to transverse great alluvial Indo-

Gangetic plains. According to **Jhingran and Sehgal (1978)**, in the Himalayas, the origin of rivers is either antecedent (The Indus and The Brahmaputra) or consequent (the Sutlej, the Kosi, and the Teesta etc.). The Indus system originates in Tibet and after traversing through Kashmir and Pakistan drops in the Arabian Sea. It has a total catchment area of about 4,68,000 sq km upto the Indo-Pakistan border. This system embraces hundreds of rivulets and about a dozen major rivers of the region. The Ganga originating from the Gangotri glacier in the central Himalaya is the most important riverine system of north India. The total catchment area of the Ganga system is over 5,11,000 sq km, out of which about 3,00,000 sq km lies in India. The Brahmaputra, which drains the Manasarowar region of the Trans-Himalayas, is called Tsangpo in Tibet. The combined length of the Brahmaputra river system is 4023 Km with drainage area of about 935000 km<sup>2</sup> and has a mean annual flow 20,000 m<sup>3</sup> S<sup>-1</sup> (**Wetzel, 2001**). The river flows through northern slopes of Himalayas to enter India at north-east corner of Arunachal Pradesh. It has 918 km stretch in India, including 730 km in Assam alone. Among these rivers originating in the Himalayan belt, mention must be made of river Meghna and river Imphal. Meghna River arising from the hills in Assam flows southwards into Bangladesh. It is joined by several tributaries which drain part of north eastern India. Imphal River, one of the medium river, and known as Manipur River in its southern reach, originates from Manipur hills, flows south through the valley into Myanmar where it joins River Chindwin a tributary of River Irrawady.

### **2.2.1. Water Quality Parameters**

The physico-chemical factors of the medium exert profound influence on the number, abundance, distribution and diversity of its inhabitants (and help to illustrate the interaction between the inhabitants and the environment). Physical and chemical analysis of water has attained great importance and has been well accepted in recent years for the ecological studies of aquatic habitats. **Sehgal (1971)** and **Joshi *et al.*, (1974)** have studied physico-chemical characteristics of the streams of Jammu and Kashmir and Himachal Pradesh. They recognised three categories of streams.

#### **2.2.1.1. Temperature**

The air temperature is the resultant effect of several meteorological factors such as solar radiation, humidity, wind etc. and also the latitudinal and altitudinal position of the place under study (**Wetzel, 2001**). Positive and significant correlation between air and water temperature have been reported by **Chakraborty *et al.* (1959)**, **Kant and Anand (1978)**, **Rawat *et al.* (1995)** and **Wetzel (2001)**. **Mc Gregor and Neuwolt (1998)** calculated that the

mean normal lapse rate (rate of decrease in temperature with elevation) within the tropics is approximately  $0.65^{\circ}\text{C}$  per 100 m of elevation. The main significance of temperature for flowing waters is through its effect on metabolism and the capacity of water to hold dissolved oxygen (**Lewis, 2008**). The natural waters in tropical areas generally show a higher production due to more heat budget in the ecosystem as **Probst (1950)** found an average increase in carp yield of 22 kg per hectare for  $1^{\circ}\text{C}$  rise of temperature. Water temperature plays a very important role in some physiological processes like release of stimuli for breeding mechanisms in fish, both under natural and artificial conditions (**Hora, 1945; Chaudhuri, 1964. Sehgal (1974), Joshi et al., (1978), and Sehgal (1988)** have summarized average water temperature in three Himalayan zones *i.e.* Greater Himalayan zone (4000-2000 m. asl) is  $13.4^{\circ}\text{C}$ ; Lesser Himalayan zone (2000- 1000 m. asl) is  $18.7^{\circ}\text{C}$ ; Siwalik zone (below 1000 m asl) is  $22.9^{\circ}\text{C}$ . **Sehgal (1999)** reported monthly mean temperature of  $17.3^{\circ}\text{C}$  in the rhithron zone of rivers in the Himalaya, whereas potamon zone has  $22.1^{\circ}\text{C}$ . Available literatures suggest that the water temperature of north western Himalayan River ranged from  $1.0^{\circ}\text{C} - 29.1^{\circ}\text{C}$ . The lowest water temperature was found in the Sindh river of Kashmir Himalaya and in the river of Garhwal Himalaya (**Rashid and Pandit, 2008; Nautiyal and Verma, 2009**). The highest temperature was found in the regulated high altitude rivers of Garhwal Himalaya (**Ayoade et al., 2009**). In rivers of Bhutan Himalaya water temperature ranged from  $8.5^{\circ}\text{C}$  to  $26^{\circ}\text{C}$  (**Dubey, 1978**). Lowest temperature observed in the river Kaligkhola (October) but highest temperature found in the river Torsa and Sankosh (April). **Thapa et al., (2010)** reported highest temperature  $29.6^{\circ}\text{C}$  in glacier-fed Trishuli River in Nepal. Available literature indicated that in the north eastern Himalayan Rivers, water temperature ranged from  $5.6^{\circ}\text{C}$  to  $30^{\circ}\text{C}$ . **Bhadra et al., (2003) and Barat and Jha (2002)** reported in the foot hill, river (Torsa and Mahananda of North Bengal) water temperature varied from  $17.5^{\circ}\text{C}$ -  $34^{\circ}\text{C}$ . The water temperature falling within the tolerance limits of the snow trouts and may be termed as cold (**Jhingran and Sehgal, 1978**). **Badola (1979), Sharma and Mishra (2002)** reported that glacier fed river water were cooler than the spring-fed river. Water temperature showed seasonal variation, minimum water temperature observed in winter months and maximum in monsoon and in pre monsoon months (**Singh et al., 1994**). **Bose and Gorai (1993)** reported negative significant correlation between water temperature and dissolved oxygen. Air water and water temperature showed significant positive correlation (**Wetzel, 2001; Pathani and Upadhyay, 2003**). In the Himalayan rivers water temperature increased downstream (**Singh, 1988; Mathur, 1991; Nautiyal, 2001, 2010**).

### 2.2.1.2. Flow

Streams and rivers are basically linear channels in which water flows directionally along the declining elevational gradient. Downstream water movement in a stream channel is referred to as current. Current velocities are driven by the gravitational weight of the water moving down slope and are controlled by the channel morphology and elevational gradient, water volume, type of substratum, and obstructions (**Wetzel, 2001**). Water flow is the key factor in riverine systems influencing their ecology. Flushing rates of river ecosystems are comparatively rapid and directional (**Wetzel, 2001**). The strength of water flow can vary between systems, ranging from torrential rapids to slow backwaters that almost seem like lentic systems. The speed of the water flow can also vary within a system. It is typically based on variability of friction with the bottom or sides of the channel, sinuosity, obstructions, and the incline gradient (**Allan, 1995**). **Lampert and Sommer (2007)** opined that stream velocity depends on the incline and smoothness of the substrate, but also on the cross sectional area of the stream. In addition, the amount of water input into the system from direct precipitation, snowmelt, and/or groundwater can affect flow rate. Flowing waters can alter the shape of the streambed through erosion and deposition, creating a variety of habitats, including riffles, glides, and pools (**Cushing and Allan, 2001**). Water velocity of Himalayan River ranged from  $0.06 \text{ m sec}^{-1}$  to  $3.9 \text{ m sec}^{-1}$ . Highest velocity was found in the glacier-fed river Alaknanda (**Nautiyal, 2010**). **Sharma et al., (2007)** observed that water current remained high throughout the year but it attained the peak value during monsoon months (July-August) due to frequent flash floods. **Shrestha (1990)** reported water velocity in Karnali River in Nepal ranged from  $0.3$  to  $4.5 \text{ m sec}^{-1}$ . **Malley (1907)** and **Dash (1947)** wrote the current of river Teesta in Darjeeling is very swift, running in places at the rate of 14 miles/hour i.e.,  $6.26 \text{ m sec}^{-1}$ . In the river Brahmaputra water velocity varied from  $0.06$  to  $0.62 \text{ m sec}^{-1}$  (**Biswas and Boruah, 2002**). **Sharma et al., (2007)** observed that water current remained high throughout the year but it attained the peak value during monsoon months (July-August) due to frequent flash floods. Water velocity decreased downstream (**Singh, 1988; Mathur, 1991; Nautiyal, 2001, 2010**) and maximum velocity observed in monsoon months and minimum in winter months. Water velocity of glacier-fed river was found higher than spring-fed river (**Sharma and Mishra, 2002**).

### 2.2.1.3. Chemistry

The water chemistry is foremost determined by inputs from the geology of its watershed, or catchment area, but can also be influenced by precipitation and the addition of pollutants from human sources (**Allan, 1995; Cushing and Allan, 2001**). Large

differences in chemistry do not usually exist within small lotic systems due to a high rate of mixing. In larger river systems, however, the concentrations of most nutrients, dissolved salts, and pH decrease as distance increases from the river's source (**Giller and Malmqvist, 1998**).

#### **2.2.1.3.1. Specific Conductance**

Conductivity is simply the relative amount of electricity that can be conducted by water (**Dodds, 2002**). Conductivity is a measure of ability of a water sample to conduct an electrical current proportional to the ionic strength of the water. This mostly depends upon the nature of various dissolved ionized substances, their relative concentrations and temperature. The conductivity of water depends upon the concentration of ions and its nutrient status and the variation dissolved solid content is indicated by conductivity measurements. Conductivity is the inverse of resistivity, or  $1/\text{ohm cm}^{-1}$ , is linked to the level of mineral (electrolysable) salts dissolved in water (**Faurie et al., 2001**). The specific conductance of the common bicarbonate type river water is closely proportional to concentration of the major ions ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{CO}_3^{2-}$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ ) (**Juday and Birge, 1933; Rodhe, 1949**). Specific conductance of north western Himalayan river water ranged from 20 to 468.2  $\mu\text{mho cm}^{-1}$  and it increased upstream to downstream (**Singh, 1988; Mathur, 1991; Nautiyal, 2001**). In glacier-fed Trishuli river system of Nepal it varied from 8.2 to 534.0  $\mu\text{mho cm}^{-1}$  (**Thapa et al., 2010**) and in the rivers of Bhutan Specific conductance ranged from 20-140  $\mu\text{mho cm}^{-1}$  (**Dubey, 1978**). **Boruah and Biswas (2000)** observed range of conductivity was 87-145.7  $\mu\text{S cm}^{-1}$  in the Brahmaputra River. **Bhadra et al. (2003)** reported specific conductance of a foot hill river Torsa in north Bengal, varied from 100-280  $\mu\text{mho cm}^{-1}$ . Inverse relation of conductivity with water level has been reported by **Imevbore (1975)**, **Adebisi (1980)** and **Mishra et al., (1999)** and **Mondal (2009)**. In streams of the Venezuelan Sierra Nevada, conductivity increased from 35–95  $\mu\text{S cm}^{-1}$  (3180–3735 m asl) to 20–880  $\mu\text{S cm}^{-1}$  at lower elevations (830–1650 m asl) (**Segnini and Chacón, 2005**). The specific conductance of water had significant positive correlation with pH, DO, total alkalinity, total hardness has been recorded by **Mariappan and Vasudevan (2002)** and **Mondal (2009)**.

#### **2.2.1.3.2. pH**

The **pH** value characterizes the acidity of river water. By definition, pH of a solution is the logarithm of the inverse of the concentration of hydronium ions ( $\text{H}_3\text{O}^+$ ), produced as a result of dissociation of water (**Faurie et al., 2001**).

$$\text{pH} = -\log[\text{H}_3\text{O}^+]$$

The pH of natural water is governed to large extent by the interaction of  $\text{H}^+$  ions arising from the distribution and dissociation of  $\text{H}_2\text{CO}_3$  and from  $\text{OH}^-$  ions produced during the hydrolysis of bicarbonate. The pH of natural water ranges between the extremes of <2 -12 (**Wetzel, 2001**). In the fresh water, the variations in pH are intimately linked to the nature of soils of the sloped basin and to the rainfall. Available literature indicated that the range of pH generally varies from 6.5 to 8.7 in north western Himalayan Rivers. However **Pathani and Upadhyay (2003)** found pH 10.05 in the river Ramganga (west) during winter. **Dubey (1978)** reported pH ranged from 6.8 to 8.7 in the rivers of Bhutan, but **NWWFCC (2001)** found highest value 9.4. In the rivers of Nepal Himalaya values of pH varied from 5.4 to 8.6, lowest value observed by **Juttner et al. (2003)** and highest value found by **Thapa et al. (2010)** and **Juttner et al. (2003)**. **Shrestha (1990)** reported that pH around 8.0 in Karnali river of Nepal. Rivers of north eastern Himalaya showed pH values ranged from 6.0 to 8.2, lowest value found in the river Siyom of Arunachal Pradesh (**Bagra and Das, 2010**) and highest value in the river Brahmaputra (**Biswas and Boruah, 2002**) with an average value of 7.6. **Haque et al. (2010)** found alkaline pH in the river Teesta in Sikkim. **Chakraborty et al. (1959)** recorded pH more or less constant at 8.0 throughout the year with a slight variation of  $\pm 0.2$  in river Jamuna. **Kumar and Bhagat (1978)** observed pH range of 7.1 to 7.8 in streams of Kashmir. pH recorded during the present study are comparable with others. **Chakravorty (1998a)** during his limnological studies of a mountain lake in Darjeeling district, the pH ranged between 7.4 and 7.8. According to (**Roule, 1930**) the largest fish crops are usually produced in water which is just on the alkaline side of neutrality between pH 7.0 and 8.0. The limit above or below which pH has a harmful effect is given by **Ohle (1938)** as 4.8 and 10.8. **Hutchinson et al., (1939)** and **Roy (1955)** have shown that the higher pH is associated with the phytoplankton maxima. **Goutam (1990)** reported highest pH in summer and lowest in rainy season. Several workers like **Hannan and Yong (1974)**; **Bais et al., (1995)** have reported low pH during the low photosynthesis due to formation of carbonic acid. In streams of the Venezuelan Sierra Nevada, pH increased from 6.5–7.7 (3180–3735 m asl) to 6.8–8.5 (830–1650 m asl) (**Segnini and Chacón, 2005**). A similar downstream increase has been described for the Purari River, Papua New Guinea (**Petr, 1983**). pH showed positive and significant correlation with Conductivity, DO, total alkalinity, hardness and negative significant correlation with water temperature and free  $\text{CO}_2$  have been observed by **Thapa Chhetry and Pal (2011)** and **Mondal (2009)**. **Bharti and Kore (1975)** have obtained close relation between pH and carbonates. A significant correlation between pH and alkalinity has

also been reported by **Trivedy (1988)**. **Rawat et al. (1995)** reported positive correlation of pH of water of Deoria Tal of Garhwal Himalaya with total alkalinity and inverse correlation with water temperature.

#### **2.2.1.3.3. Dissolved Oxygen**

**Oxygen** is likely the most important chemical constituent of lotic systems, as all aerobic organisms require it for survival. It enters the water mostly via diffusion at the water-air interface. Oxygen's solubility in water decreases as water temperature increases. Fast, turbulent streams expose more of the water's surface area to the air and tend to have low temperatures and thus more oxygen than slow, backwaters (**Giller and Malmqvist, 1998**). Range (0.4- 15.2 mg L<sup>-1</sup>) of dissolved oxygen in Himalayan Rivers, Lowest value observed in river Tawi in Central Himalaya (**Sharma and Choudhury, 2011**) and the highest value reported from river Gaula (856 m asl) of Kumaun Himalaya (**Singh, 1990**). **Badola (1979)** observed highest value of 18.1 and 16.8 mg L<sup>-1</sup> of dissolved oxygen in glacier-fed river Alaknanda and spring-fed river Nayar respectively and the value of DO decreased downstream (**Singh, 1988; Mathur, 1991; Nautiyal 1996, 2001**). In the rivers of Nepal Himalaya values of dissolved oxygen ranged from 5.6 to 14 mg L<sup>-1</sup>, lowest value observed by **Thapa et al., (2010)** in Trishuli River where as highest value reported by **Ranjit (2002)** in Sunkoshi River. Values of dissolved oxygen ranged from 7.0 to 13.5 mg L<sup>-1</sup> in the rivers of Bhutan Himalaya (**Dubey, 1978; NWWFCC, 2001**). In the rivers of north eastern Himalaya values of dissolved oxygen ranged from 3.6 to 15.4 mg L<sup>-1</sup>. Both values found in the river Brahmaputra (**Jhingran, 1991; Biswas and Boruah, 2000**) with an average value of 9.4 mg L<sup>-1</sup>. **Haque et al. (2010)** found range of dissolved oxygen to be 6.8 to 9.89 mg L<sup>-1</sup> in the river Teesta in Sikkim. **Hancock (1973)** discussed about seasonal average and fluctuations in DO; he reported that it was maximum in winter and minimum in summer. The decreased water temperature during winter season has a greater capacity to hold DO than warm water and probably led to a lower rate of respiration thereby allowing maximum DO in winter (**Welch, 1952**). **Dudgeon (2008)** reported that oxygen concentration is almost constant with increasing altitude because the decreasing atmospheric pressure of oxygen with altitude offsets the effect of decreasing temperature (and thus increase solubility) but, some authorities indicated the value of DO decreased downstream (**Singh, 1988; Mathur; 1991; Nautiyal, 2001**).

#### **2.2.1.3.4. Free Carbon dioxide**

Though **carbon dioxide** (CO<sub>2</sub>) is readily soluble in water very little CO<sub>2</sub> is in simple solution because of the small amount of it being present in the atmospheric air. Apart from

this, decomposition of organic matter and the respiration of aquatic plants and animals contribute to the free CO<sub>2</sub> present. Water percolating through the vegetation and soil take up CO<sub>2</sub> released from the soil air. Carbon dioxide combines chemically with water to form carbonic acid (H<sub>2</sub>CO<sub>3</sub>), dissociates partly to produce hydrogen (H<sup>+</sup>) and bicarbonate (HCO<sub>3</sub><sup>-</sup>) ions (**Faurie et al., 2001**). Free carbon dioxide is subjected to wide fluctuations because of its capacity to combine with Calcium, Magnesium and other elements, its utilization during photosynthesis process and release during respiration of organisms. Available literature indicated that in general the values of free CO<sub>2</sub> ranged from 0-8.0 mg L<sup>-1</sup> in the north western Himalayan Rivers, but **Badola (1979)** reported highest value of 35.6 mg L<sup>-1</sup> and 18.8 mg L<sup>-1</sup> in spring-fed river Nayar and glacier-fed river Alaknanda respectively. **Thapa-Chhetry and Pal (2011)** reported range of free CO<sub>2</sub> from 4.15 to 5.92 mg L<sup>-1</sup> in Nepal Himalaya. In the rivers of Bhutan values of free CO<sub>2</sub> varied from 1.0 to 8.9 mg L<sup>-1</sup> (**NWWFCC, 2001**). Values of free CO<sub>2</sub> ranged from 0.96 - 12.3 mg L<sup>-1</sup> in the north eastern Himalayan Rivers. **Biswas and Boruah (2002)** reported range of free CO<sub>2</sub> from 1.9 to 12.3 mg L<sup>-1</sup> in the river Brahmaputra with a average value of 5.2 mg L<sup>-1</sup>. Concentration of free CO<sub>2</sub> increases from upstream to downstream (**Pathani and Upadhyay, 2003**). Lowest value reported in winter and pre monsoonal months and highest value in post monsoonal months (**Goutam, 1990; Sharma et al., 2007**).

#### 2.2.1.3.5. Total Alkalinity

Water is said to be **alkaline** when concentration of the hydroxyl ions exceeds that of hydrogen ions (**Trivedy and Goel, 1984**). Most of the alkalinity in natural waters is formed due to dissolution of CO<sub>2</sub> in water. Carbonates and bicarbonates thus formed are dissociated to yield hydroxyl ions. There are many other salts of weak acids such as silicates, phosphates, borates etc. which cause alkalinity in addition to that of carbonates and bicarbonates. However, carbonates and bicarbonates outnumber other ions, sharing the most part of the total alkalinity. Humic and fulvic acids also add to the alkalinity of waters. According to **Wetzel (2001)**, alkalinity is numerically the equivalent concentration of titrable base and is determined by titration with a standard solution of a strong acid to equivalency points dictated by pH values at which the alkaline contributions of hydroxide, carbonate and bicarbonate are neutralized. Total alkalinity is a measure of bicarbonates, carbonates and hydrates. Alkalinity plays an important role in aquatic production and is associated with free CO<sub>2</sub> and pH. Bicarbonate is abundant in the water with a pH of 4.5 – 8.3 (**Jhingran, 1991**). In rivers and streams of the north western Himalaya total alkalinity ranged from 10 to 221.6 mg L<sup>-1</sup>. Lowest value observed in the rivers Ramganga (W) and Bhagirathi (**Pathani and**

**Upadhyay, 2003; Nautiyal, 2010)** and the highest value found in the hill-stream Chandrabhaga of Garhwal Himalaya (**Sharma *et al.*, 2007**). In the rivers of Nepal Himalaya concentration of total alkalinity ranged from 10 to 190 mg L<sup>-1</sup>, both the values observed in the river Trishuli (**Thapa *et al.*, 2010**). However, **Shrestha (1990)** found total alkalinity of 92 mg L<sup>-1</sup> in the river Karnali. **NWWFCC (2001)** recorded range of total alkalinity from 13 to 120 mg L<sup>-1</sup> in the rivers of Bhutan. In rivers and streams of the north eastern Himalaya total alkalinity ranged from 12 to 207.7 mg L<sup>-1</sup>. Lowest value observed in the river Pachin of Arunachal Pradesh (**Hussain and Ahmad, 2002**) and the highest value found in the hill-streams of north eastern Himalaya (**Bhattacharjya *et al.*, 2002**). **Biswas and Boruah (2002)** reported range of total alkalinity from 44.3 to 110.8 mg L<sup>-1</sup> with an average value of 63.4 mg L<sup>-1</sup> in the river Brahmaputra. Total alkalinity varied in the river Teesta in Sikkim from 10-80 mg L<sup>-1</sup> (**Haque *et al.*, 2010**). Value of total alkalinity increased downstream (**Singh, 1988; Mathur, 1991; Nautiyal, 2001, 2010; Pathani and Upadhyay, 2003**). Spring-fed rivers have higher value of total alkalinity than glacier-fed rivers (**Sharma and Mishra, 2002**). According to **Bishop (1973)** low alkalinity in the monsoon months were due to dilution effect. Similar observations were also reported by **Dhanapakiam *et al.* (1999)** and **Shastri and Pandse (2001)**. Maximum total alkalinity during winter was also reported by **Chakraborty *et al.* (1959), Singh (1990), Mishra *et al.* (1998), and Thapa-Chhetry and Pal, 2011**, which was associated with high winter pH. Increase of total alkalinity downstream in both the streams, similar observation has been made by other investigators in the Himalayan streams (**Singh, 1988; Mathur, 1991; Nautiyal, 2001, 2010; Pathani and Upadhyay, 2003**). In streams of the Venezuelan Sierra Nevada, alkalinity rose from 7–32 mg L<sup>-1</sup>CaCO<sub>3</sub> (3180–3735 m asl) to 9–519 mg L<sup>-1</sup>CaCO<sub>3</sub> (830–1650 m asl) (**Segnini and Chacón, 2005**). A similar downstream increase has been described for the Purari River, Papua New Guinea (**Petr, 1983**). **Barat and Jha (2002)** reported positive significant correlation of total alkalinity with hardness. **Thapa-Chhetry and Pal (2011)** found positive and significant correlation of total alkalinity with total hardness and chloride. A positive correlation between pH and total alkalinity has been observed by **Dobriyal and Singh (1988), Trivedi (1988) and Chopra *et al.* (1990)**. **Dhanze *et al.* (1998)** confirmed that there is a positive significant relationship between total alkalinity and pH and negative significant relationship between total alkalinity and free CO<sub>2</sub>.

#### **2.2.1.3.6. Chloride**

Chloride may occur in freshwaters as a result of salt deposits in the soil being dissolved. High chloride content in inland waters may be an indication of pollution.

Maximum chloride content has been correlated with high degree of organic pollution and eutrophication. Contamination of water from domestic sewage can be monitored by chloride assays of the concerned water bodies. This is because human and animal excretions contain an average of 5 gm L<sup>-1</sup> chloride (**Paramasivam and Sreenivasan, 1981**). In natural freshwaters, **chloride** concentration remains quite low and is generally less than that of sulphates and bicarbonates. Global average chloride ion composition of unpolluted rivers is 3.05 mg L<sup>-1</sup> (**Meybeck and Helmer, 1989**). In Asia mean composition of chloride ion in river waters is 8.7 mg L<sup>-1</sup>, whereas world average is 7.8 mg L<sup>-1</sup> (**Livingstone, 1963; Benoit, 1969**). The most important source of chlorides in the waters is the discharge of domestic sewage. Pollutational sources of chlorides can modify natural concentrations greatly (**Ownby and Kee, 1967**). Therefore, the chloride concentration serves as an indicator of pollution by sewage and industries. Available literature indicated that in general the value of chloride concentration in the western Himalayan Rivers ranged from 0.12 to 20.3 mg L<sup>-1</sup>, lowest value found in the river of Kosi in Uttaranchal (**Bhandari and Nayal, 2008**) and the highest value observed in Tehri dam near the confluence of Bhagirathi and Bhilangana (**Agarwal and Rajwar, 2010**). **Goutam (1990)** reported concentration of chloride in the river Bhagirathi varied from 2.8 to 4.3 mg L<sup>-1</sup>. Chloride concentration of Torsa river ranged from 5.8 to 11.1 mg L<sup>-1</sup> as observed by **Bhadra et al. (2003)**. **Sharma and Chowdhary (2011)** found range of chloride concentration from 21.95 to 59.88 mg L<sup>-1</sup> with an average value of 36.81 mg L<sup>-1</sup> in the river Tawi of Central Himalaya. **Thapa-Chhetry and Pal (2011)** reported values of ranged from 7.11 to 11.3 mg L<sup>-1</sup> in Nepal Himalaya. **Shrestha (1990)** observed 6 mg L<sup>-1</sup> in the Karnali River. **Biswas and Boruah (2000)** reported range of chloride concentration from 1.9 to 10.2 mg L<sup>-1</sup> with an average value of 5.6 mg L<sup>-1</sup> in the river Brahmaputra. **Barat and Jha (2002)** reported highest value of 39.4 mg L<sup>-1</sup> in the river Mahananda located in the foot-hill of Darjeeling Himalaya. **Thapa-Chhetry and Pal (2011)** and **Mondal (2009)** observed highest seasonal value in of chloride in winter and post monsoon months and lowest in monsoon variations. **Thapa-Chhetry and Pal (2011)** found positive and significant correlation between chloride and total alkalinity.

#### **2.2.1.3.7. Total Hardness**

The hardness of a water is governed by the content of calcium and magnesium salts, largely combined with bicarbonate and carbonate (temporary hardness) and with sulfates, chlorides, and other anions of mineral acids (permanent hardness), The term hardness is frequently used as an assessment of the quality of water supplies (**Wetzel, 2001**). Principal cations imparting **hardness** of natural waters are calcium and magnesium. However, other

cations such as strontium, iron, and manganese also contribute to the hardness. The anions responsible for hardness are mainly bicarbonate, carbonate, sulphate, chloride, nitrate and silicates etc (**Trivedy and Goel, 1984**). Hardness is called *temporary* if it is caused by bicarbonate and carbonate salts of the cations, since it can be removed simply by boiling the water. *Permanent* hardness is caused mainly by sulphates and chlorides of metals. According to **Swingle (1967)**, a total hardness of  $50 \text{ mg L}^{-1}$  is the dividing line between soft and hard water. **Kannan (1991)** proposed that water with a hardness value  $0 - 60 \text{ mg L}^{-1}$  is considered as soft. In general, total hardness of north western Himalayan River ranged from 25 to 138  $\text{mg L}^{-1}$ , lowest value found in the river Ramganga (west) of Uttaranchal (**Pathani and Upadhyay, 2003**) and highest value observed in Ramganga river (**Bhatt and Pathak, 1990**). **Goutam (1990)** observed in mountainous Bhagirathi at Uttarkashi, Tehri and Deobprayag, the value of total hardness ranged from 27 to  $71 \text{ mg L}^{-1}$ , being minimum in high flow seasons and maximum in lean season. However, **Kumar and Dua (2009)**, reported range of total hardness varied from 80 to  $730 \text{ mg L}^{-1}$  in river Ravi. During his study of the five lotic water bodies in Darjeeling, **Mukhopadhyay (1996)** observed a lower range of hardness varying between 5.0 and  $17.0 \text{ mg L}^{-1}$ . **Haque et al., (2010)** reported total hardness of Teesta river water in Sikkim ranged from 9.5 to  $20 \text{ mg L}^{-1}$ . Total hardness of the river Mahanada ranged from 16.2 to  $28.4 \text{ mg L}^{-1}$  (**Barat and Jha, 2002**) in Darjeeling Himalayan foot hill. In Nepal Himalaya total hardness ranged from 27.63 to  $96 \text{ mg L}^{-1}$ , but **Thapa et al., (2010)** found total hardness ranged from nil to  $320 \text{ mg L}^{-1}$  in the river Trishuli River. **Shrestha (1990)** observed total hardness  $104 \text{ mg L}^{-1}$  in Karnali River. **NWWFCC (2001)** reported total hardness ranged from 12 to  $120 \text{ mg L}^{-1}$  in the rivers of Bhutan. **Biswas and Boruah (2002)** reported range of total hardness from 53.7 to  $106.5 \text{ mg L}^{-1}$  with an average value of  $67.1 \text{ mg L}^{-1}$  in the river Brahmaputra. The maximum total hardness in winter season was obtained by **Misra et al., (1999)**, **Thapa-Chhetry and Pal (2011)** they related it to low volume of water and slow current of water. Minimum quantity of total hardness in rainy season may be due to more dilution of water (**Patralekh, 1994**). Similar relationship has also been recorded by **Ruttner (1953)**, **Thapa-Chhetry and Pal (2011)**. **Thapa-Chhetry and Pal (2011)** found positive and significant correlation between total hardness and total alkalinity. **Mondal (2009)** reported positive correlation of total hardness with conductivity and negative correlation with water temperature in Mirik Lake of Darjeeling.

#### 2.2.1.4. Nutrients

**Nitrogen** and **phosphorus** constitute what are called *nutrients*. They are essential to the composition of living matters. Nitrogen is present in river water, in five different

chemical forms ( $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{NH}_4^+$ ,  $\text{NH}_3$  and organic nitrogen e.g., urea) apart from its molecular form ( $\text{N}_2$ ). The quantities of dissolved inorganic ( $\text{NO}_3^-$ ,  $\text{NO}_2^-$ , and  $\text{NH}_4^+$ ) and organic nitrogen compounds are highly diverse and variable because of marked differences in the inputs from surface and ground water sources, particularly as affected by human activities (e.g., **Spalding and Exner, 1993**), and because of many competing reactions occurring in the nitrogen cycle (**Wetzel, 2001**).

#### 2.2.1.4.1. Ammonium Nitrogen ( $\text{NH}_4\text{-N}$ )

**Ammonium ion** ( $\text{NH}_4^+$ ) is also brought to natural waters by animal and human wastes. The ammonia ion is either released from proteinaceous organic matter and urea or is synthesized after the fixation of atmospheric nitrogen (**Train, 1979**). Even more than nitrates, it is preferentially absorbed by plants. It is also produced by fishes and zooplankton, which leads to very rapid development of phytoplankton in waters in which this chemical form of nitrogen cannot be detected by chemical analyses (**Faurie et al., 2001**). Distribution of  $\text{NH}_4\text{-N}$  in unpolluted Rivers ranges from 0.005 to 0.040  $\text{mg L}^{-1}$  with an average value of 0.018  $\text{mg L}^{-1}$  (**Wetzel, 2001**). The range of  $\text{NH}_4\text{-N}$  concentration in western Himalayan rivers varied from traces to 0.644  $\text{mg L}^{-1}$  (**Semwal and Akolkar, 2006**), but **Singh et al., (2008)** reported range (nil to 3.1  $\text{mg L}^{-1}$ ) of  $\text{NH}_4\text{-N}$  concentration in Yamuna River. **Thapa et al. (2010)** observed concentration of  $\text{NH}_4\text{-N}$  ranged from nil to 0.013  $\text{mg L}^{-1}$  in the Trishuli River of Nepal. Jhingran (1991) recorded ammoniacal nitrogen only during January to April in the river Brahmaputra. **Barat and Jha (2002)**, reported value of  $\text{NH}_4\text{-N}$  in the river Mahananda ranged from 0.080 to 0.460  $\text{mg L}^{-1}$ . **Jha and Barat (2003)** recorded  $\text{NH}_4\text{-N}$  concentration varied from 0.006 to 0.072  $\text{mg L}^{-1}$  in Mirik lake and suggested that the low concentrations may be due to the fact, that aquatic autotrophs rapidly utilize ammonium ions preferring these to nitrates; accordingly,  $\text{NH}_4\text{-N}$  does not reach a harmful concentration. Present investigation revealed a trend of downstream increase of  $\text{NH}_4\text{-N}$  in both the streams. **Jacobsen (2008)** opined that nutrient (like  $\text{NH}_4\text{-N}$ ) levels in tropical high-altitude streams are not necessarily different from lowland streams, but they may be elevated as a result of human activities or the sometimes naturally-fertile highland soils. **Jana and Barat (1984)** observed significant correlation between DO and  $\text{NH}_4\text{-N}$ .

#### 2.2.1.4.2. Nitrite Nitrogen ( $\text{NO}_2\text{-N}$ )

**Nitrites** ( $\text{NO}_2^-$ ) are the chemical form that is not abundant in water and are generally formed in water due to bacterial action on ammonia and organic nitrogen. They are rare because they constitute only a passing form between the nitrate and ammonia, during the

processes of nitrification and denitrification. Since nitrites are readily oxidized to nitrates, they are seldom present in significant concentration in surface waters. In natural waters, any concentration higher than  $10\mu\text{g L}^{-1}$  indicates a dysfunction of microbial mechanisms involved in the nitrogen cycle (**Faurie et al., 2001**). Nitrite nitrogen concentrations are very low ( $<3\mu\text{g N L}^{-1}$ ;  $<1.5\%$  of total dissolved inorganic nitrogen, DIN) among well oxygenated, unpolluted waters (**Wetzel, 2001**). Nitrite nitrogen concentrations in the Himalayan Rivers ranged from traces to  $0.035\text{ mg L}^{-1}$  (**Semwal and Akolkar, 2006**). **Thapa et al. (2010)** recorded range of  $\text{NO}_2\text{-N}$  and  $\text{NO}_3\text{-N}$  together in the river Trishuli of Nepal Himalaya ranged from nil to  $0.138\text{ mg L}^{-1}$ . Range of  $\text{NO}_2\text{-N}$  in the two sub Himalayan Rivers of north Bengal (Torsha and Mahananda) were  $0.001\text{-}0.008\text{ mg L}^{-1}$  and  $0.002\text{-}0.030\text{ mg L}^{-1}$  respectively (**Bhadra et al., 2003; Barat and Jha, 2002**). Highest value of  $\text{NO}_2\text{-N}$  in winter and lowest value in pre monsoon has been reported by **Bhadra et al. (2003)**. **Jacobsen (2008)** opined that nutrient (like  $\text{NH}_4\text{-N}$ ) levels in tropical high-altitude streams are not necessarily different from lowland streams.

#### 2.2.1.4.3. Nitrate Nitrogen ( $\text{NO}_3\text{-N}$ )

The Nitrate-nitrogen is one of the most oxidisable forms of nitrogen and is essential plant nutrient. Due to its higher mobility, its concentration in fresh water, apart from autochthonous production and utilization by plants, is also regulated by waste loading, agricultural runoff and ground water inputs. Thus,  $\text{NO}_3\text{-N}$  concentration is associated with rainwater runoff, sewage and sullage discharge. Welch (1952) opined that nitrate in natural waters will be in a continuously changing state due to the relation of nitrate with nitrifying bacteria and demand by nitrate consuming organisms such as phytoplankton and higher aquatic plants. An average  $\text{NO}_3\text{-N}$  concentration of nearly  $100\mu\text{g N L}^{-1}$  is found in natural river waters (**Wetzel, 2001**). Nitrates ( $\text{NO}_3^-$ ) are the majority and they are linked to the leaching of soils. Their mean concentration is  $1\text{ to }2\text{ mg L}^{-1}$  but increases rapidly following the spreading of nitrogenous fertilizers by farmers, especially if the vegetation is not quick to take it up and if it rains (**Faurie et al., 2001**). An average  $\text{NO}_3\text{-N}$  concentration of nearly  $100\mu\text{g N L}^{-1}$  is found in natural river waters (**Wetzel, 2001**). Range of  $\text{NO}_3\text{-N}$  in Himalayan River varied from traces to  $0.315\text{ mg L}^{-1}$  (**Semwal and Akolkar, 2006**), but **Agarwal and Rajwar (2010)** recorded concentration of nitrate-nitrogen from  $0.08\text{ to }1.19\text{ mg L}^{-1}$  in Tehri dam area. **Ormerod (1996)** found range of  $\text{NO}_3\text{-N}$  from  $0.06\text{ to }0.28\text{ mg L}^{-1}$  in Nepal Himalaya. The concentration of nitrate-nitrogen was more during monsoon than during winter months in the river Brahmaputra and ranged from  $0.030\text{ to }0.300\text{ mg L}^{-1}$  (**Jhingran, 1991**). Range of  $\text{NO}_3\text{-N}$  in the two sub Himalayan Rivers of north Bengal (Torsha and

Mahananda) were 0.090-2.200 mg L<sup>-1</sup> and 0.080- 0.042 mg L<sup>-1</sup> respectively (**Bhadra et al., 2003; Barat and Jha, 2002**). **Jacobsen (2008)** opined that nutrient (like NO<sub>3</sub>-N) levels in tropical high-altitude streams are not necessarily different from lowland streams, but they may be elevated as a result of human activities or the sometimes naturally-fertile highland soils.

#### **2.2.1.4.4. Phosphate Phosphorus (PO<sub>4</sub>-P)**

**Phosphorus** is found in water in two chemical forms; the orthophosphates (PO<sub>4</sub><sup>3-</sup>) and organic matter compounds (ATP, NADP etc). Phosphorus is always available in the form of phosphate in natural water and is generally low or medium in levels. This element is essential to life, and is considered as one of the limiting nutrient regulating plant production in aquatic ecosystems. Nevertheless, plants can assimilate, in addition to phosphates, phosphorus of organic origin by means of appropriate enzymes, phosphatases (**Faurie et al., 2001**). PO<sub>4</sub>-P averages about 10 µg L<sup>-1</sup> worldwide among unpolluted rivers (**Meybeck, 1982**). PO<sub>4</sub>-P concentrations in the north western Himalayan Rivers ranged from 0.010 to 1.6 mg L<sup>-1</sup>, lowest value found in the river Ramganga (**Bhatt and Pathak, 1990**) and highest value found in Tehri dam area (**Agarwal and Rajwar, 2010**). But **Singh et al., (2008)** reported range (1.2 to 3.1 mg L<sup>-1</sup>) of PO<sub>4</sub>-P concentration in Yamuna River. In the rivers of Nepal Himalaya, PO<sub>4</sub>-P concentration ranged from 0.02 to 0.04 mg L<sup>-1</sup> (**Thapa et al., 2010** in Trishuli River) and nil to 0.177 mg L<sup>-1</sup> (**Ormerod et al., 1996**). Phosphates range from traces to 0.55 mg L<sup>-1</sup> in the river Brahmaputra (**Jhingran, 1991**). **Barat and Jha (2002)** reported that values of PO<sub>4</sub>-P in the river Mahananda ranged from 0.060 to 0.0340 mg L<sup>-1</sup>. **Chakraborty (1998b)** observed the available phosphorus to vary between 0.005 and 0.008 mg L<sup>-1</sup> in natural hillstreams in Darjeeling. Similar range of average phosphate-phosphorus values of 0.027 and 0.028 ppm have been reported by **Kumar and Dobriyal (1993)** in the hillstreams of Garhwal. **Dhanze et al., (1998)** also observed lower phosphate concentrations in the Beas river system and gave possible reason to be low receipt of phosphorus from allochthonous source.

#### **2.2.2. Phytoplankton Community**

Algae, consisting of **phytoplankton** and **periphyton**, are the most significant sources of primary production in most streams and rivers (**Giller and Malmqvist, 1998**). The net primary productivity of phytoplankton was estimated to be in the range of 178.4 - 314.4 mg C m<sup>-2</sup>d<sup>-1</sup> in some hill streams (Jiabharali, Lohit and Manas) of north eastern Himalaya (**Bhattacharjya, 2005**). He also estimated fish production potential based on the primary

productivity in these rivers ranged from 61 (R. Jiabharali) to 107 kg ha<sup>-1</sup> yr<sup>-1</sup> (R. Manas). **Jhingran (1991)** reported the minimum and maximum value of primary productivity in the river Brahmaputra River during the period of study (1973-1980) were 12.3 mg C m<sup>-3</sup>hr<sup>-1</sup> and 62 mg C m<sup>-3</sup>hr<sup>-1</sup>. Gross and net primary production at Gouhati ranged from 15.6 – 31.25 and 12.3 – 19.36 mg C m<sup>-3</sup>hr<sup>-1</sup>, respectively.

### 2.2.2.1. Taxonomic diversity and Relative Abundance

**Phytoplankton** float freely in the water column and thus are unable to maintain populations in fast flowing streams. River phytoplankton generally exhibit fast growth rates and tend to be smaller in size. **Ryder and Presendorfer (1989)** have summarized that i. phytoplankton diversity is very low in low order streams; increasing in high order large rivers; ii. Biomass of phytoplankton is very low in low order streams, increasing in large rivers, although often light limited; and iii. Phytoplankton productivity is also low, often light-limited by advective flows and turbidity. The generation times of river phytoplankton must be more rapid than the time of displacement downstream (**Wetzel, 2001**). Survival in rivers is aided by a number of water retentive mechanisms, particularly backwater “dead zones” of reduced currents near and among the banks and flood plains. These backwater areas retain water sufficiently to permit additional cell divisions of suspended phytoplankton (**Allan, 1995; Wetzel, 2001**). Thus, Perenniation of phytoplankton in rivers arises from surviving periphytic and benthic populations, often of backwater areas (**Cummins, 1964; Reynolds and Descy, 1996**) in various stages of growth or dormancy (**Wetzel, 2001**). Despite the large amount of literature available on the spatial and temporal variations in phytoplankton in lakes, little information is available on their distribution in hill stream especially in eastern Himalaya. **Vass et al., 1977; Raina et al., 1982** reported the plankton community of River Jhelum in Kashmir Himalaya. But, **Nautiyal (1984)** reported that the diatoms account for more than 80% of the potamo-phytoplankton in Himalayan streams and rivers. During their study on phytoplankton production in the snowfed river, Bhagirathi in the Garhwal Himalaya, **Joshi et al. (1993)** found the planktonic production was maximum during December- February and minimum in July- August. **Singh et al., (1993)** compared phytoplankton communities in two hillstreams [Alaknanda (A) and Nayar (N)] of Garhwal Himalaya. They found Bcillariophyceae was the most dominant group (A-49% and N-69%) followed by Chlorophyceae (A-32% and N-19%) and Myxophyceae (A-20% and N-13%). **Joshi et al., (1996)** observed planktonic density of Ganga canal at Jawalapur (Hardwar) and reported that the plankton density was maximum during winter and it decreased due to increased turbidity during rainy season. Maximum planktonic concentration (1104 unit/L)

was observed in the month of December and minimum (191 unit/L) in June. Members of Bacillariophyceae (67.6%), Chlorophyceae (18.5%), Desmidiaceae (11.6%) showed maximum density in the month of January whereas, Myxiphyceae (12.8%) were maximum in the October. **Negi et al., (2007)** reported a total of 38 genera of phytoplankton from three streams of District Nainital where Bacillariophyceae was the dominant group with 21 genera followed by Chlorophyceae (13 genera), Xanthophyceae (2 genera), Crysophyceae (1 genus) and Cryptophyceae (1 genus). A total of 75 taxa of phytoplankton were recorded along the longitudinal gradient of River Sindh, a tributary of River Jhelum in Kashmir valley (**Rashid and Pandit, 2008**). The phytoplankton represented by 32 genera and 98.13% of total plankton population in the in two regulated high altitude streams (Bhagirathi and Bhilangana) of Garhwal Himalaya (**Ayoade et al., 2009**). Green algae which accounted for 69.5% of the phytoplankton density were represented by 10 genera, this is followed by diatoms represented by 12 genera (26.75%), others were desmid(1.94%) and blue green algae(1.84%). In the lentic zone of rivers Bhagirathi and Bhilangana, plankton density was higher (mean=947 ± 624.36 units/l) and (881.5 ± 546.59 units/l) respectively compare to lotic zone (367.5 ± 463.15units/l) and (342.5 ± 359.92 units/l) respectively. Downstream (zeropoint), plankton density (mean = 101.5 ± 105.36units/l) was least during study period. Green algae were found to dominate among the planktonic organisms in lacustrine zone of rivers Bhagirathi (83.51%) and Bhilangana (81.9%). **Negi and Rajput (2011)** recorded a total of 45 species in the hill streams of Kumaun Himalaya, representing by four class viz. Chlorophyceae, Bacillariophyceae, Euglenophyceae and Cyanophyceae. Out of which maximum species diversity was recorded in Chlorophyceae followed by Bacillariophyceae, Cyanophyceae and Euglenophyceae. **Juttner et al., (2003)** found a total of 113 diatom taxa in the Kathmandu Valley streams and 106 in the Middle Hills. Of 168 taxa recorded, 62 occurred only in the Kathmandu Valley, 56 only in the Middle Hills and 50 were common to both areas. Most taxa found only in the Kathmandu Valley belonged to the genus *Navicula* while most taxa confined to the Middle Hills were *Achnanthes*, *Fragilaria* and *Gomphonema*. A total 18 fresh water algae have been identified from streams and rivers of Gajurmukhi VDC, Ilam, Nepal (**Rai et al., 2008**). A total 51 taxa of cyanophycean algae belonging to 28 genera have been enumerated from different lotic and lentic freshwater bodies of east Nepal during October, 2002 to June, 2004 (**Rai and Misra, 2010**). The average monthly plankton density varied from 13 – 81 uL<sup>-1</sup> in the river Brahmaputra (**Jhingran, 1991**). At Tezpur, the ratio of phyto- and zooplankton was 75:25. The average yearly occurrence showed that bacillariophyceae formed the most dominant group (27.7%), followed by Chlorophyceae (25.0%), Myxophyceae (19.6%) and Desmidiaceae (2.7%) among plankton. Whereas at Dhubri

Chlorophyceae (29.7%) was dominant over the other groups. **Biswas and Boruah (2000)** found among phytoplankton of Brahmaputra River Diatoms was dominant. **Bhattachrjya (2005)** also observed that plankton population was low (49 – 177 uL<sup>-1</sup>) in north eastern Himalayan hill streams except in river Borgung (753 uL<sup>-1</sup>) among which phytoplankton was well dominated and Bacillariophyceae was the maximum. A total of 28 different genera of phytoplankton groups were recorded from Pagladia river of Assam (**Das and Dutta, 2011**). Among these, classes Cyanophyceae were represented by 7 genera, Chlorophyceae were represented by 12 genera, Bacillariophyceae were represented by 7 genera, Euglenophyceae were represented by 1 genus, and Dinophyceae were represented by 1 genus. Chlophyceae were found to be dominant class (42 %) and Euglenophyceae along with Dinophyceae as the classes with least abundance (4 %).

#### 2.2.2.2. Density and Diversity Indices

**Jhingran, (1991)** observed low phytoplankton density in the river Brahmaputra which varied from 13 – 81 unit L<sup>-1</sup>. Biomass and productivity of phytoplankton is very low in Himalayan streams, they are even low in low order streams. **Dobriyal (1991)** have found glacial snow-fed Bhagirathi with high water velocity favours low growth of phytoplankton (0.1 to 4.6 units/ml) while spring-fed and moderately warm Nayar with low velocity favours good phytoplankton growth (0.4 – 9.06 units/ml). **Nautiyal (1984)** have also reported similar low (0.55 to 4.59 units/ml) diatom density in glacier-fed Alaknanda and high (0.40 to 9.06 units/ml) in spring-fed Nayar. **Chankraborty et al., (1959)** reported low densities in fast flow areas and high densities in slow flow areas. **Joshi et al. (1996)** observed planktonic density of Ganga canal at Jawalapur (Hardwar) and reported that the phytoplankton density was maximum during winter and it decreased due to increased turbidity during rainy season. Maximum planktonic concentration (1104 unit/L) was observed in the month of December and minimum (191 unit/L) in June. Members of Bacillariophyceae (67.6%), Chlorophyceae (18.5%), Desmidiaceae (11.6%) showed maximum density in the month of January whereas, Myxophyceae (12.8%) were maximum in the October.

Species diversity has two basic components: richness, or number of species in a given area, and evenness, or how relative abundance or biomass is distributed among species (**Huston, 1994; Purvis and Hector, 2000; Magurran, 2004**). These components are combined in Shannon-Wiener diversity index (H'). **Rout and Gour (1994)** have reported S-W diversity index > 4.0 have in Shillong stream (range was 1.6 to 4.1). Lesser Himalayan spring-fed tributaries of Garhwal Himalaya had relatively higher diatom diversity levels (2.02 to 3.02) in the Saung and (2.37 to 3.58) in the Nayar (**Nautiyal, 1997**). In Shannon-Wiener

legislation, the aquatic environment (soil/water) is classified as – very good when  $H'$  is  $> 4$ , good quality 4- 3, moderate quality 3-2, poor quality 2-1 and very poor quality  $<1$  (**Mishra et al., 2010**). A scale of pollution in terms of species diversity (3.0 - 4.5 slight, 2.0 - 3.0 light, 1.0 - 2.0 moderate and 0.0 - 1.0 heavy pollution) has been described by **Staub et al., (1970)**.

Evenness measures attempt to quantify this unequal representation against a hypothetical community in which all species are equally common. **Pielou (1966)** proposed that 'evenness' be measured by the ratio between the diversity  $H'$  calculated and that which would be obtained, for the number of species surveyed, in case of equiproportionalities. The ratio varies from 0 to 1 (**Faurie et al., 2001; Krebs, 1989**). **Pielou's (1966)** evenness index is an excellent measure of "relative evenness", because it is not independent of richness. But, **Ludwig and Reynolds (1988)** have reported that evenness indices are more difficult to interpret.

Margalef's Species Richness Index is a simple and easily interpretable indicator of biological diversity (**Peet, 1974**). Environmental stress such as flash floods, high water velocity and turbidity might have resulted in the dominance and which in turn responsible for lowest value of richness index **Plafkin et al., (1989)**. Neutral diversity theories predict that species number and immigration rates are sufficient to predict animal and plant community abundance distributions (**Caswell, 1976; Bell, 2000; Hubbel, 2001**), and Caswell's model makes explicit predictions that evenness and richness will be positively correlated in the absence of species interactions.

Simpson index measures the strength of dominance, because it weights towards the abundance of the most common species and varies inversely with species diversity (**Whittaker, 1972**). A value of this index ranges from 0-1; zero represents no dominance and 1, for maximum dominance; viz: only one species in the sample (**Greenberg, 1956; Berger and Parker, 1970**). According to **Whittaker (1963)** the value of dominance index is always higher where the community is dominated by a fewer number of species and when the dominance is shared by a large number of species. Similarly, **Walting et al., (1979)** opined that whenever dominance index of phytoplankton species was higher the evenness index was lower and vice versa. A community dominated by relatively few species indicates environmental stress (**Plafkin et al., 1989**).

Altitude is frequently correlated with changes in diversity (**Lomolino, 2001**). Generally, the observed pattern is marked by a decrease in species diversity and the substitution of species as altitude increases; however, the processes that determine those patterns remain poorly understood (**Lomolino, 2001**). Several hypotheses have been proposed to explain such changes in diversity associated with altitude; most of them are

based on only a few ecological factors. These can be summarized as: (1) reduction in the available area and environmental complexity, (2) greater severity of climatic conditions, (3) reduction in the diversity of available resources and (4) decrease in primary productivity with increasing altitude (**Huston, 1994**). There is no consensus on how these ecological factors co-vary and interact with environmental variables to generate the patterns of diversity observed in mountains (**Nogués-Bravo et al., 2008**). The density and diversity of phytoplankton assemblages along the gradient of streams is in agreement with the “river continuum concept” (**Vannote et al., 1980**). Central to the “River Continuum Concept” or RCC (**Vannote et al., 1980**) are the linked concepts that: (a) physical variables within a river network present a ‘continuous gradient’ of physical conditions from headwaters to a river’s mouth; and (b) this longitudinal gradient ‘ . . . should elicit a series of responses within the constituent populations resulting in a continuum of biotic adjustments and consistent patterns of loading, transport, utilization and storage of organic matter along the length of a river’. Such concept involving energy sources and allocation (**Vannote et al., 1980**) *i.e.*, at lower altitudes, there are higher amounts of energy available because of more solar radiation, more resources (for example, minerals and water); as a result, even higher levels of species richness can be allowed at lower altitudes.

### **2.2.3. Zooplankton Community**

Zooplankton as a biotic component of the aquatic ecosystems play a key role in cycling of organic materials, helping in regulating algal and microbial productivity through grazing, as suspension feeders and predators in the transfer of primary productivity to fish and other consumers (**Dejen et al., 2004**). They often exhibit dramatic changes in response to the changes in the physico-chemical and biotic properties of the aquatic environment hence are good bioindicators for the assessment of trophic state of water (**Vilela et al., 2003, Paturej and Goździejewska, 2005, Imoobe and Adeyinka 2010**). The zooplankton community structure within rivers is commonly dominated by small forms, such as protists, rotifers, bosminids, and juvenile copepods, throughout the year (**Pace et al., 1992**). Zooplankton in rivers tend to be significantly fewer, which would result in less efficient herbivory of phytoplankton in river ecosystem and their biomass tends to be negatively correlated with water velocities and positively correlated with temperature and phytoplankton chlorophyll a biomass (**Wetzel, 2001**). **Steveninck et al., (1992)** have pointed out that water velocity plays an important role in the both composition and abundance of zooplankton in the lotic water ecosystems. The other factors such as short retention of nutrients in fast flowing water, washing out of eggs and food availability also contribute for occurrence and

abundance of zooplankton (**Dizk and Zanlen, 1995**). The cladoceran zooplankton has low abundance in the rivers may be due to predation by juvenile fish **Zaret (1980) and Garcia et al., (2009)**. The dominant status of rotifer species in rivers comparative to the cladocerans and copepods is characteristic of tropical lakes and rivers and this has been reported in the studies of **Bidwell and Clarke (1977)**, **Neves et al., (2003)** and **Mwebaza-Nadwula et al., (2005)**, in particular **Edema et al., (2002)** had reported that numerically, the rotifers constituted 72.60% of plankton during a preliminary studies of the zooplankton and macrobenthos of the Okhuo River. According to **Arimoro and Oganah (2010)**, the ability of rotifers to undergo vertical migration, which minimizes competition through niche exploitation and food utilization, could be probably the reason for their dominance in the river. Also, rotifer richness in the stream probably could be due to high microhabitat diversity. The high population abundance of rotifer may also be attributed to their parthenogenetic reproductive pattern and short developmental rates under favourable conditions in most fresh water systems (**Akin-Oriola, 2003**).

### **2.2.3.1. Taxonomic diversity and Relative Abundance**

A total of 17 taxa of zooplankton were recorded along the longitudinal gradient of River Sindh, a tributary of River Jhelum in Kashmir valley (**Rashid and Pandit, 2008**). The zooplankton were observed to be negatively correlated with the current velocity ( $r = -0.382$ ). In comparison to the fast flowing reaches, the slow flowing calm water reach of the river recorded a good density and diversity of zooplankton. The zooplankton represented by 14 genera and 1.98% of total plankton community were encountered in Tehri dam reservoir area (**Ayoade et al., 2009**). The zooplankton consisted of rotifers, (51.8%), crustaceans (36.5%), and protozoans (11.7%). The maxima faunal density in winter and minima in monsoon season may be due to water temperature, water velocity, and turbidity been lower in winter months and these provide favourable environment for the growth of plankton. This has been confirmed by **Shastri et al (1992) and Agarwal et al., (2005)**. **Negi and Negi (2010)** studied the zooplankton diversity of Hinvall freshwater stream at Shivpuri of Garhwal region (Uttarakhand) and reported a total of 16 genera among which Rotifers constituted the major zooplanktonic diversity (7 genera) followed by Protozoans (4 genera), Cladocerans (4 genera) and Nematoda (1 genus). Only three groups of zooplankton viz: Rotifera, Cladocera and Copepoda were collected from the lotic and lentic water bodies of Kathmandu valley (**Vaidya and Yadav, 2008**). Rotifers were found to be more diversified than Cladocerans and Copepods in all water bodies except in Nagpokhari. A total of seventy one species of zooplankton were recorded during that period. The lentic water bodies supported a higher

species richness constituting seventy species whereas the lotic water bodies (Bagmati River) constituted only seven species of zooplankton. In the Bagmati river, Rotifers were recorded only in the upstream zone. Cladocerans predominated (74 %) in the upstream, Copepods predominated (70 %) in the mid-stream and again Cladocerans predominated (60 %) in the down-stream of the river. In the Trisuli River of Nepal zooplankton community were predominantly composed of protozoa (41%) and rotifera (39%) (**Thapa et al., 2010**). Similar observation has been made by **Ali et al., (2003)** in the Indus river of Pakistan. **Djurkovic (2006)** also found similar pattern of dominance. **Jhingran (1991)** reported dominant zooplankton genera in the river Brahmaputra were *Filina*, *Lecane*, *Brachionus*, *Cyclops*, *Bosmina*, *Daphnia* and Copepod nauplii. At Tezpur, rotifers share (13.5%), Copepods (8.3%) and Protozoan (2.7%) of total plankton community. **Boruah and Biswas (2002)** found 21 species of zooplankton in the river Brahmaputra with a density  $58 \text{ uL}^{-1}$  during the monsoon months and zooplankton populations increased considerably during the winter and summer. The two most important factors that appeared to restrict the growth of plankton in the Brahmaputra River were probably high current velocity and the turbidity of the river water during the major part of the year (May to October). A total of 14 different genera of zooplankton consisting of 5 groups were recorded from Pagladia river of Assam (**Das and Dutta, 2011**). Among these Protozoans were represented by 2 genera, Rotifera were represented by 6 genera, Cladocera were represented by 4 genera, Ostracoda were represented by 1 genera Copepoda were represented by 3 genera. Rotifers were found to be dominant group (37 %) and Ostracoda as the group with least abundance (6 %) through the study period. The tropical rotifer fauna are characterised by the abundance of certain families and genera. Out of 25 families known from the country, five, viz Lecanidae, Brachionidae, Colurellidae, Notommatidae and Trichocercidae are reported to constitute nearly 58.5% of total recorded species (**Sharma, 1999 b**). However, from West Bengal, only three families constituted the bulk of species composition (**Sharma, 1999 a**). Among genera, the dominance of the species belonging to *Brachionus* and *Lecane* in tropical waters of the world is by now well established and they have been rightly designated as ‘tropic centre genera’ (**Khan, 2003**).

### 2.2.3.2. Density and Diversity Indices

**Boruah and Biswas (2002)** found 21 species of zooplankton in the river Brahmaputra with a density  $58 \text{ uL}^{-1}$ . **Bhattacharjya (2005)** also found  $11.0 \text{ uL}^{-1}$  of zooplankton density in the Manas River but, the density was  $20.0 \text{ uL}^{-1}$  in the river Borgung of Assam with Copepods as a dominant group. Zooplankton with limited power of locomotion, largely move by means

of flagella or various mechanisms altering their distribution by changes in buoyancy and are more or less passively drifted by waves and water currents (**Westlake, 1980**). Many microcrustaceans are associated with substrata in benthic and littoral backwater habitats as a mean of alleviating downstream movement (**Quiros and Cuch, 1990; Richardson, 1991, 1992; Robertson et al., 1995**). Microcrustacea and rotifers tend to be moved from prevailing habitats of backwater areas and lower areas of pools during periods of flow exceeding  $2.5 \text{ cm s}^{-1}$  and exported downstream (**Wetzel, 2001**). **Steveninck et al., (1992)** have pointed out that water velocity plays an important role in the both composition and abundance of zooplankton in the lotic water ecosystems. The other factors such as short retention of nutrients in fast flowing water, washing out of eggs and food availability also contribute for occurrence and abundance of zooplankton (**Dizk and Zanlen, 1995**). Zooplankton biomass tends to be negatively correlated with water velocities and positively correlated with temperature and phytoplankton chlorophyll a biomass (**Wetzel, 2001**). Increased nutrient loadings during monsoon flood bring a change in the ratio of macronutrients that may alter zooplankton species composition, dominance and succession has been reported by **Breitburg et al., (1999) and Park and Marshall (2000)**. In freshwater systems, the total zooplankton abundance may increase with increasing eutrophication, while large species may be replaced by small species (**Beaver and Crisman, 1982; Bays and Crisman, 1983; Pace, 1986**).

**Balloch et al. (1976)** and **Ismael and Dorgham (2003)** advocated that the diversity index (Shannon's) was found to be a suitable indicator for water quality assessment. Diversity indices are good indicators of pollution in aquatic ecosystem (**Mason, 1998**). **Datta (2011)** recorded mean values Shannon's index ( $H'$ ) of zooplankton were ( $2.82 \pm 0.08$ ) and ( $2.39 \pm 0.21$ ) in two flood plain wetlands of Teesta river in Jalpaiguri district. The diversity Index of zooplankton observed to be ranged from 0.69 to 1.19 in Tungabhadra river (**Suresh et al., 2009**).

**Pielou's (1966)** evenness index is an excellent measure of "relative evenness", because it is not independent of richness. Evenness indices standardize abundance and range from near 0 when most individuals belong to a few species, to close to 1, when species are nearly equally abundant (**Smith and Wilson 1996**). The mean value of the evenness index ranged from 0.54 to 0.94 in two flood plain wetlands of Teesta river in Jalpaiguri district (**Datta, 2011**).

As the species richness index ( $R$ ) depend upon the number of species as well as number of individuals in each species and contribute equally to the value of  $R$  (**Ludwig and Reynolds, 1988**). Hence if any one of these two variables decreases or increases, it will affect the overall value of species richness index ( $R$ ). Higher species richness is characterized by

larger food chain (**Dumont, 1999**). **Datta (2011)** recorded range of zooplankton richness index varied from 2.08 to 4.52 in two flood plain wetlands of Teesta river in Jalpaiguri district.

Simpson index measures the strength of dominance, because it weights towards the abundance of the most common species and varies inversely with species diversity (**Whittaker, 1972**). A value of this index ranges from 0-1; zero represents no dominance and 1, for maximum dominance; viz: only one species in the sample (**Greenberg, 1956; Berger and Parker, 1970**).

#### **2.2.4. Ichthyofauna**

Fishes are cold blooded aquatic vertebrates which breathe by means of pharyngeal gills, propelling and balancing themselves by means of paired and unpaired fins supported by fin-rays (**Jhingran, 1991**). Fish constitute almost half of the total number of vertebrates in the world. They live in almost all conceivable aquatic habitats; c 21,723 living species of fish have been recorded out of 39,900 species of vertebrates (**Jayaram, 1999**). Of these, 8,411 are freshwater species and 11,650 are marine fish. Fishes are probably the best-known inhabitants of lotic systems. The upland water at high altitudes of Himalayan mountains remain cooler than the rest and the cold-water fishes flourish in these region. The fishes that are adopted to live between 10°C and 20°C water temperature are generally regarded as the cold-water fishes. The water temperature falling within the tolerance limits of the snow trouts and may be termed as cold (**Jhingran and Sehgal, 1978**). Apart from the members of the family Salmonidae, which are commonly known as the cold-water fishes, the cyprinids belonging to the sub- family Cyprininae, which inhabits streams, lakes and reservoirs receiving snowmelt water directly from their adjacent watersheds, are also included in the definition of cold-water fish (**Ayyappan, 2006**). On the basis of the temperature tolerance, the cold-water fishes are categorized as eurythermal (having broad temperature tolerance range) and stenothermal (having a narrow temperature tolerance range). Fish species like *Schizothorax richardsonii*, *Cyprinus carpio* and *Barilius bendelisis*, which can withstand a wide spectrum of temperature, can be categorized as eurythermal. The Brown trout (*Salmo trutta fario*), Eastern brook trout (*Salvelinus fontinalis*) and Tibetan snow-trout (*Diptychus maculates*) are the examples of stenothermal species, which can tolerate only a narrow range of temperature, nearly up to freezing point of water. It is the upper level of the tolerance limit that determines survival, occurrence and distribution of fish in time and space (**Ayyappan, 2006**).

### 2.2.4.1. Taxonomic Diversity

India is one of the megabiodiversity countries in the world and occupies the ninth position in terms of fresh water megabiodiversity (**Mittermeier & Mittermeier, 1997**). In India there is about 2 319 fish species that have so far been documented, of which about 838 fishes inhabit freshwaters (**Lakra & Sarkar 2010**). Around 750 species may be considered as freshwater fishes in India (**Daniels, 2002**). However subject to differences in definition of “freshwater” and “Indian region” the number of species may vary between 440 and 930 (**Talwar and Jhingran, 1991; Menon, 1999; Jayaram, 1999**). **Menon (1962)** has listed 218 species of fishes in whole Himalayas. There are 258 fish species, indigenous and exotic, belonging to 76 genera spread over in the Himalayan and the peninsular plateau. The important ones are snow-trouts (*Schizothorax* spp and *Schizothoraichthys* spp), mahseer (*Tor* spp), minor carps (*Labeo dero*, *L dyocheilus*, *Crossocheilus* spp and *Garra* spp), lesser barils, minnows, catfishes and loaches among indigenous species, and trouts and Chinese carps among the exotics (**Mahanta, 2006**). **Jayaram (1999)** stated that the fish fauna of the Indian hill stream is well documented and shows perfect adaptations to the living conditions. The fish fauna of the Indian hill streams consists of 133 fish species (excluding the exotic species and some culturable native carps and commercial fishes which are abundantly available in the water bodies located in the foot hills), belonging to 31 genera and mainly two orders, namely Cypriniformes and Siluriformes. Some of the streams, which are ecologically degraded, also supports member of the orders Channiformes, Atheriniformes and Mastacembeliformes in the middle Himalayan zone. The order Cypriniformes has 21 genera and 101 fish species whereas the order Siluriformes is represented by 10 genera and 32 species (**Johal, 2006**). Greatest diversity in Cypriniformes and Siluriformes has been reported by **Johal and Rawal (2005)** in western Himalayan hill stream and by **Shrestha (1999)** in the Nepal region of the Himalayas. According to **Sehgal (1999)** the eastern Himalayas drained by the Brahmaputra has a greater diversity of cold-water fish than the western Himalayan drainage, he also mentioned fisheries in the Indian Himalayan river are basically of two types a), Subsistence fishery and b), Sport/recreational fishery. **Menon (1962)**, related the distribution of Himalayan fish to morphological characteristics, which enable them to inhabit the torrential streams. He recognised six major groups on the basis of flow rate, nature of substratum, water temperature, and the availability of food. In the torrential streams, **Sehgal (1988)** identified several zones on the basis of the dominant fish species and the hydrographical features. According to **Richard, (1982)** and **O’Neill, et.al., (1987)** diversity of fish species is directly related to habitat unit features and there are mainly two primary type of habitat unit in the fast

flowing streams i.e. the riffles, and pools. Riffles and pools always do not have clear boundaries, but they have distinct ecological habitats. Fish inhabiting them differs markedly in taxonomic composition and morphological, physiological, and behavioural traits. **Sheldon (1968); Evans *et.al.*(1979)** and **Angermeier (1987)**, reported that the riffle dwellers are bottom-oriented fish, possessing large pectoral fins to help to maintain positions. Some lacks air bladder to reduce buoyancy. Pool dwellers, often found in aggregations are more active swimmers with more dorso-ventrally compressed body with smaller fins. Within the habitat unit, structural features, substrate, flow velocity and pool depth influences biotic diversity. Community diversity increases during the summer with the increasing level of habitat complexity.

More than 65% of the 182 fish species known in Nepal occur in the Gandaki River (**Edds, 1986**). Later on, **Edds, (1993)** investigated spatial and temporal patterns of fish assemblage composition in Nepal's Gandaki River, which exhibits extremes of altitude and environmental conditions. The ichthyofauna consisted mainly of cypriniforms and siluriforms and also included cyprinodontiforms and perciforms. The fish fauna showed longitudinal replacement and addition of species, as the number of species increased from one in the headwaters to a maximum of 33 in lowland sites. **Shrestha (2001)** has reported for Nepal a total of 182 fish species belonging to 92 genera under 31 families and 11 orders, as compared to 186 species of 75 genera, 31 families and 11 orders reported earlier. **Shrestha (2002)** reported a total of 81 cold water species under 37 genera belonging to 2 orders, 7 families and 10 subfamilies is listed, with their updated nomenclature and systematic position according to the recent classification of **Jayaram (1999)**. Genera *Naziritor* Mirza and Javed, *Salmostoma* Swainson, *Securicula* Gunther, *Acanthocobatis* van Hasselt and *Lepidocephalus* Bleeker are revised here. A number of species have been either synonymised or merged with others. **Shrestha (1990)** has reported 31 species including *Rita rita* (Hamilton-Buchanan) as the threatened species of Himalayan waters of Nepal. **Thapa Chhetry (2006)** identified 92 fish species belonging to 54 genera and 25 families in the wetland of Koshi-Tappu wild life reserve and its surroundings in Nepal. **Shrestha (1999)** studied the river Bagmati and Gandaki and listed 22 species of fish. She has also proposed river zonation based on the presence of the dominant fish species for the two rivers of Nepal. Bhutan currently lacks any detailed survey and baseline information on the distribution and abundance of its aquatic fauna. The current knowledge of fish of Bhutan is a documented list of 41 species found in rivers and lakes of southern Bhutan (**Dubey, 1978; Dhendup and Boyd, 1994; Shrestha, 1998; Petr, 1999**).

**Kottelat and Whitten (1996)** estimated the Ganga River drainage to contain 350 and Brahmaputra and Ayeyarwaddy river drainages to contain 200 species of fishes respectively. Clearly, estimates of fish diversity across the region vary widely. **Allen et al. (2010)** found Portions of the Brahmaputra drainage located in Arunachal Pradesh, Meghalaya, and northern Bengal; together with parts of Assam and the Himalayan foothills between Nepal and Bihar exhibit the most diverse fish fauna. Species richness is highest in the Tista, Kameng, Dikrong, Subansiri and Siang basins. The richness in these areas is due to the diversity of habitats and environments existing between the plains of the Brahmaputra at a low altitude (120–200 m) to the upland coldwater regions (1,500–3,500 m) in the hill ranges in Arunachal Pradesh and also in Meghalaya and Assam within a short aerial distance of 200–500 km. **Nath and Dey (2000)** have recorded a total of 131 species from drainage of Arunachal Pradesh. Ichthyological survey and review of the checklist of fish fauna of Arunachal Pradesh have been conducted by **Bagra et al. (2009)** and developed a checklist with 213 fish species for the state. They have added 43 species to the previous record of 170 species. This study confirmed the occurrence of five new species described by previous investigations and encompasses the discovery of two new species, although the taxonomic status of 27 species is uncertain and requires additional study. A total of 44 species of fishes belongs to 9 families were identified in the river Siyom of West Siang district, Arunachal Pradesh. Fishes of family Cyprinidae were found to be dominant followed by Balitoridae (**Bagra and Das, 2010**). **Boruah (1999)** reported 167 species from the upper Brahmaputra basin, of which 64 species belonged to Cyprinidae (38 percent), 19 species belonged to Sisoridae and 12 to Cobitidae. **Boruah and Biswas (2002)** opined that of which about 30 percent may be considered as ornamental varieties. Northeastern India is represented by 267 species belonging to 114 genera under 38 families and 10 orders (**Sen, 2000**). This is about 33.13% of total Indian freshwater fishes. **Choudhury (2005)** reported that rich ichthyodiversity of northeast India comprises 297 fish species belonging to 114 genera under 38 families and 10 orders. It forms about 33% of the total Indian fresh water fishes. **Kar (2005)** reported the occurrence of 103 species of fishes through an extensive survey conducted in six principal rivers in Barak valley (Assam), Mizoram and Tripura. **Tamang (1993)** reported about 48 species of fish from Sikkim. However, only 37 species were recorded in 2001 (**MOEF, 2002**). Very recently, **Goswami et al., (2012)** published lists of 422 fish species from north east India, belonging to 133 genera and 38 families.

There is no extensive study on fish diversity in North Bengal. Though, the ichthyodiversity of this region is unique from the zoogeographical point of view. The fish fauna represents mostly the Chinese, Malayan and Indian elements of fishes of the Oriental

realm (**Hora and Gupta 1940**). **Hooker (1854)** reported about Cyprinoids big fishes that were abundantly found in crystal clear water of river Rangit. **Malley (1907)** in his Darjeeling district Gazetteers wrote that the fish found in the district include the *Mahseer*, the *Katli* and the freshwater shark and many others. He also mentioned that the *Mahseer* and the *Katli* give good sport, the former running upto 50 pounds. **Shaw and Shebbeare (1937)** published in the Journal of Royal Asiatic Society of Bengal an illustrated account of the 'Fishes of Northern Bengal' and listed 131 species', a few of which are stated to be exotic as they had been purchased from the markets at Siliguri and similar other places served by railway. All the same, the indigenous species of this region certainly number over one hundred. **Hora and Gupta (1940)** surveyed the Kalimpong Duars and the portion of the Terai in the Siliguri subdivision of the Darjeeling district and the collections of fish were made from large number of small streams, ponds and ditches. 58 species of fishes were obtained by them and they have added three more species to the species listed by Shaw and Shebbeare. **Dash** wrote 'Over 125 species of fish' in the Darjeeling district gazetteer of 1947, "have so far been recorded from this area. Some of them are found in torrential streams and are remarkably well adapted for clinging to rocks in swift currents". Environment Impact Assessment (**EIA**) on Teesta Low Dam Project reported 26 fish species in Teesta river among which 9 are commercially important and 5 are migratory in nature (**Anon, 2002**). **Jha et al., (2004)** studied the fish fauna of Mahananda reservoir, near Siliguri town and Identified 49 species of fish. **Barat et al. (2005)** reported 21 species of fishes from Darjeeling uplands. **Mukherjee et al. (2011)** reported 22 species of endangered/ vulnerable/ threatened fishes from Darjeeling and 8 species from Siliguri. **Chakraborty and Bhattacharjee (2008)** investigated ichthyofaunal resources of south Dinajpur district. **Sarkar and Pal (2008)** studied the diversity of fish in different reservoir and rivers of Terai region and altogether 83 species of fish belonging to 24 families and 51 genera were collected. **Patra et al., (2011)** reported Ichthyofauna diversity of Karala River in Jalpaiguri, a total of fifty five species belonging to eight orders and twenty families were identified.

#### **2.2.4.2. Density and Diversity Indices**

**Pokharel (2011)** have reported low fish CPUE (Ranged from 246.95/0.1 ha to 510.70/0.1 ha) in Seti Gandaki river of Nepal. In flowing waters the numbers of fish species were more numerous with increasing water depth (**Sheldon 1968, Bain 1995**). **Patra et al., (2011)** found Shannon-Wiener species diversity index of ichthyofauna ranged from 3.18-3.75 in Karala river, a tributary of Teesta river near Jalpaiguri town. **Murugan and Prabakaran (2012)** reported Shannon-Weiner index for fish diversity in Kamala reservoir ranged from 2.2

to 4.10. **Pereira (2000)** used this same index to evaluate the diversity of Camaleao Lake, finding values varying from 3.9 to 4.1. In Central Amazonian lakes, **Barthem (1981)** found variation in the Shannon index of from 2.2 to 3.2. **Sarkar *et al.*, (2013)** reported slight variations of Shannon-Wiener diversity index between protected river and unprotected stretch of river. The values ranged from 3.8 to 5.8 with a mean of 4.4 as compared to unprotected habitat ranged from 2.9-4.8 with a mean value of 4.2.

Evenness measures attempt to quantify this unequal representation against a hypothetical community in which all species are equally common. **Pielou (1966)** proposed that 'evenness' be measured by the ratio between the diversity  $H'$  calculated and that which would be obtained, for the number of species surveyed, in case of equiproportionalities. Evenness indices standardize abundance and range from near 0 when most individuals belong to a few species, to close to 1, when species are nearly equally abundant (**Smith and Wilson, 1996**). **Patra *et al.*, (2011)** reported evenness index for ichthyofauna ranged from 0.887 – 0.949 in the Karala river. Fish communities in riverine systems typically follow a pattern of increasing species diversity and abundance from upstream to downstream (**Bayley and Li, 1994**).



# *Chapter 3*



## *Materials and Methods*

## ***3. Materials and Methods***

---

### **3.1. Study area**

Darjeeling Himalaya, as it popularly known, is the hilly Himalayan part of the northern most Darjeeling district of Indian state of West Bengal. Like other parts of Himalaya this region has a pronounced seasonal climate and lies north of the tropical belt. The district lies between 27°13' 05" and 26°17'10"North latitudes and between 88° 53' 00" and 87° 59' 30" East longitudes. The district resembles an irregular triangle, of which the base resting on Sikkim, its sides touching Nepal Bhutan and the Jalpaiguri district of West Bengal, while its apex projects into the Purnea district of Bihar, North Dinajpur district of West Bengal, and Bangladesh.

#### **3.1.1. River system**

The region fosters many perennial rivers which flow through deep gorges. The district has 3397.63 ha of riverine resources, which belongs to the Himalayan or extra-peninsular rivers. The rivers of this group are glacier, spring and rain-fed, originating from the Himalayas to traverse great alluvial Indo-Gangetic plains. Descending on the plains, they become sluggish and inundate vast land area. The rivers of the Darjeeling district drain eventually to the south through the Ghum and the Labha saddles cause a number of tributaries of the Great Rangit, the Teesta and the Jaldhaka rising on their northern faces to flow north while others flow east or west before joining the main streams. Thus a complicated pattern of drainage has evolved amidst the myriad interlacing ridges and ramifying spurs. The valleys on the south-eastern side of the Singalila ridge are drained by the Mechi, Balasan and the Mahananda rivers while the rest of the Darjeeling hill is drained by the Teesta and its tributaries, except the extreme eastern portion where the chief effluent is the Jaldhaka. Rivers of the Darjeeling Himalaya have been classified into 3-categories, on the basis of length and volume of water. The rivers in Darjeeling Himalaya are locally called 'Khola' or 'Chu'.

##### **3.1.1.1. River Teesta**

The '*Teesta*' or '*Tista*' is the biggest and by far most turbulent glacier fed river of Darjeeling district (Detail feature given in **Annexure A**). The term '*Teesta*' or '*Tista*' is a Nepalese abbreviation of the Sanskrit word '*Tri-srota*', meaning, it has three '*srotas*' or currents. This probably because the river once (before 1787 A.D.) flowed through three

different channels- the *Atrai*, *Punarbhaba*, and *Karatoya*, each of which followed independent courses to the Ganges and Meghna. The Bhotia name for this river is '*Tsang-Chhu*' or the pure water, while the Lepcha call it the '*Rangnyung*' or the great straight going water, in allusion to the fact that it continues in a straight unaltered course in spite of receiving a great accession to its water from the great Rangit joining to it at straight angles. It has been suggested, however, that the word is derived from '*di*' or '*ti*', the Bodo word for water.

The river takes its rise as 'Chumbu chu' (the upper most Teesta) in the North-East edges of North Sikkim from Pounhri (Pouhungri) glacier ( $29^{\circ}59'$  N and  $88^{\circ}48'$  E) at an altitude about 6200 m asl. River Teesta outfalls into the river Brahmaputra (Jamuna) at Kamarganj in Rangpur district of Bangladesh. It belongs to the Brahmaputra system of rivers. The river rising from the greater Himalayan hills is enlarged by the contribution of quite a large number of tributaries in the Himalayan and sub-Himalayan regions. Tracing its course in the hilly catchment, which lies in the Sikkim state, the river gets its name Teesta below the confluence of two rivers, Lachung chhu from the north-eastern direction and Lachen chhu from from north-western direction. The Lachen chhu is fed by a snow-fed turbulent stream of fifth order right bank Zemu chhu at Zema. The Lachung chhu is fed by left bank tributary Sebzung chhu (fourth order). The combined flow of the Lachung chhu and Lachen chhu, after emerging from, Chungthang or Thunthang ( $27^{\circ}39'$  N and  $88^{\circ}39'$  E) goes by the name of Teesta River. The Teesta forms the boundary of the Darjeeling district from the point where it is joined by the Rangpo chhu to its junction with the great Rangit. From the latter point it flows entirely within the Darjeeling district through a deep gorge known as Sivok-Gola pass until it leaves it at Sivok.

### **3.1.1.2. Hill-stream Relli**

Relli or Rilli is a spring fed torrential left hand tributary of mighty river Teesta. '*Rilli*', is the Lepcha word for the Swirling River (Detail feature given in **Annexure B**). Though popularly called river, the Relli is a hill-stream. The hill stream has its origin in the Algarah-Lava ridge of Kalimpong subdivision (Lat.  $26^{\circ} 51'$  to  $27^{\circ} 12'$  N and Long.  $88^{\circ} 28'$  to  $88^{\circ} 53'$  E) of Darjeeling district in the Khampang reserve forest at an altitude of about 1800 meter asl. The total length of the stream Relli is about 32 km and joined to the river Teesta at an altitude of about 212 m. The point of joining is situated at 7 km. down from Teesta bazaar. The average width of the stream bed varies from 90-150m. The longitudinal slope of the stream is  $11\text{m.km}^{-1}$ . The slope of the stream bank varies from 20 to  $90^{\circ}$ . During the monsoon the stream is quite swift but in

dry season it dries down into a small stream. The catchment area of the stream is 165 km<sup>2</sup> and the catchment is hilly and well managed.

### **3.1.2. Teesta Basin**

#### **3.1.2.1. Physical and Geomorphic features**

Teesta drainage basin in hilly region of both Sikkim (6930 km<sup>2</sup>) and Darjeeling Himalaya (1121 km<sup>2</sup>) covers an area of 8051 km<sup>2</sup>. In southernmost part of Sikkim, Teesta river flows in southwest direction and defines the inter-state boundary between Sikkim and West Bengal up to Melli Bazar where it is joined by Rangit river which drains West Sikkim district. North Sikkim is endowed with a number of glaciers that descend from the eastern slopes of Khangchendzonga and western slopes of Pauhunri *e.g.*, Zemu glacier. The high altitude district North Sikkim forms the upper Teesta basin and is endowed with number of glacial lakes of various sizes and shapes. Among the entire catchment area in Darjeeling Himalaya, the Takdah spur is the most significant geomorphological feature on the right bank, and the Kalimpong dome on the left bank and a deep gorge known as Sevoke-gola pass through which Teesta flows. Altitude of the Teesta basin varying from about 145 m in the south at Sevoke to above 8,500 m (Mt. Khangchendzonga: 8,598 m) in the north-west and northeast (Pauhunri: 7,056 m). More than 43% of Teesta basin in Sikkim is characterized by very steep slopes and escarpments. The slope of catchment in Darjeeling region ranges between 14<sup>0</sup> and 40<sup>0</sup> and the relative relief ranges between 160 m to 800m. The terraces and flood plains, valley side slopes, and land slide slopes, alluvial cones of different types and generations, tors, kettle shaped depressions, terrace – isles, sickle shaped ranges, bevelled plains, undulating plains and deeply dissected valleys, glacial or periglacial deposits, related sedimentary structure, crevasses, etc., are the distinctive geomorphologic features of the Teesta basin. The landforms assemblages are the result of continuous denudation and deposition process that are constantly modifying the newly formed landforms in upper reaches and burying the existing landforms in the lower reaches. Middle and lower parts of basin are marked by subdued relief, slopes, wash slides and slips, scourge and filling, abandoned channels, etc,

#### **3.1.2.2. Physiography**

The landforms and drainage of Teesta river basin are characterized mainly by the four tiered terraces, canyons or gorge-valleys at different altitudes, asymmetric valleys, polyprofilic U-shaped valleys and steps or troughs, lakes, alluvial cones, truncated ridge-

spurs, terracettes (soil landscape systems), rectangular-barbed-parallel-trellis-radial to sub-dendritic drainage patterns, straight to meandering and braided channels. All these physiographic features are indicative of active processes of weathering, denudation and deposition making the area physically very sensitive. Ten broad landforms could be identified in the basin. These are ridge, rocky cliff, escarpment, landslide zone, morainic zone, low mountain (< 1,000 m), narrow valley, middle mountain (1,000 - 2,000 m), high mountain (2,000 - 3,000 m), very high mountain (3,000 - 4,000 m) and extremely high mountain (> 4,000 m) along with glaciers.

### **3.1.2.3. Geological setup**

The present configuration and geomorphology of the Teesta river basin reveals its geological history. The key to the past (some 40 million years ago) lies mainly in the folded structure which was outlined during the tertiary period, on the site of an ancient sea or geosyncline stretching between the Tibetan highland and South Indian massif and termed Tethys, that had accumulated sediments from both the sides of different geological ages. The mountains are made up of folded rocks piled one over another by a series of north-south horizontal compressions and tangential thrusts which folded the strata on the sea floor and caused their vertical upheaval by several intermittent phases (Mukherjee *et. al.* 1980).

The following five types of rock formation are observed from south to north of the basin.

1. Siwalik formation: It comprises the sediments by the ancient Himalayan rivers in their channels and flood plains in the last 16-1.5 million years, where the coarse grained sand stone, shaly sand stone, silt stone and conglomerate are the main components.
2. Gondwana formation: It comprises feldspars and micaceous quartzite sand stone, carbonaceous shales, and thin lenses of crushed and sheared coal and pebble/boulder bed.
3. Daling formation: It is mostly represented by the slates, phyllite, quartz phyllites inter banded with quartzite, quartz-chlorite, sericite schist, epidiorite, carbonaceous phyllite and quartzite sulphide. Mineralization is mostly located in the quartz-chlorite schist horizon.
4. Buxa formation: It comprises predominantly of dolomite, orthoquartzite, variegated phyllite interbanded with quartzites/dolomites.
5. Darjeeling formation: It comprises granitiferous biotite gneiss, varieties of high grade schistose rock and magnetite.

### 3.1.2.4. Soil

Soils of the Teesta river basin area are heterogenous in nature. The soil developed on steep hill slopes are shallow to very shallow, excessively drained with severe to very severe erosional hazards. These are mostly the residual of the eroded soil and lack profile development. The texture varies from gravelly loam to loam and is classified as lithic and Typic udorthents. The soil, developed on foothill slopes and valley are moderately deep to deep, well drained, loamy in texture with moderate erosional hazards, they show some degree of profile development and are classified as Umbric and /or Fluventic Dystrochrepts, Lithic and / or Typic Haplumbrepts. These soils are strongly to moderately acidic in reaction and are rich in humus content with moderate to low base saturation. **Anonymous (2002)** reported that Soil of Teesta river catchment belongs to 3 orders, 4 sub orders, 7 great groups and 14 sub groups. Inceptisols are dominant and covers 52.96% of the catchment area followed by Entisols (30.77%) and Mollisols (16.27%). Darjeeling Himalayan soil generally classified into six types such as Mountain glacial soil, Forest soil, Brown forest soil, Cinchona soil, Terai soil and Tea soil (**De and Bera, 1990**).

### 3.1.2.5. Forest

Teesta basin has different kinds of vegetation cover due to various climatic, edaphic, topographical and altitudinal variations. Teesta basin in Sikkim is the richest in floristic diversity with 3,262 km<sup>2</sup> of forest. The vegetation of Sikkim can be classified under following heads.

1. Tropical semi – evergreen forests (upto 900m).
2. Sub- tropical broad leaved hill forests (900 to 1800m).
3. Himalayan wet temperate forests (1800 to 2700m).
4. Sub alpine forests (2700 to 3700m).
5. Moist alpine forests (3700 to 4000m).
6. Dry alpine forests (above 4000m).

The five major forest types according to altitudinal variation found in Darjeeling Hill Areas are:

1. Tropical moist deciduous forest (300-1000m).
2. Tropical evergreen lower montane forest (1000-2000m).
3. Tropical evergreen upper montane forest (2000-3000m).
4. Temperate forest (3000-3500m).
5. Sub temperate forest (above 3500m).

About 30% of the forest covers found in the lower hills are deciduous. Evergreen forest constitutes only about 6% of the total forest coverage. *Shorea robusta* remains the most prominent species of Tropical moist deciduous forest along with heavy under growth. Tropical lower montane evergreen forests are found on steep higher slopes, where drainage condition is good. Tropical upper montane evergreen forests are found in the areas where high humidity along with dense fogs and less sunlight is available. Undergrowth is dense and contains Nettles, Raspberries, Ferns and bamboos. On the steep ridges, Rhododendrons and bamboos are abundant.

### **3.1.2.6. Climate and Seasons**

The climate of Teesta river basin is interesting because of its position in relation to the Tibetan land mass, the wide differences in altitudes (145m-8598m), the powerful effect of the monsoons against the Himalayan barrier and the peculiar configuration of the neighbouring mountains which deflect winds and affect local temperature and rainfall. Within the same watershed of the river, sub-tropical or even tropical climate is often observed at the lower end of the watershed in the valley, where in temperate climate prevails in the upper reaches.

The rainfall in Sikkim, decreases with elevation upto a certain limit. Rainfall at Chungthang (1,600 m) is 2,650 mm and at Lachen (2,730 m) being situated at a distance of only about 20 km north of Chungthang is 1,680 mm, whereas Thangu (3,800 m), located about 20 km further north, receives only 840 mm of rain annually. As a result across the altitudinal gradient of Teesta basin, the southern and middle valleys are hot humid and wet, while northern parts are comparatively drier and cold. Teesta river basin in Darjeeling experiences heavier rainfall in the southern ridges and slopes near the plains. Kalimpong dome, near the northern border of the area, gets about 2,254 mm. The precipitation during the south-west monsoon constitutes about 80 per cent of the rainfall, July being the wettest month. On an average there are about 120 rainy days in a year. At Kalimpong it is 105 days. Temperature varies with altitude and slope aspects. It generally decreases with increase in altitude. The maximum and minimum temperature varies from 28<sup>0</sup> C in summer to – 10<sup>0</sup>C in winter in Sikkim basin. In Daarjeeling Himalayan basin at Kalimpong dome the maximum summer temperature is 27°C and the minimum 16°C. The maximum temperature in winter is 17° C and the minimum 5°C. Throughout the year the relative humidity remains above 70% in most parts of the basin. The relative humidity in Darjeeling basin is ranges from 90 to 95% during rainy season. Sky remains heavily overcastted during the monsoon. Fog or mist is very common in June to September but rare in December. The rainfall, temperature and relative

humidity data collected during the study period (March 2007 to February 2009) at Kalimpong dome is presented in **Tables 3-1, 3-2 and 3-3**.

The climate of Teesta basin in Sikkim can be categorised into four distinct seasons viz. i) Winter season from mid-November to mid April, ii) Spring (summer equivalent) season from mid-April to mid-June, iii) Monsoon season from mid-June to mid-September, and iv) Autumn season from mid-September to mid-November. The basin in Darjeeling has five climatic seasons namely, a) spring b) summer c) monsoon/rainy d) autumn and e) winter. These seasons are usually marked from the mid of the months following the English calendar. Spring season usually prevails from the mid February to mid April during the period the region experience frequent hail storm. The summer season starts from mid of April and continues to the mid of June when the district has a short hot weather. The Rainy season starts from the mid-June and last upto the mid of September, during which the area experiences the continuous rainfall, thick clouds, fog and mist and the increased relative humidity. The autumn season starts from the latter half of September and lasts upto November. The winter season starts from the latter half of the November and lasts upto the mid of February during which the average temperature drops down causing a cold weather. Generally the winter and the monsoon/rainy seasons are longer than the other seasons however the short spring and autumn seasons are favourable. **But, for the convenience of study the seasons of the study area expressed as-** a. Pre monsoon (**March, April and May**) b. Monsoon (**June, July and August**) c. Post monsoon (**September, October and November**) d. Winter (**December, January and February**).

### **3.1.2.7. Population and Land use pattern**

Total population of Sikkim is 6.07 lakh as found in census of 2011 with a decadal growth rate 12.36%. Density is 86 persons per km<sup>2</sup>. According to draft report by Census of India, 2011 the total population of Darjeeling district is 18.42 lakh. The decadal (2001-2011) growth rate of the population is 14.47% and the density is 585 persons per km<sup>2</sup>. Thus, in the Teesta river basin of Darjeeling total projected population is about 6.56 lakh.

The land use in the Teesta river basin is mainly includes agricultural activities, tea and medicinal plant plantations, construction works along with forests, rivers, jhoras etc. Major crops cultivated are paddy, millet, maize, soya bean, seasonal vegetables are crucifers, cabbage, cauliflowers, cucurbits; cash crops are ginger, turmeric, large cardamom etc.

### 3.1.3. Sampling sites

In the present investigation, four sampling stations (TR-I, TR-II, TR-III and TR-IV) in the river Teesta and three sampling stations (RR-I, RR-II and RR-III) in the hill-stream Relli were selected for collection of water samples, plankton and fishes. Descriptions of sampling sites are as follows-

#### 3.1.3.1. Description of sampling sites in the river Teesta

**TR-I** is located at Teesta bazaar near Teesta Bridge. Several activities like extraction of building materials, fishing, car washing, river rafting were found to be exercised here. **TR-II** is situated at the confluence with a small stream Geil khola, and 3 km down from the TR-I. Activities like extraction of building materials, waste disposal, fishing and river rafting were observed at this site. Teesta Low Dam Project-III (TLDP-III) is being constructed by NHPC about 3 km down from TR-II. **TR-III** is positioned in between the confluence with the Sweti jhora and Kalijhora where Teesta Low Dam Project-IV (TLDP-IV) is being constructed by NHPC and 12 km down from the TR-II. The site was a nice picnic spot, fishing activities practiced here. **TR-IV** is located near the Sevoke rail bridge, and 9 km down from the TR-III. The river flowed here in two channels. This is a famous picnic spot. Several activities like extraction of building materials, fishing were regularly exercised. Physical characteristics and channel morphology is summarized in **Table-3.4**.

#### 3.1.3.2. Description of sampling sites in the hill-stream Relli

**RR-I** is located at a distance of 10 km from the origin, and near the confluence with *Payong khola*. The site is almost out of any kind of disturbance except fishing. **RR-II** is situated at a distance of 6 km from RR-1, and near the confluence with *Pala khola*. Several activities like extraction of building materials, fishing and car washing had been practiced here. It is a famous picnic spot. **RR-III** is positioned at a distance of 8 km from RR-II, and near the confluence with *Khoni khola*. This site is also least disturbed but with little fishing activities. Physical characteristics and channel morphology is summarized in **Table-3.5**.

**Table 3-1 Range (maximum and minimum) and Average temperature (<sup>0</sup>C) at study area during study period.**

Months /Year		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
<b>2007-2008</b>	Max. range & Avg	28-19 24.6	29-21 25.8	32-35 29.3	30-24 28.3	31-22 26.4	33-25 28.52	30-22 26.6	31-22 26.7	26-21 23.7	21-16 19.0	22-11 17.8	20-14 17.30
	Min. range & Avg	18-10 15.0	19-14 16.7	22-17 19.5	22-19 20.53	24-20 21.2	23-19 21.26	22-18 20.4	21-16 18.1	17-12 14.1	14-09 10.8	12-06 9.19	10-07 8.69
<b>2008-2009</b>	Max. range & Avg	27-19 24.60	29-23 26.58	31-26 28.03	29-22 26.65	29-22 26.76	31-22 27.25	31-24 27.56	30-24 27.35	27-21 23.53	24-15 20.41	20-17 18.27	24-19 21.60
	Min. range & Avg	17-12 14.56	19-12 16.05	21-16 18.51	21-19 20.20	22-19 20.52	24-20 21.22	21-19 20.13	20-15 17.87	16-12 13.70	14-11 12.38	12-09 10.72	17-11 12.60

Source: Regional Sericultural Research Station, 7<sup>th</sup> mile, Kalimpong (972 m).

**Table 3-2 Range (maximum and minimum) and average of relative humidity at study area during study period.**

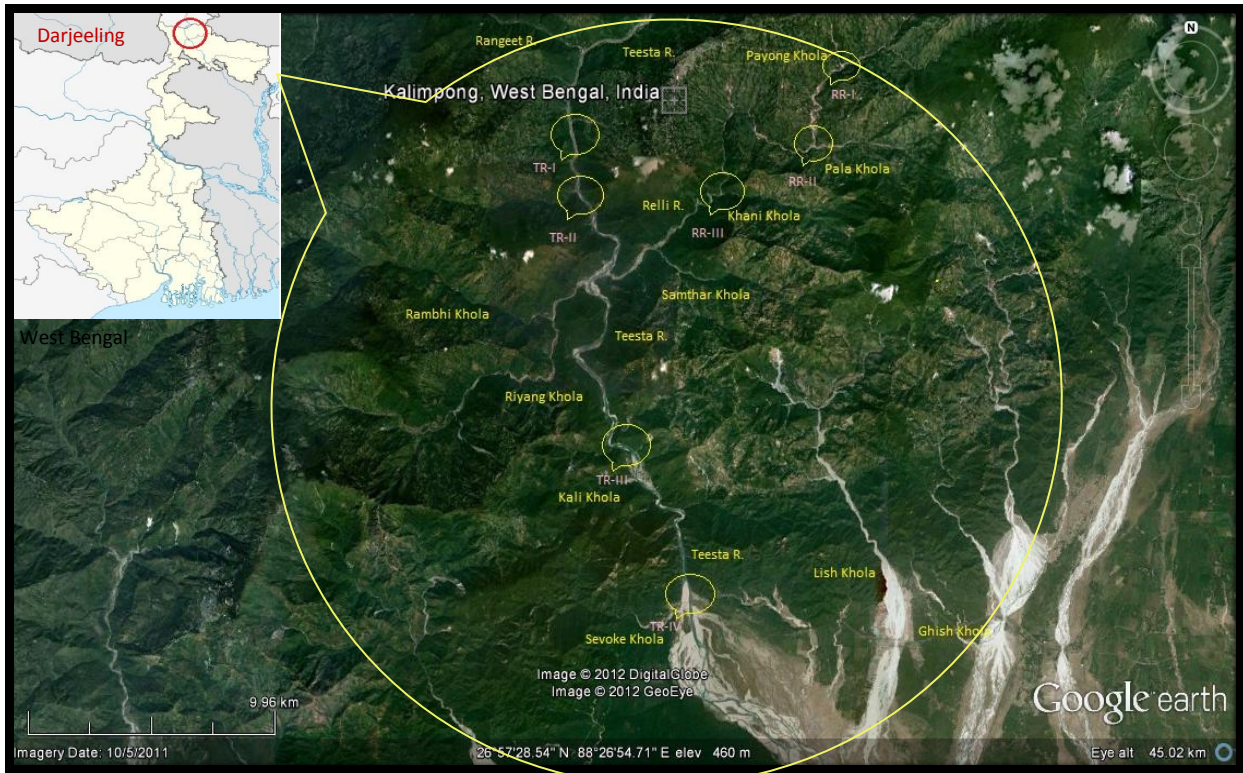
Months /Year		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
<b>2007-2008</b>	Max. range & Avg	80-60 75.74	95-63 82	96-52 83	100-83 91.93	100-84 94	100-84 92.77	100-80 94.83	100-81 88.74	100-59 83.36	94-72 81.8	93-67 79.73	93-69 82
	Min. range & Avg	69-33 55.0	82-46 67	77-49 66	91-59 77.6	96-69 84	92-64 79.38	95-66 83.88	91-53 72.4	81-36 61.5	80-42 60.0	87-42 66.92	76-52 65.15
<b>2008-2009</b>	Max. range & Avg	90-52 68.8	89-48 70.05	91-66 79	96-83 91.28	96-84 92.70	100-83 93.19	100-83 90.13	95-71 83.06	84-68 76.1	94-63 84.06	94-67 84.0	89-66 80
	Min. range & Avg	65-36 53.0	76-39 57.17	83-50 69.38	91-64 82.71	92-77 84.35	91-69 82.77	91-59 77.70	83-58 73.16	80-45 59.63	83-45 68.0	80-52 65.55	81-52 63.0

Source: Regional Sericultural Research Station, 7<sup>th</sup> mile, Kalimpong (972 m).

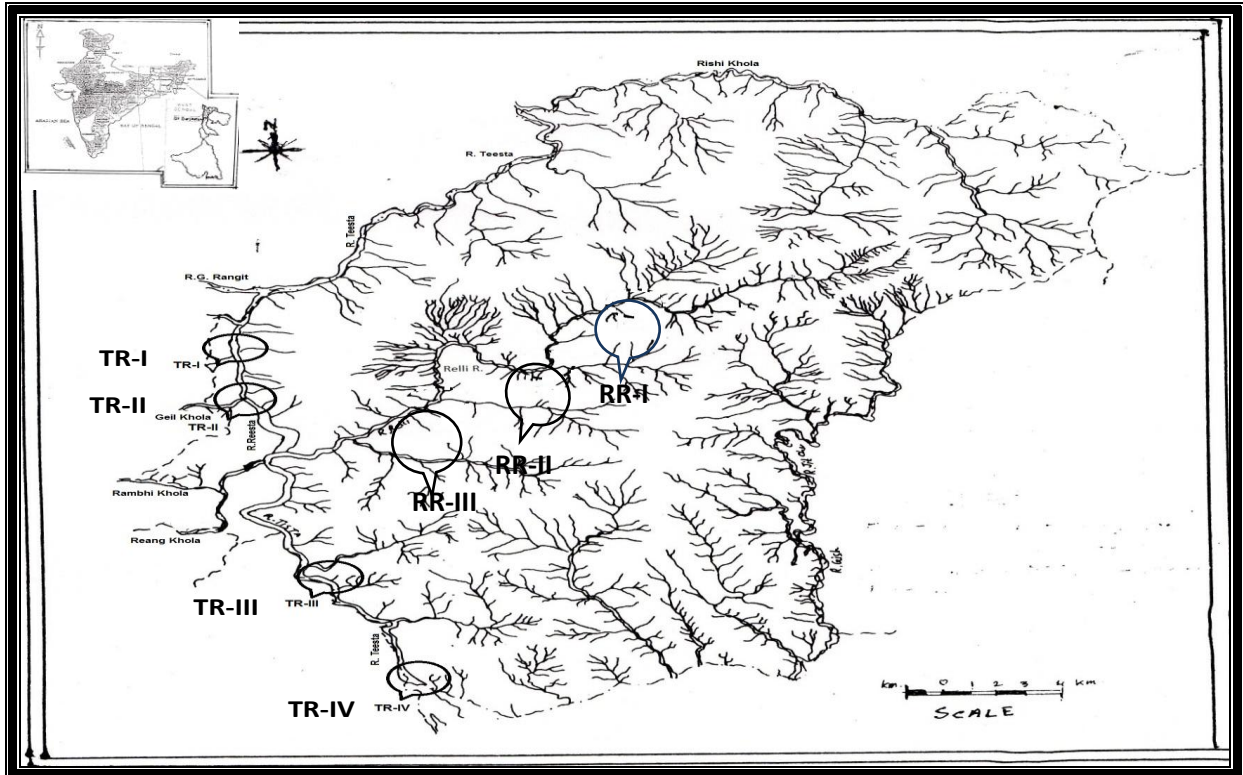
**Table 3-3 Rainfall data (mm.) and number of rainy days at study area during study period.**

Months/Year		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Total
<b>2007-2008.</b>	<b>Rainfall (mm.)</b>	45.5	53.1	86.2	274.9	962.4	340.0	579.4	36.1	0.0	0.0	16.0	0.0	2393.6
	<b>Rainy Days</b>	6	9	9	15	29	17	13	3	0	0	2	0	103
<b>2008-2009.</b>	<b>Rainfall (mm.)</b>	13.9	71.5	100.2	283.0	561.2	649.0	121.5	56.2	16.0	22.5	0.0	0.0	1895
	<b>Rainy Days</b>	3	3	10	17	17	17	14	4	2	2	0	0	89

Source: Regional Sericultural Research Station, 7<sup>th</sup> mile, Kalimpong (972 m).



**Figure 3-1** Map showing study area and sampling sites in the river Teesta and hill-stream Relli (courtesy Google Earth).



**Figure 3-2** Map showing study area and sampling sites in the river Teesta and hill-stream Relli.



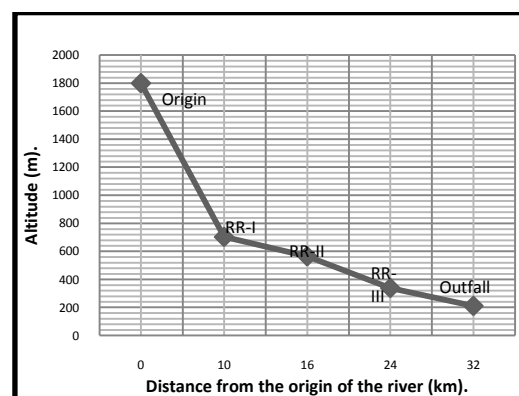
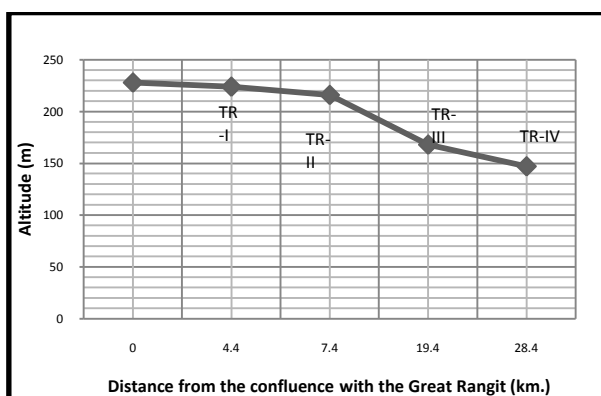
**Figure 3-3** Satellite images of sampling sites (courtesy Google Earth) and photo of author at the river side.

**Table 3-4 Physical characteristics, location, and channel morphology in the sampling sites of the river Teesta.**

Sampling sites	Latitudes (North)	Longitudes (East)	Altitudes, at river bed.(m asl)	Distance from the Great Rangit (Km)	River Width (m)	Channel width (m)	Depth (m)	Substrate
TR-I	27 <sup>0</sup> 03'05"	88 <sup>0</sup> 25'36"	224	4.4	125	93	3.4	Sand, gravel, cobbles, boulders and bedrocks
TR-II	27 <sup>0</sup> 01'47"	88 <sup>0</sup> 25'43"	216	7.4	128	60	3.9	Sand, gravel, cobbles, boulders and bedrocks
TR-III	26 <sup>0</sup> 56'30"	88 <sup>0</sup> 27'13"	168	19.4	162	88	3.7	Sand, gravel, cobbles, boulders and bedrocks
TR-IV	26 <sup>0</sup> 52'55"	88 <sup>0</sup> 28'37"	147	28.4	414	30/96	1.2/ 2.7	Silt, Sand, gravel, cobbles, boulders and bedrocks

**Table 3-5 Physical characteristics and channel morphology in the sampling sites of the hill stream Reli.**

Sampling sites	Channel width (m).	Stream depth (m).	Habitat	Substrate	Longitude/ Latitude	Altitude (m)	Riparian vegetation
RR-I	7.81	0.52	Shallow pool, Riffles, Runs, Side channel.	Sand, gravel, cobbles, boulders and bedrocks.	88 <sup>0</sup> 34'34"E /27 <sup>0</sup> 05'43" N	704	Trees, shrubs, Grasses.
RR-II	9.79	0.43	Shallow pool, Riffles, Runs, Side channel.	Sand, gravel, cobbles, boulders and bedrocks.	88 <sup>0</sup> 31'44"E /27 <sup>0</sup> 02'40" N	566	Trees, shrubs, Moderate encroachment.
RR-III	13.12	0.61	Shallow pool, Riffles, Runs, Side channel.	Sand, gravel, cobbles, boulders and bedrocks.	88 <sup>0</sup> 29'25"E /27 <sup>0</sup> 01'39" N	340	Trees, shrubs, Grasses.



(a)

(b)

**Figure 3-3 Slope gradient and sampling sites in Teesta river (a) and Reli (b) in Darjeeling Himalaya.**

## **3.2. Examination procedure**

### **3.2.1. Collection of water sample for water quality analyses**

Water samples were collected at monthly intervals from March' 2007 to February' 2009, from pool, riffle, run and side channels of fixed sampling sites of the river Teesta and its tributary stream Relli as mentioned above. Collections were generally carried out between 7.00 and 11.00 AM.

### **3.2.2. Methods for water analyses**

Water quality parameters estimated and the method applied for estimation of water quality during the present investigation is summarized in the **Table 3.6**.

#### **3.2.2.1. Air and Water temperature**

Air and water temperature was determined by using a calibrated standard mercury thermometer, graduated (0-50<sup>0</sup>C) with an accuracy of 0.1<sup>0</sup>C. Air temperature was recorded at all sampling sites during the study period by simply keeping the thermometer in air avoiding direct sunlight. A glass-beaker was kept in river water prior to collection of water. Soon after collection of the water the thermometer was immersed in the beaker water and the reading taken. In this case direct sunlight was also avoided.

#### **3.2.2.2. Water Velocity**

The velocity of river water was measured monthly during the study period. A distance of 10 metres was measured at the sampling site on a river section and marked. A float (usually an orange coloured cork) was released and time was noted to cross the 10m distance with the help of a stop watch. Then velocity was calculated and expressed as m sec<sup>-1</sup>.

#### **3.2.2.3. pH and Electrical Conductivity**

Battery operated pocket pH meter (Hanna Instruments, Model pHep) and conductivity meter (Hanna Instruments, Model DiST 3) were used to record pH and conductivity of water during the study period at every sampling sites. A glass-beaker was kept in river water prior to collection of water. Soon after collection of the water the pH meter and conductivity meter were immersed in beaker water and noted the reading. In this case direct sunlight was also avoided.

#### **3.2.2.4. Dissolved Oxygen (DO), Free Carbon dioxide (Free CO<sub>2</sub>), Total Alkalinity, Total Hardness and Chloride**

Water quality parameters like Dissolved Oxygen (DO), Free Carbon dioxide (Free CO<sub>2</sub>), Total Alkalinity, Total Hardness and Chloride were determined titrametrically according to methods as described by APHA (2005) mentioned in the **Table 3.6**.

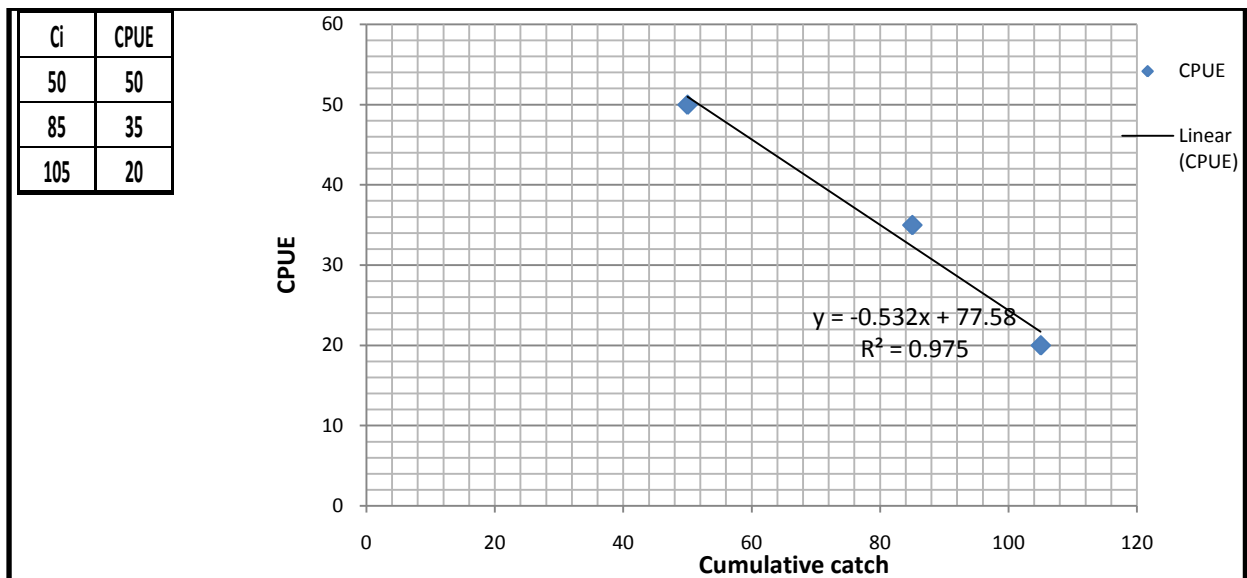
**Table 3-6 Water quality parameters estimated and the method applied for estimation of water quality during the survey.**

Parameters and units.	Preservative and method of sample treatment (If any).	Method of Analysis	Reference
1. Air and water temperature ( $^{\circ}\text{C}$ ).	Air and Water temperature was measured on the spot during sampling. Direct sun light was avoided.	A standard mercury filled Celsius thermometer graduated ( $0-50^{\circ}\text{C}$ ) up to an accuracy of $0.1^{\circ}\text{C}$ was used.	<b>Adoni et. al., 1985.</b>
2. Water velocity ( $\text{m sec}^{-1}$ ).	Water velocity was determined on the spot during sampling.	Water velocity was determined by calculating the time taken by a float (cork) to cross a known (10m) distance.	<b>Adoni et. al., 1985.</b>
3. pH	pH of water was determined on the spot during sampling.	A battery operated pocket pH meter (Hanna make) was used.	<b>APHA, 2005.</b>
4. Conductivity ( $\mu\text{S cm}^{-1}$ ).	Conductivity of water was determined on the spot during sampling.	A battery operated pocket conductivity meter (Hanna make) was used.	<b>APHA, 2005.</b>
5. Free $\text{CO}_2$ ( $\text{mg L}^{-1}$ ).	Free $\text{CO}_2$ of water was determined on the spot during sampling.	Titrimetric method.	<b>APHA, 2005.</b>
6. Dissolved $\text{O}_2$ ( $\text{mg L}^{-1}$ ).	Dissolved $\text{O}_2$ of water was determined on the spot during sampling.	Winkler's Iodometric method.	<b>APHA, 2005.</b>
7. Total Alkalinity ( $\text{mg L}^{-1}$ ).	Total Alkalinity of water was determined on the spot during sampling.	Titration method (Field method) by using phenolphthalein and methyl orange indicators.	<b>APHA, 2005.</b>
8. Total Hardness ( $\text{mg L}^{-1}$ ).	Total Hardness of water was determined on the spot during sampling.	EDTA Titrimetric method.	<b>APHA, 2005.</b>
9. Chloride ( $\text{mg L}^{-1}$ ).	Chloride of water was determined on the spot during sampling.	Argentometric method.	<b>APHA, 2005.</b>
10. Phosphate -P ( $\text{PO}_4\text{-P}$ ) ( $\text{mg L}^{-1}$ ).	Water sample was collected in acid washed glass bottle and stored in an ice box for further analysis within 24 hours.	Stannous Chloride method.	<b>APHA, 2005.</b>
11. Ammonium-N ( $\text{NH}_4\text{-N}$ ) ( $\text{mg L}^{-1}$ ).	Water sample was collected in acid washed glass bottle and treated with $\text{H}_2\text{SO}_4$ (1ml per litre) and $\text{CHCl}_3$ (3 ml per litre). Then stored in an ice box for further analysis within 24 hours ( <b>Svobodova et al., 1993</b> ).	Phenate method or Phenol-Hypochlorite method.	<b>APHA, 2005.</b>
12. Nitrite-N ( $\text{NO}_2\text{-N}$ ) ( $\text{mg L}^{-1}$ ).	Water sample was collected in a clean glass bottle and treated with $\text{H}_2\text{SO}_4$ (1ml per litre) and stored in an ice box for further analysis within 24 hours ( <b>Svobodova et al., 1993</b> ).	$\alpha$ -naphthylamine and Sulphanilic acid method.	<b>APHA, 2005.</b>
13. Nitrate-N ( $\text{NO}_3\text{-N}$ ) ( $\text{mg L}^{-1}$ ).	Water sample was collected in acid washed glass bottle and treated with $\text{H}_2\text{SO}_4$ (1ml.per litre) and stored in an ice box for further	Brucine-Sulphate method.	<b>Trivedy and Goel, 1984.</b>

	analysis within 24 hours <b>(Svobodova et al., 1993).</b>		
14. Water colour.	Water colour was determined on the spot during sampling.	‘Apparent Colour’ of river water was noted and photograph was taken in all the sampling sites. ‘True Colour’ of water sample was determined simply by placing a beaker of filtered water on a white paper.	<b>APHA, 2005.</b>
15. Odour and Taste (Flavour) of water sample.	Flavour of water was determined on the spot during sampling.	Flavour of water was determined by Flavour Rating Assessment (FRA) to estimate acceptability with the help of three volunteer testers and a list of nine statements.	<b>APHA, 2005.</b>

### Statements of Flavour Rating Assessment (FRA)

1. I would be very happy to accept this water as my everyday drinking water.
2. I would be happy to accept this water as my everyday drinking water.
3. I am sure that I could accept this water as my everyday drinking water.
4. I could accept this water as my everyday drinking water.
5. May be I could accept this water as my everyday drinking water.
6. I don't think I could accept this water as my everyday drinking water.
7. I could not accept this water as my everyday drinking water.
8. I could never drink this water.
9. I can't stand this water in mouth and I could never drink it.



**Figure 3-4** Depletion estimation of fish population size (N). Extrapolation to the x-intercept will be the estimate of the population. The fish population (N) estimate using simple linear regression and determining the x-intercept for the cumulative catch.

### **3.2.2.5. Ammonium-N (NH<sub>4</sub>-N), Nitrite-N (NO<sub>2</sub>-N), Nitrate-N (NO<sub>3</sub>-N) and Phosphate-P (PO<sub>4</sub>-P)**

With the aid of spectrophotometer (Systronics, model 106), the concentration of nutrients like Ammonium-N (NH<sub>4</sub>-N; Phenol-hypochlorite Method), Nitrite-N (NO<sub>2</sub>-N;  $\alpha$ -Naphthalamine and Sulphanilic Acid Method) and Phosphate-P (PO<sub>4</sub>-P; Stannous Chloride Method) were determined according to standard methods as described by APHA (2005). The concentration of Nitrate-N (NO<sub>3</sub>-N; Brucine Method) was also determined using a spectrophotometer (Systronics, Model 106) as described by Trivedy and Goel (1984).

### **3.2.3. Qualitative and Quantitative Estimation of Plankton**

Qualitative and quantitative estimation of phytoplankton and zooplankton was carried out by two different methods as mentioned below. But while doing phytoplankton estimation zooplankton was also considered and *vice versa*. The process of estimation is described below-

#### **3.2.3.1. Collection of Phytoplankton and counting technique**

Qualitative and quantitative phytoplankton samples were collected by filtering 10 litre of water into a Whatman filterpaper No 4 and washing thoroughly with small quantity of water and 100 mL sample fixed in 0.7 mL. Lugol's solution or fixed and preserved in 4% formalin. Samples were stained with 0.04% Rose Bengal stain in some cases. In the laboratory, water samples were centrifuged at 1500 r.p.m. for 15 minutes and then 10 mL concentrated samples were kept in vial for further analysis. Phytoplankton samples were identified and counted under high power microscope and generic identification was done following, **Desikacharya, 1959; Ward and Whipple, 1959; Presscott, 1982; Philipose, 1967; Bellinger and Sigeo, 2010 and APHA, 2005**. Photographs were taken by using digital compact camera (Nikon, Coolpix L10).

Lackey's Drop Counting method given in APHA (2005) was used for the quantitative enumeration of the phytoplankton and the density of the phytoplankton is presented as unit per litre. The Lackey's Drop (Microtransect) Method (**Lackey, 1938**) is a simple method for obtaining counts of considerable accuracy. Filamentous algae >10 $\mu$ , one colony (*e.g.*, *Microcystis*) or 2, 4, 8-celled colonies like that of *Scenedesmus* were counted as one unit (**Trivedy and Goel, 1984**). Number of organisms per millilitre (ml) concentrate was calculated as follows:

$$\text{Number of organisms per mL or Unit per litre (unit L}^{-1}\text{)} = \frac{C \cdot A_c}{A_f \cdot N_f \cdot V_c}$$

Where,

C = Number of organisms counted in all fields.

A<sub>c</sub> = Area of cover slip (mm<sup>2</sup>).

A<sub>f</sub> = Area of one microscopic field (mm<sup>2</sup>).

N<sub>f</sub> = Number of fields counted.

V<sub>c</sub> = Volume of sample in the cover slip (mL).

### 3.2.3.2. Collection of zooplankton and counting technique

Zooplankton samples were collected by filtering the surface water. 50 litre of water was filtered through a plankton net made of bolting silk (No. 25, mesh size 56μ). 100 mL sample was preserved in 4% formalin and stained with 0.04% Rose Bengal stain in some cases. In the laboratory, zooplankton samples were concentrated to 50 mL by centrifugation at 1500 r.p.m. for 15 minutes. Zooplankton samples were identified under microscope with different magnification and generic identification was done following, **Ward and Whipple, 1959; Needham and Needham, 1973; Pennak, 1953; Michael and Sharma, 1988; Battish, 1992 and APHA, 2005.**

Quantitative analysis, identification and enumeration were done simultaneously on a Sedgwick Rafter Counter Cell by taking 1mL sub sample and then raising to total volume of water filtered and were reported number of organisms per litre. The density of zooplankton was calculated as follows:

$$\text{Number of organisms per litre (Org.L}^{-1}\text{)} = \frac{C \cdot V_c}{V_r \cdot V_f}$$

Where,

C = Number of zooplankton counted in 1 mL concentrate.

V<sub>c</sub> = Volume of concentrated samples used (mL).

V<sub>r</sub> = Volume of replicate counted from concentrated samples (mL).

V<sub>f</sub> = Volume of original water sample filtered through net (liter).

### 3.2.4. Qualitative and Quantitative Estimation of Ichthyofauna

Monthly fish collection sampling was carried out (from March 2007 to February 2009) in all the sampling sites of the river Teesta and its tributary stream Relli following fishermen or local people who used to catch fish in this region.

- About 1000 m<sup>2</sup> of stream channel in each sampling site was blocked by gill nets and traps (closed population) to prevent movement of fishes in out of the site.
- Using cast net (*Bhureli jal*) which is small in size (r =1.2m; weigh about 5kg) having a mesh ranging from 0.5 to1.5 cm with an average 1.0 cm and covers an area of about 4.5 m<sup>2</sup>), three separate and sequential efforts were made within the blocked stream. Effort (one person, casting nets 25 times) was kept constant. Thus, catch per unit effort (CPUE) is also represents individuals per 100 m<sup>2</sup>. Following each effort, captured fish were put into separate bucket with effort number. The catch for efforts 1, 2, 3 was denoted as n<sub>1</sub>, n<sub>2</sub> and n<sub>3</sub>, respectively.
- In the shallow water rock-striking method was also used. Area of a flat stone was measured for this purpose on which a weighty iron hammer is struck with full force. The intensity, vibration and sound thus produced cause fish to float over water-surface which were hiding under the stone. The fishes were scooped with nets and density calculated and compared with the catches of cast net.
- Other gears and methods like scoop net, hook and line, various traps (*Dhadiya, tip, thokre and thali trap*), electro-fishing, water diversion, were also followed as and when available. Here only those fish species were taken into accounts which were not found in the catches of cast net.
- Catch per unit effort (CPUE) was expressed as number of fish caught per 100 m<sup>2</sup> of sampling area, here  $(n_1 + n_2 + n_3)/3 / 100 \text{ m}^2$ .
- The cumulative catch for efforts 1, 2, and 3 were n<sub>1</sub>, (n<sub>1</sub> + n<sub>2</sub>), (n<sub>1</sub> + n<sub>2</sub> + n<sub>3</sub>), respectively. Presented them as C<sub>i</sub>, where i=1, 2, 3.
- Removal or depletion estimates (**Li and Li, 2007**) were made by extrapolation of CPUE (y-axis) vs. accumulated catches (x-axis). The population estimate N also calculated using simple linear regression and determining the x-intercept for the cumulative catch. It was expressed as estimated population size of ichthyofauna (N) per 1000 m<sup>2</sup> of river channel

$$\text{CPUE} = \text{intercept}_y - \text{slope} \times \sum C_i$$

$$N = \text{intercept}_y / \text{slope} \text{ (when CPUE} = 0\text{)}.$$

The fishes caught were examined for their morphological features, colour bands or spots present on the body and these were recorded in the field along with their length and weight. Photographs were taken by digital compact camera (Nikon, coolpix L10). Gut content of fishes were collected for the analyses of food habit. Two specimens of each species were

taken for identification and their species were ascertained on the basis of their morphometric characters and meristic counts following the criteria given by **Shaw and Shebbeare (1937)**; **Talwar and Jhingran (1991)**; **Sen (1992)**; **Tekriwal and Rao (1999)**; **Nath and Dey (2000)**; and **Jayaram (2009)**. Valid scientific names were taken from *Fish Base* (**Froese & Pauly 2012**).

### 3.2.5. Measurement of Diversity

The number of species, density of individual species and total plankton and ichthyofaunal density were used to compute following diversity indices:

#### 3.2.5.1. Shannon – Wiener Diversity index (Krebs, 1999)

The most popular measures of species diversity are based on information theory. The basic idea is that an event carries as much information as the probability of its occurrence is low, and the inverse is also true. The capture of an individual in the network of a sample being considered an event, it is possible to measure the overall information provided by the entire sampled community. The total information,  $H'$ , which represents the entropy of the whole, is expressed by the Shannon – Wiener equation as follows:

$$H' = -\sum_{i=1}^S p_i \log_2 p_i$$

Where,

$H'$  = Information content of sample (bits/ individual) = Index of species diversity.

$S$  = Number of species.

$p_i$  = Proportion of total sample belonging to  $i^{\text{th}}$  species ( $n_i/N$ ).

$n_i$  = number of individuals of  $i^{\text{th}}$  species in the sample.

$N$  = Total number of individuals in the sample =  $\sum n_i$

#### 3.2.5.2. Evenness Index

Heterogeneity contains two separate ideas- Species Richness and Evenness. **Lloyd and Ghelardi (1964)** were the first to suggest evenness concept. Evenness measures attempt to quantify unequal representation of species in a natural community against a hypothetical community in which all species are equally common. The most commonly used Index of Evenness (**Pielou 1966**) in the literature is based on Shannon-Wiener function (**Krebs, 1999**) as follows:

$$J' = \frac{H'}{\log_2 S}$$

Where,

J' = Evenness measure (range 0-1).

H' = Shannon-Wiener function.

S = total number of species.

### 3.2.5.3. Species Richness Index

This is the oldest and the simplest concept of species diversity-the number of species in the community. **McIntosh (1967)** coined the name Species Richness to describe this concept. The species diversity of plankton and ichthyofauna in both the river was assessed by **Margalef's** Species Richness index (R) as modified by **Brower and Zar (1977)** as follows:

$$R = \frac{S - 1}{\ln N}$$

Where,

R = Index of species Richness

S = Number of species

N = Number of individuals

### 3.2.5.4. Index of Dominance (Simpson, 1949; Whittaker, 1972)

$$\lambda = \sum_{i=1}^S p_i^2$$

Where,

$\lambda$  = Index of Dominance.

N= Total number of individual.

Ni= Number of individuals in each species.

### 3.2.5.5. Similarity index

Similarity index approaches to asses association based on presence, absence or binary data. When species of stations A and B are compared on the basis of their presence or absence in samples from different locations, Similarity Index of **Sorensen (1948)** can be applied as:

$$\text{Coefficient of community (CC)} = 2C / a + b$$

Where,

a = Number of species in community A

b = Number of species in community B

c = Number of species common to both communities

### 3.2.6. Statistical analyses

The data collected on physico-chemical factors, plankton species, and fish species were then subjected to statistical analysis. Range, Mean and Standard deviation were calculated by using Microsoft Excel statistical function of computer software (WINDOWS 7).

#### 3.2.6.1. Fisher's t-test

Test for equality of two means also known as **Fisher's t (Das, 1997)** which follows t distribution with degrees of freedom ( $n_1+n_2-2$ ). Test of significance for difference in means (Fisher's t-test) was performed (Using MS Excel, Windows 7) for seasonal, altitudinal and annual variation of physico-chemical water quality, density and diversity of plankton and ichthyofauna to understand whether the observed seasonal difference connotes any real difference among groups. The null hypothesis for testing of differences between means is  $H_0: \mu_1 = \mu_2$ , where,  $\mu_1$  is a mean of a variable in one season and  $\mu_2$  is a mean of same variable in other season.

#### 3.2.6.2. Karl Pearsons's Correlation

To examine individual relationship between physico-chemical variables, density and diversity indices of plankton and ichthyofauna, Pearson's correlation matrix were calculated using SPSS vers.16 software.

#### 3.2.6.3. Principal Component Analysis (PCA)

To extract the main tendencies of physico-chemical variables, a Principal Component Analysis (PCA) was performed using SPSS vers.16 software. As PCA is a non-parametric method of classification, it makes no assumptions about the underlying statistical distribution of the data (**Kalin et al., 2000; Wunderlin et al., 2001**). Kolmogorov–Smirnov test was performed to understand the distribution of variables. To examine the suitability of these data for factor analysis, Kaiser–Meyer–Olkin (KMO) and Bartlett's tests were performed. KMO is a measure of sampling adequacy that indicates the proportion of variance which is common variance, that is which might be caused by underlying factors. High value (near to 1) generally indicates that factor analysis may be useful, if KMO test value is less than 0.6, factor analysis will not be useful. Finally, PCA was applied to standardized data, and so the covariance matrix coincides with the correlation matrix.

#### **3.2.6.4. Simple Linear Regression**

To understand causal relationship between the principal components of physico-chemical parameters and density and diversity of plankton and ichthyofauna Ordinary Least Square (OLS) or simple linear regression analysis was performed using SPSS vers.16 software.

# *Chapter 4*



## *Results*

## ***4.1. Water quality of the river Teesta***

---

Apparent colour of Teesta river water appeared to be sea-green in March, December (2007), and January and in February (2008 and 2009) during the study period. Water was clear if taken in a glass beaker during this period. But, water became muddy brown in April (2008), May, June, July, August, September and in October (2008). During this period water was slightly turbid in a glass beaker. Water was light muddy brown and slightly turbid in April (2007), October (2007) and November (2008). Light sea green and clear water was found in November (2007) and December (2008). FRA revealed that the river water couldn't be accepted as everyday drinking water.

### **4.1.1. Monthly variations of water quality parameters**

Summary of the Physico-chemical water quality parameters of the river Teesta evaluated during two years of the study period is shown in the **Table 4.1-1**.

#### **4.1.1.1. Air temperature**

Air temperature recorded at the sampling sites of the river ranged from 14.8<sup>0</sup> to 35.6<sup>0</sup>C with a mean value 26.8<sup>0</sup>C ( $\pm 5.2$ ). Lowest air temperature is recorded at TR-I during January 2008 and highest air temperature recorded at TR-IV during July 2008. Monthly variations of air temperature observed at the Teesta river showed steady rise from February and touched peak in the month of July then gradually descended to be lowest in January (**Figure 4.1-1**).

#### **4.1.1.2. Water temperature**

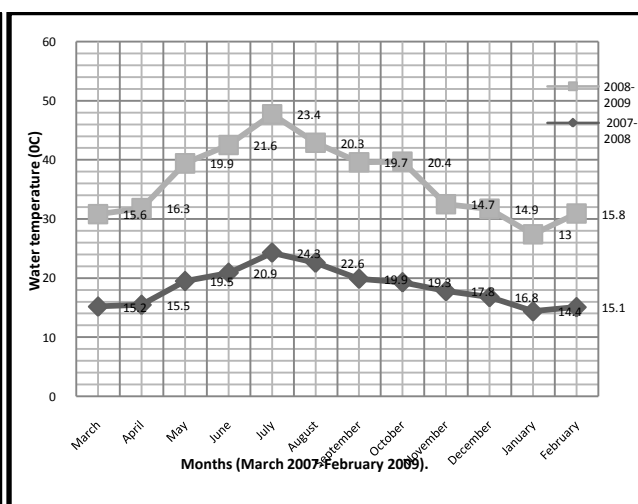
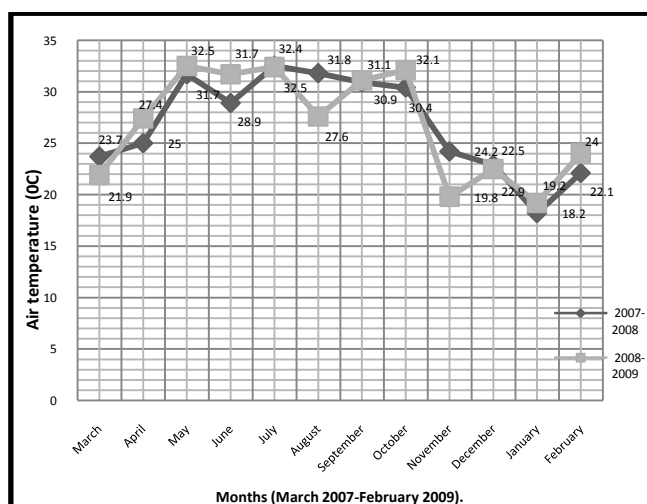
Water temperature documented in river Teesta varied from 12.2<sup>0</sup>C to 24.9<sup>0</sup>C with a mean value 18.2<sup>0</sup>C ( $\pm 3.2$ ). Lowest water temperature was recorded at TR-I in January 2009 and highest water temperature recorded at TR-IV in July 2007. Monthly variations of recorded water temperature in the river revealed a steady increase from the month of February and attained maximum in July and then gradually decreased to lowest point in the month of January (**Figure 4.1-1**).

#### **4.1.1.3. Water velocity**

Water velocity recorded in the Teesta River ranged from 1.93 m sec<sup>-1</sup> to 4.31 m sec<sup>-1</sup> with a mean value 2.75 m sec<sup>-1</sup> ( $\pm 0.74$ ). Lowest water velocity was recorded at TR-IV in January 2008 and highest velocity was found at TR-II in July 2007. Monthly variations of water velocity showed the slow rise from February to May then ascended abruptly and touched peak in the month of July then gradually descended to be lowest in January (**Figure 4.1-2**).

**Table 4.1-1 Summary of the Water Quality Parameters (range, average, standard deviation) in the River Teesta (n=96) during two Years of Study Period.**

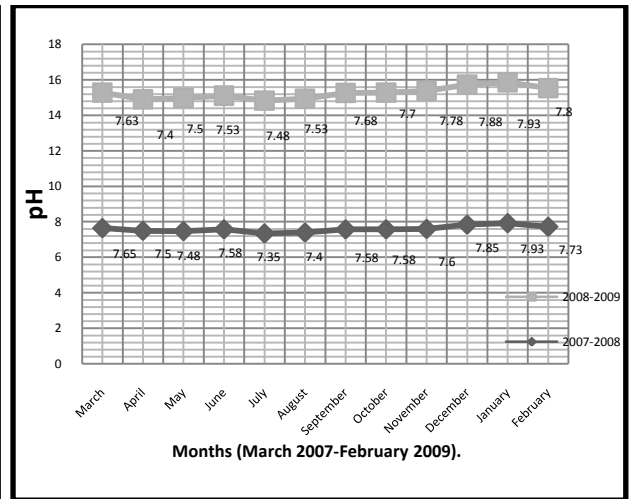
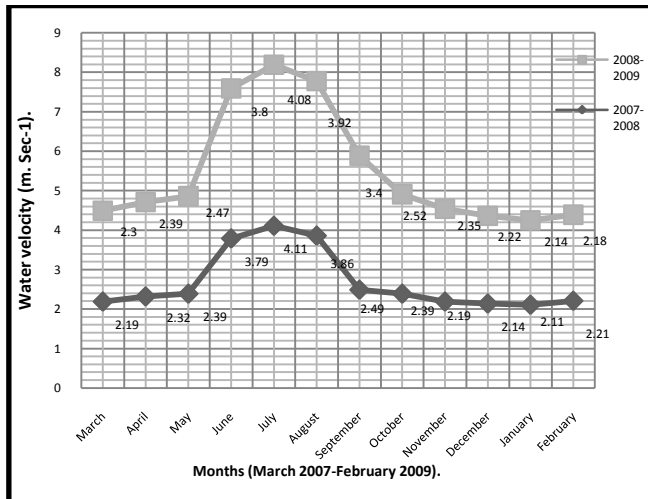
Period of study	March 2007 – February 2009		
Parameters	Range	Mean	S.D (±)
1. Air temperature ( <sup>0</sup> C).	14.8 – 35.6	26.8	5.2
2. Water temperature ( <sup>0</sup> C).	12.2 - 24.9	18.2	3.2
3. Water velocity (m sec <sup>-1</sup> ).	1.93 – 4.31	2.8	0.7
4. pH.	7.3 – 8.1	7.6	0.2
5. Conductivity (µS cm <sup>-1</sup> ).	46 - 98	70.5	13.3
6. Dissolved oxygen (mg L <sup>-1</sup> ).	7.3 -12.2	9.5	1.05
7. Free CO <sub>2</sub> (mg L <sup>-1</sup> ).	1.2 – 4.2	2.5	0.6
8. Total alkalinity (mg L <sup>-1</sup> ).	23.3 – 45.6	34.2	5.8
9. Chloride ion (mg L <sup>-1</sup> ).	3.2 – 6.5	4.5	0.5
10. Total hardness (mg L <sup>-1</sup> ).	20.3 – 30.9	24.7	2.6
11. Phosphate-P (mg L <sup>-1</sup> ).	0.013-0.049	0.025	0.010
12. Ammonium-N (mg L <sup>-1</sup> ).	0.016-0.037	0.024	0.005
13. Nitrite-N (mg L <sup>-1</sup> ).	0.008-0.019	0.013	0.003
14. Nitrate-N (mg L <sup>-1</sup> ).	0.032-0.062	0.046	0.007



(a)

(b)

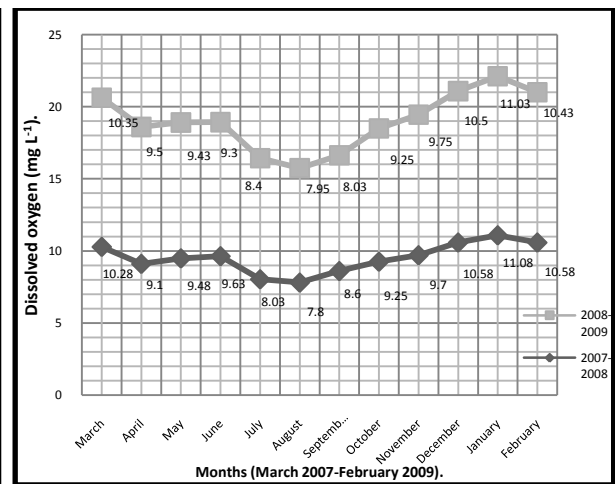
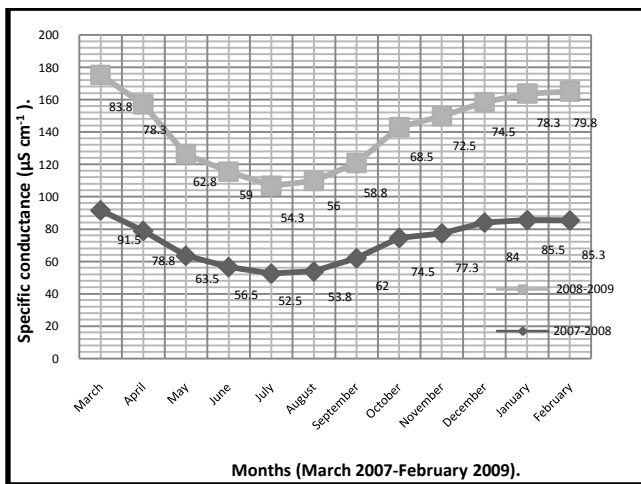
**Figure 4.1-1 Monthly variations of air (a) and water (b) temperature during first and second year of the study period (March 2007-February 2009).**



(a)

(b)

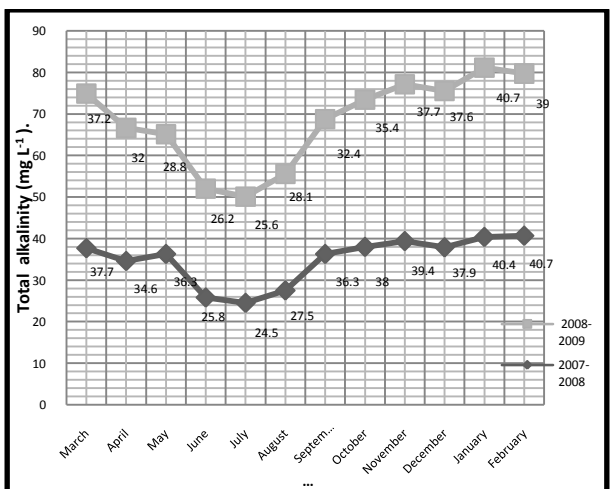
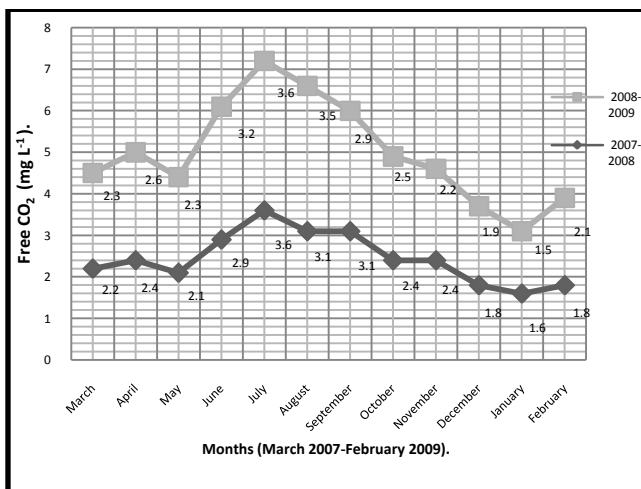
**Figure 4.1-2** Monthly variations of water velocity (a) and pH (b) of the hill stream water during first and second year of the study period (March 2007-February 2009).



(a)

(b)

**Figure 4.1-3** Monthly variations of specific conductance (a) and dissolved oxygen (b) of the hill stream water during first and second year of the study period (March 2007-February 2009).



(a)

(b)

**Figure 4.1-4** Monthly variations of free CO<sub>2</sub> (a) and total alkalinity (b) of the hill stream water during first and second year of the study period (March 2007-February 2009).

#### **4.1.1.4. Power (Puissance) of the hydrogen ion activity (pH)**

Documented pH of Teesta river water during the study period ranged from 7.3 to 8.1 with a mean value 7.6 ( $\pm 0.19$ ). Lowest pH was recorded at TR-I (April 2007 and May 2008), TR-II (July 2007), TR-III (April 2008) and TR-IV (July and August 2007) and highest pH was found at TR-IV in January 2008 and 2009. Monthly variations of pH explained the slow descend from March to May (2007-08) and April (2008-09) then rose in June and fall in July. Then, value of pH gradually ascended to touch peak in the month of January (**Figure 4.1-2**).

#### **4.1.1.5. Specific conductance**

Specific conductance of the river water ranged from  $46 \mu\text{S cm}^{-1}$  to  $98 \mu\text{S cm}^{-1}$  with a mean value  $70.5 \mu\text{S cm}^{-1}$  ( $\pm 13.3$ ). Lowest conductivity was recorded at TR-III in July 2008 and highest conductivity was found at TR-III in March 2007. Monthly variations of specific conductance exhibited the gradual descend from peak in March to be lowest in July then again rose (**Figure 4.1-3**).

#### **4.1.1.6. Dissolved oxygen (DO)**

Recorded values of dissolved oxygen in the Teesta river water ranged from  $7.3 \text{ mg L}^{-1}$  to  $12.2 \text{ mg L}^{-1}$  with a mean value  $9.5 \text{ mg L}^{-1}$  ( $\pm 1.1$ ). Highest DO was recorded at TR-I in January 2008 and lowest DO was found at TR-IV in September 2008. Monthly variations of DO explained the slow descend from March to be lowest in the month of August then gradually ascended to touch peak in the month of January (**Figure 4.1-3**).

#### **4.1.1.7. Free carbon dioxide (FCO<sub>2</sub>)**

Chronicle of free carbon dioxide in the river water varied from  $1.2 \text{ mg L}^{-1}$  to  $4.2 \text{ mg L}^{-1}$  with a mean value  $2.484 \text{ mg L}^{-1}$  ( $\pm 0.6$ ). Lowest free CO<sub>2</sub> was recorded at TR-III in January 2009 and highest free CO<sub>2</sub> was found at RR-IV in July 2007. Monthly variations of free CO<sub>2</sub> exhibited the trend of slow ascend from March to be highest in the month of July then gradually descended to be lowest in January, a small depression found in May (**Figure 4.1-4**).

#### **4.1.1.8. Total alkalinity**

Documented total alkalinity of the river water ranged from  $23.3 \text{ mg L}^{-1}$  to  $45.6 \text{ mg L}^{-1}$  with a mean value  $34.2 \text{ mg L}^{-1}$  ( $\pm 5.8$ ). Lowest value of total alkalinity was recorded at RR-I in July 2007 and highest value of total alkalinity was found at RR-II in January 2009. Monthly variations of total alkalinity exhibited a trend of slow descend from March to be lowest in the month of July then gradually ascended to be highest in January (2008-09) and February (2007-08) (**Figure 4.1-4**).

#### **4.1.1.9. Chloride**

Chloride ion recorded in the river water varied from 3.2 mg L<sup>-1</sup> to 6.5 mg L<sup>-1</sup> with a mean value 4.5 mg L<sup>-1</sup> ( $\pm 0.5$ ). Lowest value of chloride ion was recorded at TR-I in May 2007 and highest value of chloride ion was found at TR-I in November 2008. Monthly variations of Chloride ion exhibited the slow descend from March to be lowest in the month of May then gradually ascended to be highest in November (**Figure 4.1-5**). A small depression observed in the month of September.

#### **4.1.1.10. Total Hardness**

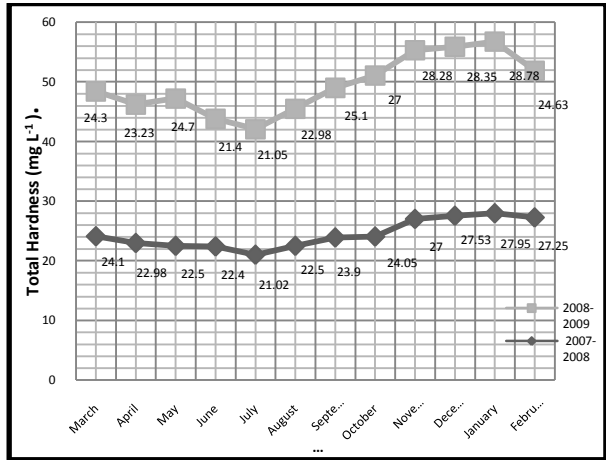
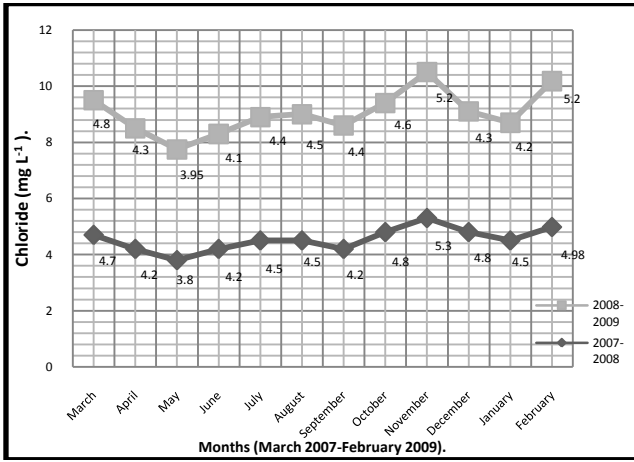
Recorded total hardness of the river water spanned from 20.3 mg L<sup>-1</sup> to 30.9 mg L<sup>-1</sup> with a mean value 24.7 mg L<sup>-1</sup> ( $\pm 2.6$ ). Lowest value of total hardness was recorded at TR-I and TR-IV in July 2007 and highest value of total hardness was found at TR-IV in January 2009. Monthly variations of total hardness exhibited the trend of slow descend from March to be lowest in the month of July then gradually ascended to be highest in January (**Figure 4.1-5**).

#### **4.1.1.11. Ammonium-nitrogen (NH<sub>4</sub>-N)**

Documented values of ammonium nitrogen in the river water spanned from 0.016 mg L<sup>-1</sup> to 0.037 mg L<sup>-1</sup> with a mean value 0.024 mg L<sup>-1</sup> ( $\pm 0.005$ ). Lowest value of NH<sub>4</sub>-N was recorded in January 2009 (TR-I) and February 2009 (TR-III) and highest value of NH<sub>4</sub>-N was found at TR-IV in August 2007. Monthly variations of NH<sub>4</sub>-N showed the style of slow rise from March and touched peak in the month of August (2007-08) and in September (2008-09) then gradually descended to be lowest in January (**Figure 4.1-6**).

#### **4.1.1.12. Nitrite-nitrogen (NO<sub>2</sub>-N)**

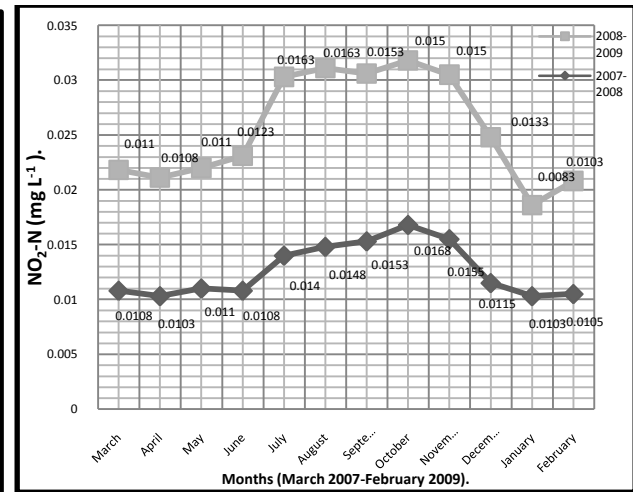
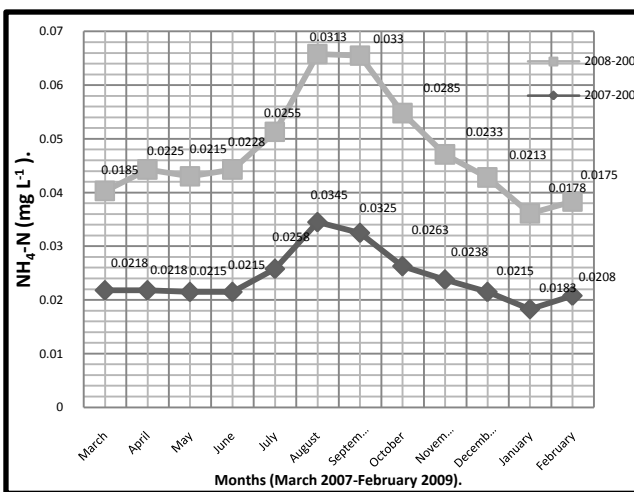
Observed values of nitrite nitrogen in the river water ranged from 0.008 mg L<sup>-1</sup> to 0.019 mg L<sup>-1</sup> with a mean value 0.013 mg L<sup>-1</sup> ( $\pm 0.003$ ). Lowest value of NO<sub>2</sub>-N was recorded at TR-II, TR-III. And TR-IV in the month of January 2009 and highest value of NO<sub>2</sub>-N was found in October 2007 at TR-IV. Monthly variations of NO<sub>2</sub>-N showed the trend of slow rise from March and touched peak in the month of July, August (2008-09) and October (2007-08) then gradually descended to be lowest in January (**Figure 4.1-6**).



(a)

(b)

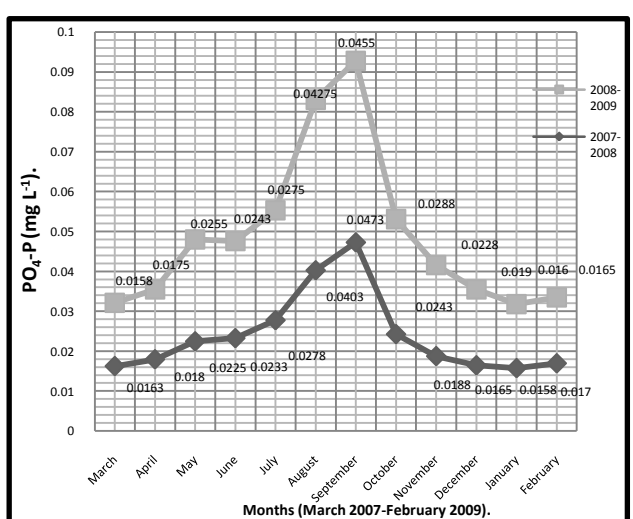
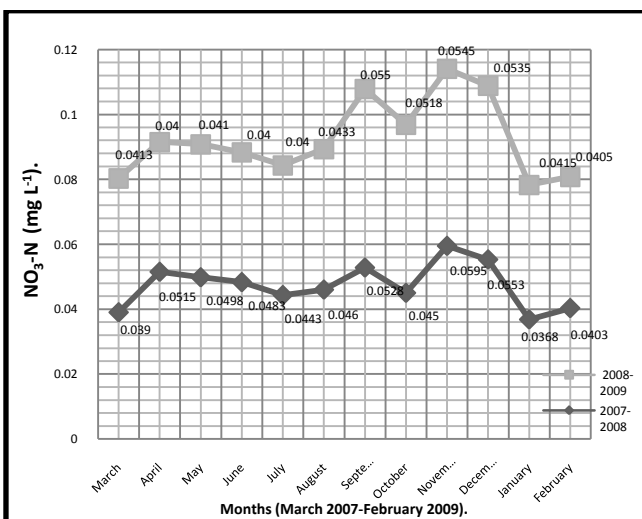
**Figure 4.1-5** Monthly variations of chloride (a) and total hardness (b) of the hill stream water first and second year of during the study period (March 2007-February 2009).



(a)

(b)

**Figure 4.1-6** Monthly variations of ammonium nitrogen (a) and nitrite nitrogen (b) of the hill stream water first and second year of during the study period (March 2007-February 2009).



(a)

(b)

**Figure 4.1-7** Monthly variations of nitrate nitrogen (a) and phosphate phosphorus (b) of the hill stream water during first and second year of the study period (March 2007-February 2009).

#### **4.1.1.13. Nitrate-nitrogen (NO<sub>3</sub>-N)**

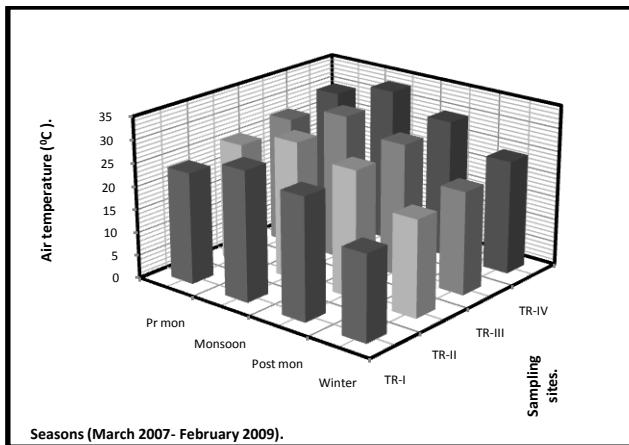
Recorded amounts of nitrate nitrogen in the river water varied (Table) from 0.032 mg L<sup>-1</sup> to 0.062 mg L<sup>-1</sup> with a mean value 0.046 mg L<sup>-1</sup> ( $\pm 0.007$ ). Lowest value of NO<sub>3</sub>-N was recorded at TR-I in January 2008 and highest value of NO<sub>3</sub>-N was found at TR-I in November 2007. Monthly variations of NO<sub>3</sub>-N showed the tendency of slight rise from March to the month of April then gradually descended to be lowest in July and again ascended to be highest in the month of November (Figure 4.1-7). A small depression observed in the month of October.

#### **4.1.1.14. Phosphate-phosphorous (PO<sub>4</sub>-P)**

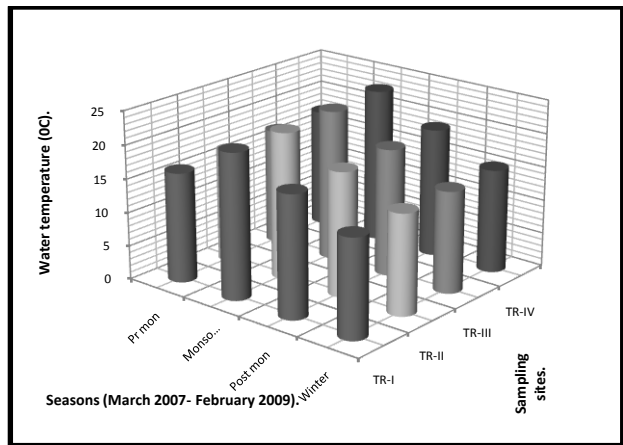
Observed values of phosphate phosphorus in the river water ranged (Table) from 0.013 mg L<sup>-1</sup> to 0.049 mg L<sup>-1</sup> with a mean value 0.025 mg L<sup>-1</sup> ( $\pm 0.010$ ). Lowest value of PO<sub>4</sub>-P was recorded at TR-I in January 2008 and December 2008 and TR-II in January 2009. Highest value of PO<sub>4</sub>-P was found at TR-IV in September 2007. Monthly variations of PO<sub>4</sub>-P showed the tendency of slow rise from March and touched peak in the month of September then gradually descended to be lowest in February (Figure 4.1-7).

### **4.1.2. Seasonal variations of water quality parameters**

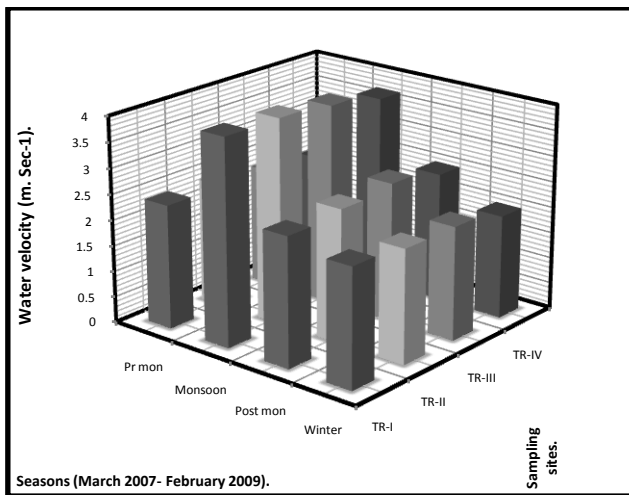
When data on monthly variations of water velocity, free CO<sub>2</sub>, air and water temperature were pooled into seasonal values, the monsoon showed the highest values and lowest in winter at all the sampling sites of the river Teesta. On the contrary, seasonal variations of conductivity, dissolved oxygen, total alkalinity and total hardness showed highest values in winter months and lowest values in monsoon months at all sites. Seasonal variation of pH showed highest value in winter months at all sites and lowest in Pre monsoon months at TR-I and in monsoon months at all other sites. Chloride revealed highest seasonal value in winter months at TR-III, IV and in post monsoon months at TR-I, II. Lowest value found in monsoon months at TR-II, IV and in pre monsoon months at TR-I, III. Lowest seasonal value of PO<sub>4</sub>-P and NH<sub>4</sub>-N was found in winter months at all sites. Highest value of PO<sub>4</sub>-P recorded in monsoon (TR-I & II) and post monsoon months at TR-II, III & IV but, highest value of NH<sub>4</sub>-N observed in post monsoon months at TR-II & III and in monsoon months at TR-I & IV. NO<sub>2</sub>-N showed highest seasonal value in post monsoon months at all sites and also in monsoon months at TR-II. Lowest value of NO<sub>2</sub>-N found in winter months at all sites and also in pre monsoon months at TR-II, III and IV. NO<sub>3</sub>-N in the river water exhibited highest seasonal value in post monsoon months at all sites. Lowest value of NO<sub>3</sub>-N found in monsoon months at TR-I & II pre monsoon months at TR-III & IV. **Figure 4.1-8, 4.1-9 and 4.1-10** explains seasonal variations of physico-chemical water quality parameters in the four sampling sites during the study period.



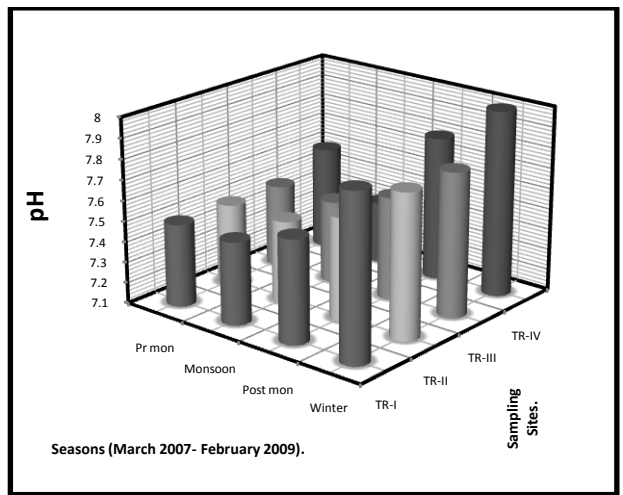
(a)



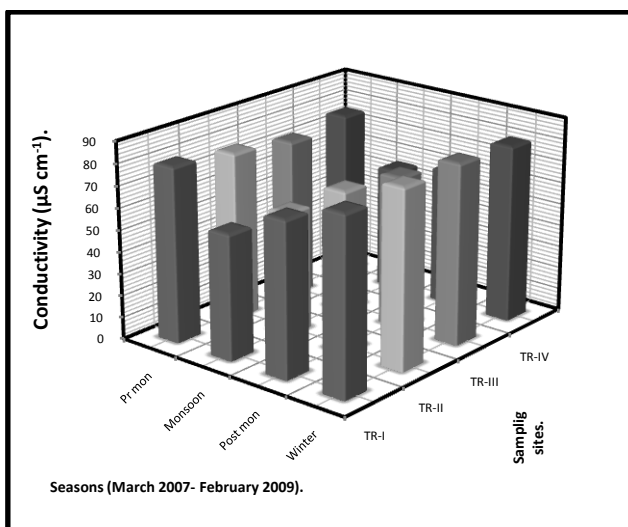
(b)



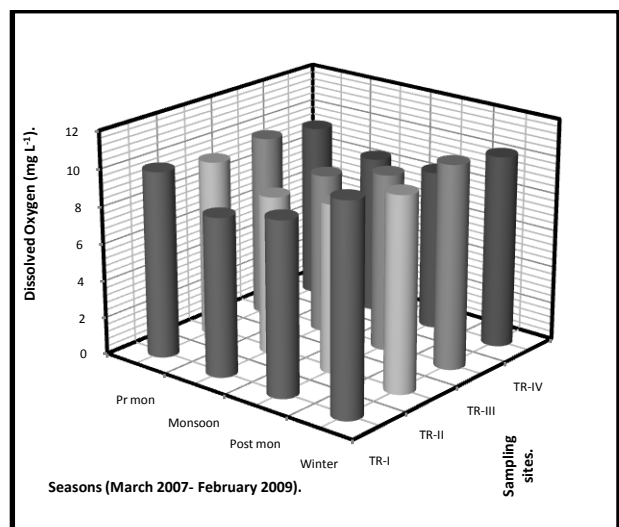
(c)



(d)

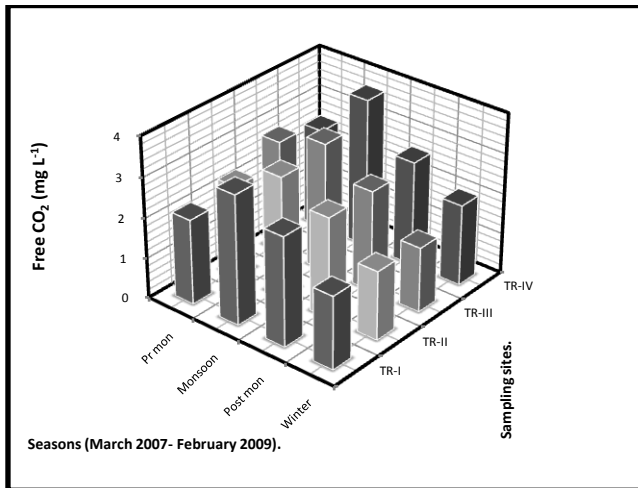


(e)

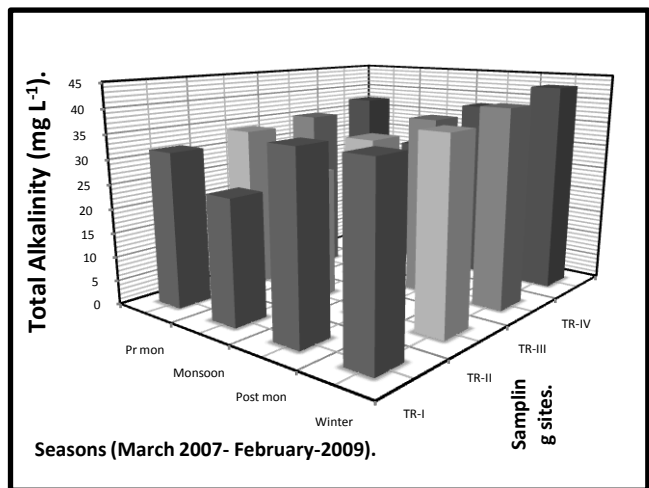


(f)

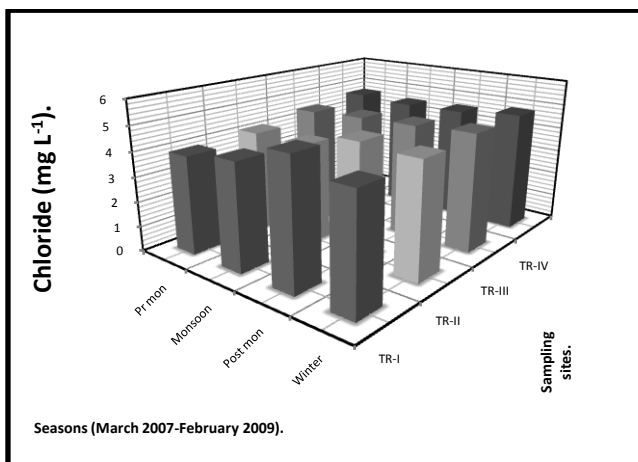
**Figure 4.1-8** Seasonal variations of air temperature (a), water temperature (b), water velocity (c), pH (d), specific conductance (e) and dissolved oxygen (f) in the three sampling sites of the Teesta river water during the study period (March 2007-February 2009).



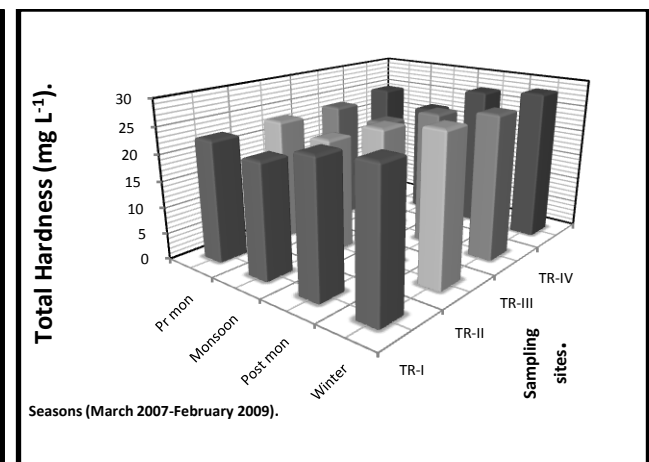
(g)



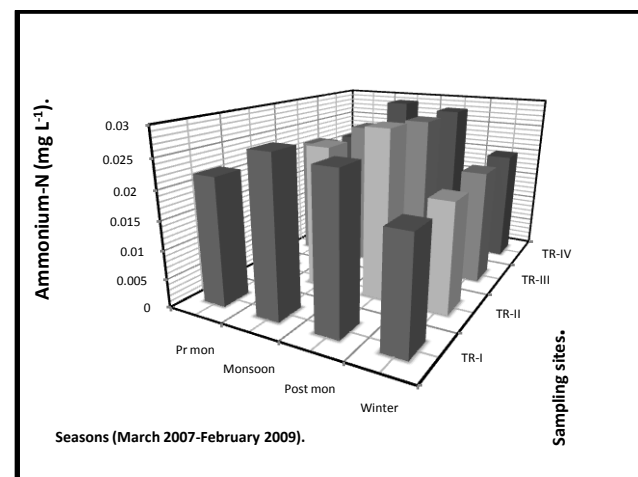
(h)



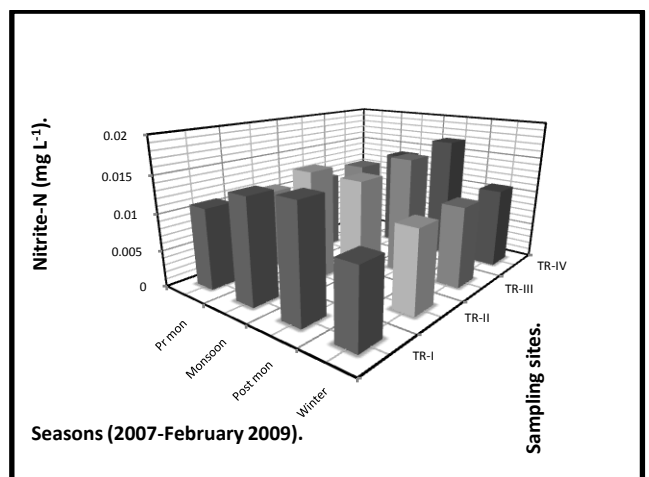
(i)



(j)

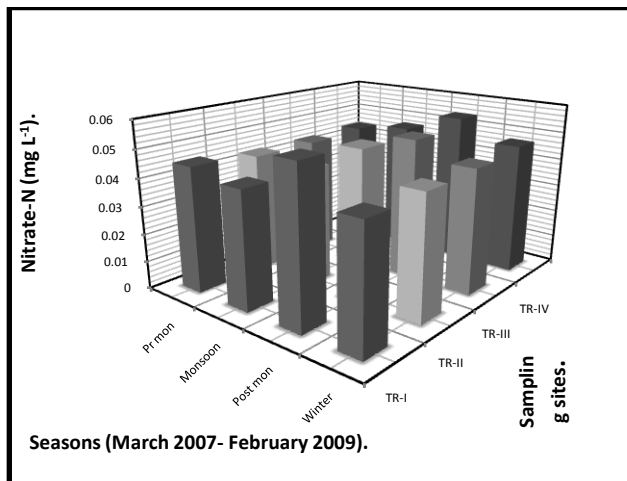


(k)

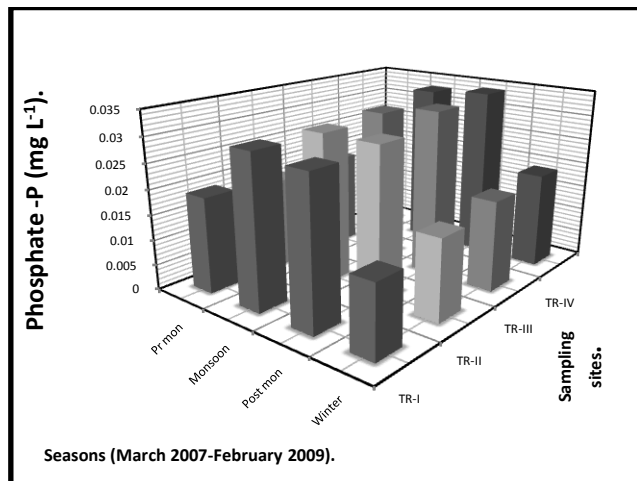


(l)

**Figure 4.1-9** Seasonal variations of free Carbon dioxide (g), total alkalinity (h), Chloride (i) total hardness (j), Ammonium-N (k) and nitrite-N (l) in the three sampling sites of the hill stream water during the study period (March 2007-February 2009).



(m)



(n)

**Figure 4.1-10** Seasonal variations of Nitrate-N (m) and phosphate-P (n) in the three sampling sites of the hill stream water during the study period (March 2007-February 2009).

**Table 4.1-2** Results of Test of Significance for Difference in Means (Fisher's t) of Seasonal Values of Physico-Chemical Parameters of Water Quality of the River Teesta During the Study Period (March 2007 to February 2009).

	pm/mon	pm/psm	pm/win	mon/psm	mon/win	psm/win
<b>Air temperature</b>	3.206*	0.733	4.677*	2.283**	10.19*	5.46*
<b>Water temperature</b>	9.578*	2.674*	3.975*	6.658*	17.185*	7.272*
<b>Water velocity</b>	33*	2.179**	4.828*	13.701*	40.696*	4.101*
<b>PH</b>	1.426	3.244*	8.66*	5.091*	11.276*	5.421*
<b>Conductivity</b>	7.183*	2.122**	1.614	5.71*	18.424*	5.082*
<b>Dissolved oxygen</b>	5.796*	2.829*	5.752*	2.553*	11.112*	7.863*
<b>Free CO<sub>2</sub></b>	9.51*	2.99*	6.198*	6.159*	14.284*	8.317*
<b>Total alkalinity</b>	8.584*	1.974**	4.638*	14.29*	18.39*	3.258*
<b>Chloride</b>	0.51	2.485*	2.484*	2.438**	2.582*	0.533
<b>Total hardness</b>	5.188*	4.464*	8.356*	8.347*	13.105*	2.688*
<b>NH<sub>4</sub>-N</b>	6.268*	4.656*	2.542*	0.084	8.028*	5.78*
<b>NO<sub>2</sub>-N</b>	0.083	6.008*	0.442	6.894*	0.544	4.473*
<b>NO<sub>3</sub>-N</b>	6.252*	13.64*	0.322	2.422**	5.512*	10.176*
<b>PO<sub>4</sub>-P</b>	5.133*	6.478*	3.445*	0.696	6.53*	7.912*

pm-pre monsoon; mon-monsoon; psm-post monsoon; win-winter.\*1%level significant, \*\*5%level significant.

Test of significance for equality of two means (Fisher's t) was performed to understand whether the observed seasonal differences of physico-chemical parameters connote any real difference among groups. The null hypothesis for testing of differences between means is  $H_0: \mu_1 = \mu_2$ , where  $\mu_1$  is a mean of a variable in one season and  $\mu_2$  is a mean of same variable in other season. As  $H_a$  is two sided, a two tailed test for determining the rejection region at 1% level which comes to as under, using table of t-distribution for 34 degrees of freedom: Critical Region:  $|t| \geq 2.46$  and at 5% level it is: Critical Region:  $|t| \geq 1.70$ . The observed values of t for physico-chemical parameters in different seasons is presented in the **Table 4.1-2**, most of which fall in the rejection region and thus,  $H_0$  is rejected and concluded that seasonality affect physico-chemical factors of the river water.

### 4.1.3. Annual variations of water quality parameters

When data on monthly variations of physico-chemical parameters of water quality were pooled into annual values, the average value of air and water temperature, conductivity, DO, total alkalinity, chloride and  $\text{NO}_3\text{-N}$  in first year were found slightly higher in first year (March 2007 – February 2008) than second year of study (March 2008 – February 2009). On the contrary, annual variations of water velocity, pH, free  $\text{CO}_2$ , total hardness and  $\text{PO}_4\text{-P}$  showed highest values in the second year (March 2008 – February 2009). Annual values of  $\text{NH}_4\text{-N}$  and  $\text{NO}_2\text{-N}$  were found to be equal in both year of study. Fisher's t were not significant except air temperature ( $|t|=3.43$ ,  $p < 0.01$ ), total alkalinity ( $|t|=2.25$ ,  $p < 0.05$ ) and chloride ( $|t|=2.16$ ,  $p < 0.05$ ). **Table 4.1-3** showed the comparisons of annual mean values of physico-chemical parameters of water quality of the Teesta river during two years of study period.

### 4.1.4. Altitudinal variations of water quality parameters

Along the elevational gradient of the river Teesta that is in three sampling sites, TR-I (224m), TR-II (216m), TR-III (168m) and TR-IV (147m) average values of air and water temperature and total alkalinity slightly decreased (TR-I < TR-II < TR-III < TR-IV) with the increase in altitude. But, average values of water velocity, conductivity and DO showed the tendency of increment as the altitude increased with exception in one site. Water quality parameters like pH, free  $\text{CO}_2$ , chloride and total hardness exhibited trend of decline with the increase in altitude. Nutrients ( $\text{PO}_4\text{-P}$ ,  $\text{NH}_4\text{-N}$ ,  $\text{NO}_2\text{-N}$  and  $\text{NO}_3\text{-N}$ ) showed little or no fluctuations along the altitudinal gradient. Fisher's t were significant only in case of air temperature (between TR-I and TR-III,  $|t|=2.36$ ,  $p < 0.05$ ; I and IV, II and IV,  $|t|=3.82$  and  $2.48$ ,  $p < 0.01$ ), dissolved oxygen (TR-I and TR-IV,  $|t|=1.75$ ,  $p < 0.05$ ), total alkalinity (I and IV,  $|t|=2.54$ ,  $p < 0.01$ ; II and IV,  $|t|=1.95$ ,  $p < 0.05$ ), chloride (II and III,  $|t|=1.84$ ,  $p < 0.05$ ; II and IV,  $|t|=2.48$ ,  $p < 0.01$ ) and total hardness (I and IV,  $|t|=2.37$ ,  $p < 0.05$ ). **Table 4.1-3** showed the comparisons of altitudinal mean values of physico-chemical parameters of water quality of the Teesta river during two years of study period.

**Table 4.1-3 Mean Values ( $\pm$  standard deviation) of Physico-Chemical Parameters of Water Quality along the Altitudinal Gradient (n=24) of Teesta and Comparisons of Mean ( $\pm$  standard deviation) Annual Values (n=48) During the two years of Study Period.**

Period of study	March 2007 – February 2009.				Annual variations	
Sampling sites	TR-I (224 m asl).	TR-II (216 m asl).	TR-III (168 m asl).	TR-IV (147 m asl).	2007-08	2008-09
Physico-chemical parameters.						
1. Air temperature ( $^{\circ}$ C).	24.1 $\pm$ 5.0	26.0 $\pm$ 5.0	27.7 $\pm$ 5.0	29.5 $\pm$ 4.5	26.9 $\pm$ 5.1**	26.8 $\pm$ 5.4**
2. Water temperature ( $^{\circ}$ C).	17.7 $\pm$ 3.2	17.9 $\pm$ 3.1	18.4 $\pm$ 3.2	18.8 $\pm$ 3.3	18.4 $\pm$ 3.1	18.0 $\pm$ 3.2
3. Water velocity (m sec $^{-1}$ ).	2.79 $\pm$ 0.7	2.82 $\pm$ 0.8	2.77 $\pm$ 0.8	2.61 $\pm$ 0.7	2.68 $\pm$ 0.7	2.81 $\pm$ 0.7
4. Hydrogen ion concentration (pH).	7.6 $\pm$ 0.19	7.6 $\pm$ 0.15	7.6 $\pm$ 0.17	7.7 $\pm$ 0.23	7.6 $\pm$ 0.19	7.7 $\pm$ 0.19
5. Specific conductivity ( $\mu$ S cm $^{-1}$ ).	71.9 $\pm$ 11.6	71.8 $\pm$ 11.7	69.0 $\pm$ 16.5	69.1 $\pm$ 13.4	72.1 $\pm$ 14.2	68.9 $\pm$ 12.2
6. Dissolved oxygen (mg L $^{-1}$ ).	9.8 $\pm$ 1.1	9.3 $\pm$ 0.9	9.7 $\pm$ 1.1	9.2 $\pm$ 1.0	9.51 $\pm$ 1.1	9.49 $\pm$ 1.0
7. Free carbon dioxide (mg L $^{-1}$ ).	2.43 $\pm$ 0.60	2.40 $\pm$ 0.58	2.40 $\pm$ 0.69	2.71 $\pm$ 0.69	2.45 $\pm$ 0.64	2.52 $\pm$ 0.65
8. Total alkalinity (mg L $^{-1}$ ).	32.3 $\pm$ 5.1	33.2 $\pm$ 5.4	34.5 $\pm$ 6.1	36.5 $\pm$ 5.9	34.9 $\pm$ 6.0*	33.4 $\pm$ 5.5*
9. Chloride ion (mg L $^{-1}$ ).	4.42 $\pm$ 0.82	4.38 $\pm$ 0.46	4.59 $\pm$ 0.33	4.66 $\pm$ 0.32	4.52 $\pm$ 0.51*	4.50 $\pm$ 0.55*
10. Total hardness (mg L $^{-1}$ ).	23.9 $\pm$ 2.0	24.7 $\pm$ 2.7	24.6 $\pm$ 2.5	25.7 $\pm$ 3.0	24.4 $\pm$ 2.5	25.0 $\pm$ 2.8
11. Ammonium-N (mg L $^{-1}$ ).	0.024 $\pm$ 0.005	0.024 $\pm$ 0.005	0.024 $\pm$ 0.005	0.025 $\pm$ 0.006	0.024 $\pm$ 0.005	0.024 $\pm$ 0.005
12. Nitrite-N (mg L $^{-1}$ ).	0.013 $\pm$ 0.003	0.013 $\pm$ 0.003	0.013 $\pm$ 0.003	0.013 $\pm$ 0.003	0.013 $\pm$ 0.003	0.013 $\pm$ 0.003
13. Nitrate-N (mg L $^{-1}$ ).	0.046 $\pm$ 0.008	0.045 $\pm$ 0.006	0.046 $\pm$ 0.006	0.048 $\pm$ 0.007	0.047 $\pm$ 0.007	0.045 $\pm$ 0.007
14. Phosphate-P (mg L $^{-1}$ ).	0.023 $\pm$ 0.01	0.024 $\pm$ 0.01	0.026 $\pm$ 0.01	0.026 $\pm$ 0.01	0.024 $\pm$ 0.01	0.025 $\pm$ 0.01

\*\*Fisher's t significant at 0.01 level and \*Fisher's t significant at 0.05 level

**Table 4.1-4 Statistical Descriptive and Kolmogorov–Smirnov Normality Tests for the Physico-Chemical Variables Analysed.**

One-Sample Kolmogorov-Smirnov Test														
	AT	WT	WV	pH	Cond	DO	FCO2	TA	CL	HARD	PO4	NO3	NO2	NH4
N	96	96	96	96	96	96	96	96	96	96	96	96	96	96
Normal Parameters <sup>a</sup>														
Mean	2.6842E1	1.8201E1	2.74708	7.62500	7.0468E1	9.49896	2.48333	3.4152E1	4.51146	2.4703E1	.02455	.04627	.01274	.02387
Std. Deviation	5.2378E0	3.1712E0	.741009	.188624	1.3307E1	1.0551E0	.641654	5.7816E0	5.29124	2.6287E0	.008996	.008930	.002661	.005081
Most Extreme Differences														
Absolute	.108	.132	.277	.157	.109	.070	.108	.159	.131	.103	.163	.139	.162	.214
Positive	.061	.132	.277	.157	.087	.068	.108	.132	.131	.103	.163	.139	.162	.214
Negative	-.108	-.096	-.146	-.104	-.109	-.070	-.055	-.159	-.094	-.078	-.122	-.107	-.098	-.098
Kolmogorov-Smirnov Z	1.058	1.291	2.712	1.537	1.069	.683	1.059	1.562	1.288	1.011	1.584	1.360	1.583	2.099
Asymp. Sig. (2-tailed)	.213	.071	.000	.018	.203	.739	.212	.015	.072	.259	.012	.049	.013	.000
a. Test distribution is Normal.														

\*(AT= Air temperature; WT= Water temperature; WV=Water velocity; pH= Power of hydrogen ion concentration; COND= conductivity; DO= Dissolved oxygen; FCO2= Free carbon dioxide; TA= Total alkalinity; CL= Chloride; Hard= Total hardness; PO4 = Phosphate-phosphorous; NO3= Nitrate- nitrogen; NO2= Nitrite-nitrogen; NH4=Ammonium-nitrogen.)

### 4.1.5. Correlation and Principal Component Analysis (PCA)

To examine individual relationship between physico-chemical variables, a Pearson correlation matrix was calculated. The numerical values of correlation coefficient are depicted in **Table 4.1-7** for all water quality parameters. Most of the calculated values depict some strong correlations. Pair having very high positive correlation between them shows the dependency of one parameter on the other while pair having very negative correlation between them shows inverse relation between them.

To extract the main tendencies of physico-chemical variables, a principal component analysis (PCA) was performed. In conjunction with the Kolmogorov–Smirnov test, it could be found (**Table 4.1-4**) that variables were normally distributed. To examine the suitability of these data for factor analysis, Kaiser–Meyer–Olkin (KMO) and Bartlett’s tests were performed. KMO is a measure of sampling adequacy that indicates the proportion of variance which is common variance, i.e. which might be caused by underlying factors. High value (close to 1) generally indicates that factor analysis may be useful, if KMO test value is less than 0.6, factor analysis will not be useful (**Table 4.1-5**). Finally, PCA was applied to standardized data, and so the covariance matrix coincides with the correlation matrix. The data set of Z scores of the physico-chemical parameters satisfies Bartlett’s Test of Sphericity. Bartlett’s test of sphericity indicates whether correlation matrix is an identity matrix, which would indicate that variables are unrelated.

The significance level which is 0 (**Table 4-6**) in this study (less than 0.05) indicate that there are significance relationships among variables. At the same time, the data set also fulfills Kaiser-Meyer Measure of Sample Adequacy as  $KMO = 0.881 > 0.6$ . The KMO measures assess the extent persisting common variance that is inherent within the data set. Hence, it is possible to perform principal component analysis on the data set.

The information on communalities of the data set is provided in **Table 4.1-6**. Initial communalities are estimates of the variance in each variable accounted for by all components, whereas extraction communalities are estimates of the variance in each variable accounted for by the components in the component solution. Small values of extraction communalities of the variables are not well fit with the component solution. PCA ordination for physico-chemical factors on main factor plane is presented in **Figure 4.1-11**.

#### 4.1.5.1. Principal Component I (PC-I): More Physical and Nutrients, Less Chemical

This component accounts for 38.42 per cent of the total variance. The physical/nutrient parameters like air and water temperature, free  $CO_2$ ,  $PO_4$ -P,  $NO_3$ -N,  $NO_2$ -N &  $NH_4$ -N have high positive weights ranging from 0.524 to 0.883. The chemical parameters DO and conductivity have high negative weights ranging from -0.648 to -0.813.

#### 4.1.5.2. Principal Component II (PC-II): More Chemical and less physical

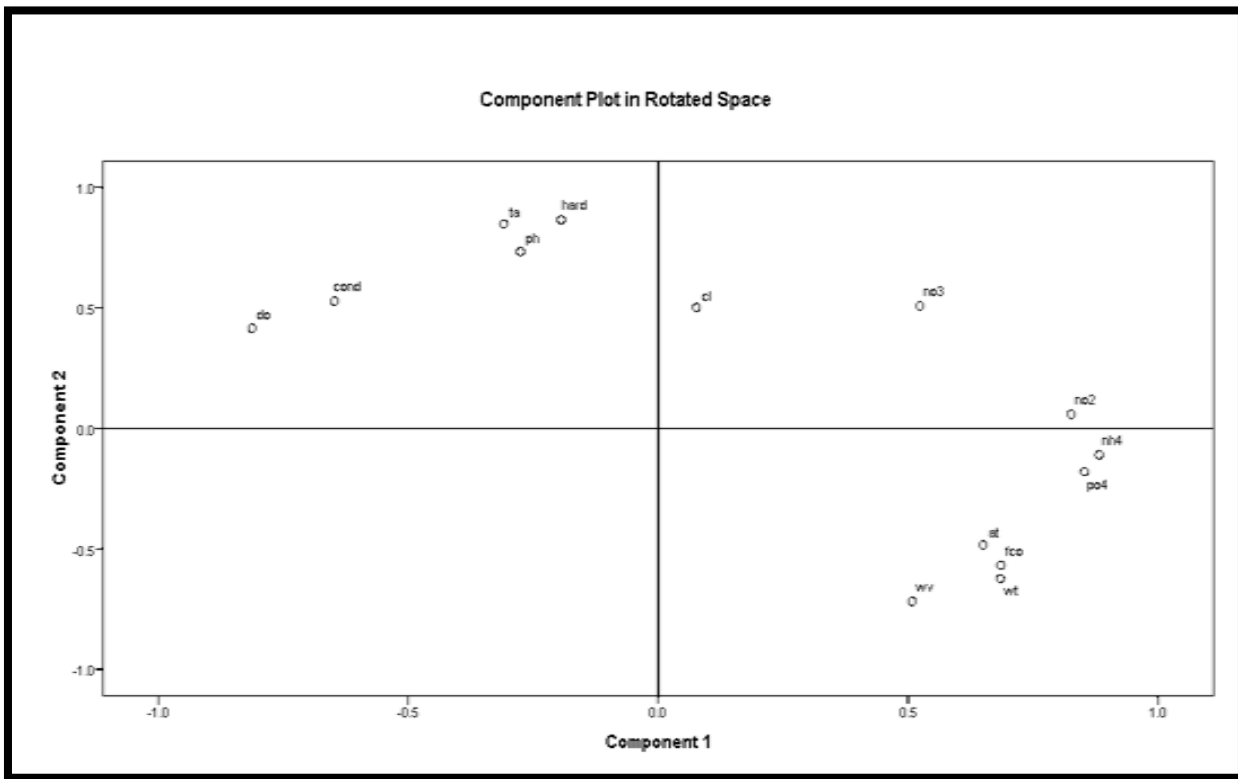
This component explains 32.01 per cent of the total variance of the original variables. Parameters like pH, total alkalinity, chloride ion and total hardness have relatively high positive weights ranging from 0.502 to 0.866. The physical parameter water velocity has high negative weight of -0.719.

**Table 4.1-5 KMO and Bartlett's Test of the Data Set**

Kaiser-Meyer-Olkin Measure of Sampling Adequacy 0.8701		
Bartlett's Test of Sphericity	Approx. Chi-Square	1280.75
	Degree of Freedom [df]	91
	Level of Significance	0.00

**Table 4.1-6 Interpretation and Eigenvalues of the Components, Component Loadings of the Variables and extracted communalities. (Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization).**

Items.	Principal Components.		Communalities Extracted.
	PC-I (more physical & nutrients, Less chemical).	PC-II (more nutrients, Less chemical).	
AT (Air temperature).	<b>0.650</b>	-0.484	<b>0.66</b>
WT (Water temperature).	<b>0.685</b>	-0.624	<b>0.86</b>
WV (Water velocity).	0.508	<b>-0.719</b>	<b>0.77</b>
PH (pH).	-0.276	<b>0.734</b>	<b>0.61</b>
COND (conductivity).	<b>-0.648</b>	0.528	<b>0.70</b>
DO (Dissolved oxygen).	<b>-0.813</b>	0.415	<b>0.83</b>
FCO (Free carbon dioxide).	<b>0.686</b>	-0.568	<b>0.79</b>
TA (Total alkalinity).	-0.309	<b>0.849</b>	<b>0.82</b>
CL (Chloride).	0.076	<b>0.502</b>	<b>0.26</b>
HARD (Total hardness).	-0.194	<b>0.866</b>	<b>0.79</b>
PO <sub>4</sub> (Phosphate-phosphorous).	<b>0.853</b>	-0.181	<b>0.76</b>
NH <sub>4</sub> (Ammonium-nitrogen.)).	<b>0.883</b>	-0.110	<b>0.53</b>
NO <sub>2</sub> (Nitrite-nitrogen).	<b>0.827</b>	0.059	<b>0.69</b>
NO <sub>3</sub> (Nitrate- nitrogen).	<b>0.524</b>	0.508	<b>0.79</b>
Eigen Value (Total Variance)	<b>5.38</b>	<b>4.48</b>	
(%) of Variance	<b>38.42</b>	<b>32.01</b>	
Cumulative (%)	<b>38.42</b>	<b>70.43</b>	



**Figure 4.1-11** PCA ordination for physico-chemical factors of Teesta on main factor plane.

\*(at= Air temperature; wt= Water temperature; wv=Water velocity; ph= Power of hydrogen ion concentration; cond= conductivity; do= Dissolved oxygen; fco= Free carbon dioxide; ta= Total alkalinity; cl= Chloride; hard= Total hardness; po4= Phosphate-phosphorous; no3= Nitrate- nitrogen; no2= Nitrite-nitrogen; nh4=Ammonium-nitrogen.). o- active.

**Table 4.1-7 Pearson's Correlation Coefficient Matrix for Physico-Chemical Water Quality of the River Teesta (n=96, d.f. 94).**

	AT	WT	WV	PH	COND	DO	FC	TA	CL	HARD	PO <sub>4</sub>	NO <sub>3</sub>	NO <sub>2</sub>	NH <sub>4</sub>
AT	1													
WT	0.865**	1												
WV	0.528**	0.794**	1											
PH	-0.538**	-0.598**	-0.529**	1										
COND	-0.675**	-0.792**	-0.763**	0.418**	1									
DO	-0.720**	-0.765**	-0.688**	0.569**	0.706**	1								
FC	0.686**	0.810**	0.775**	-0.581**	-0.706**	-0.790**	1							
TA	-0.498**	-0.727**	-0.853**	0.656**	0.648**	0.579**	-0.692**	1						
CL	-0.224*	-0.202*	-0.214*	0.281**	0.254*	0.111	-0.071	0.404**	1					
HARD	-0.523**	-0.643**	-0.667**	0.776**	0.507**	0.522**	-0.647**	0.727**	0.303**	1				
PO <sub>4</sub>	0.601**	0.625**	0.550**	-0.301**	-0.644**	-0.750**	0.649**	-0.403**	-0.197	-0.283**	1			
NO <sub>3</sub>	0.093	0.046	-0.135	0.096	-0.087	-0.192	0.046	0.189	0.135	0.279**	0.243*	1		
NO <sub>2</sub>	0.430**	0.532**	0.402**	-0.211*	-0.448**	-0.599**	0.523**	-0.221*	0.128	-0.151	0.626**	0.344**	1	
NH <sub>4</sub>	0.566**	0.607**	0.504**	-0.364**	-0.545**	-0.769**	0.615**	-0.355**	-0.086	-0.276**	0.863**	0.326**	0.677**	1

AT= Air temperature; WT= Water temperature; WV=Water velocity; pH= Power of hydrogen ion concentration; COND= conductivity; DO= Dissolved oxygen; FC= Free carbon dioxide  
 TA= Total alkalinity; CL= Chloride; Hard= Total hardness; PO<sub>4</sub> = Phosphate-phosphorous; NO<sub>3</sub>= Nitrate- nitrogen; NO<sub>2</sub>= Nitrite-nitrogen; NH<sub>4</sub>=Ammonium-nitrogen.

\*\* Correlation is significant at the 0.01level (2-tailed); \* Correlation is significant at the 0.05 level (2-tailed).

## ***4.2. Water quality of the hill stream Relli***

---

During the study period (March 2007 to February 2009) apparent water colour of the Relli was slightly bluish and true colour was clear in a glass beaker in the months of March to May and September to February. Water was muddy brown in colour and slightly turbid in glass beaker in July and August, but water was light muddy brown and slightly turbid in June. During 2008-09, apparent water colour of the Relli was slightly bluish and true colour was clear in a glass beaker in the months of March to June and September to February. Water was muddy brown in colour and slightly turbid in glass beaker in July and August. Flavor Rating Assessment (FRA) of the stream water showed that water could not be accepted as everyday drinking water.

### **4.2.1. Monthly variations of water quality parameters**

Summary of the Physico-chemical water quality parameters of the hill stream Relli evaluated during two years of the study period is shown in the **Table 4.2-1**.

#### **4.2.1.1. Air temperature**

Air temperature at the stream ranged from 15.6<sup>0</sup>C to 34.6<sup>0</sup>C with a mean value of 26.6<sup>0</sup>C ( $\pm 5.2$ ). Monthly variations of air temperature recorded at the hill stream Relli showed steady rise from February and touched peak in the month of August then gradually descended down to be lowest in January (**Figure 4.2-1**). Lowest air temperature (15.6<sup>0</sup>C) was documented at the sampling site RR-I during January 2008 and highest (34.6<sup>0</sup>C) at RR-III during August 2008.

#### **4.2.1.2. Water temperature**

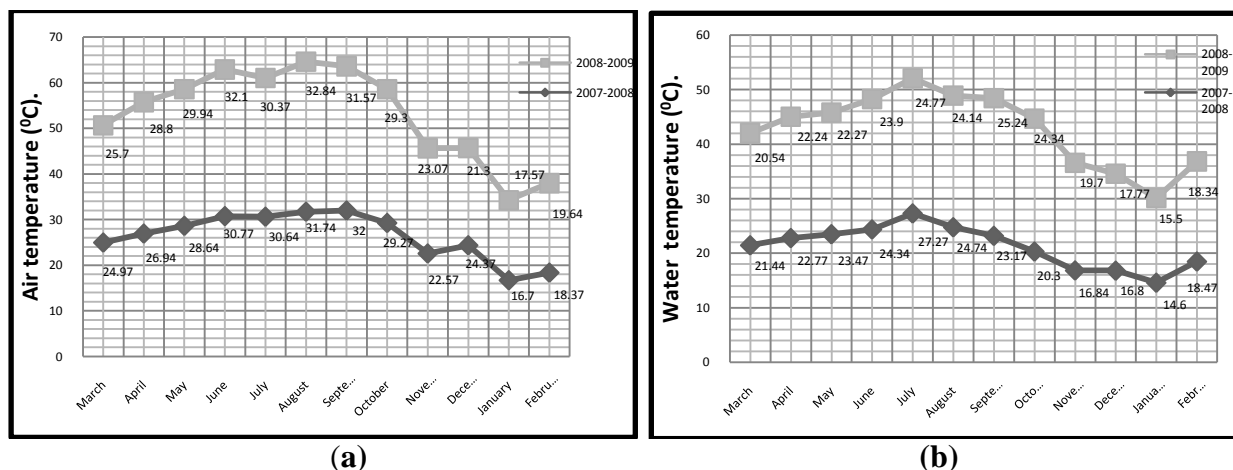
Monthly variations of documented water temperature in the stream revealed (**Figure 4.2-1**) a steady increase from the month of February and attained maximum in July and then gradually decreased to lowest point in the month of January which ranged from 13.3<sup>0</sup>C to 27.8<sup>0</sup>C with a mean value of 21.4 ( $\pm 3.4$ ). Lowest water temperature was recorded at RR-I in January 2008 and highest water temperature recorded at RR-III in July 2007.

#### **4.2.1.3. Water velocity**

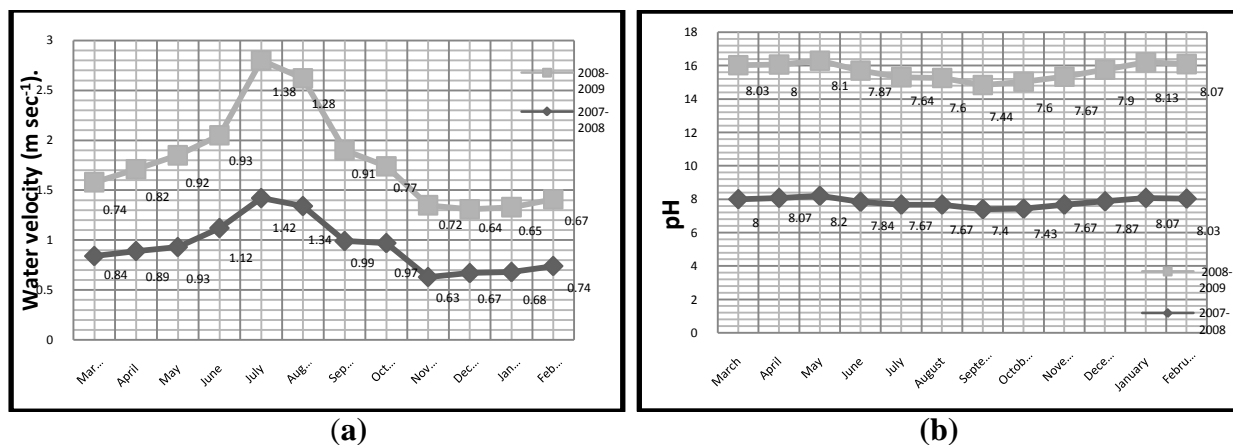
Recorded water velocity in the Relli ranged from 0.61 m sec<sup>-1</sup> to 1.51 m sec<sup>-1</sup> with a mean value 0.90 m sec<sup>-1</sup> ( $\pm 0.2$ ). Lowest water velocity was observed at RR-II in November 2007 and highest velocity was found at RR-I in July 2007. Monthly variations of water velocity showed the slow rise from February and touched peak in the month of July then gradually descended to be lowest in January (**Figure 4.2-2**).

**Table 4.2-1 Summary of the Water Quality Parameters (range, average, standard deviation) in the hill stream Relli (n=72) During Two Years of the Study Period.**

Period of study	March 2007 – February 2009		
Parameters	Range	Mean	Standard Deviation ( $\pm$ )
1. Air temperature ( $^{\circ}\text{C}$ ).	15.6 – 34.6	26.6	5.2
2. Water temperature ( $^{\circ}\text{C}$ ).	13.3 – 27.8	21.4	3.4
3. Water velocity ( $\text{m sec}^{-1}$ ).	0.61 – 1.51	0.902	0.2
4. pH.	7.3 – 8.3	7.83	0.26
5. Conductivity ( $\mu\text{S cm}^{-1}$ ).	52 - 99	77.5	13.5
6. Dissolved oxygen ( $\text{mg L}^{-1}$ ).	7.3 – 11.9	9.71	1.1
7. Free $\text{CO}_2$ ( $\text{mg L}^{-1}$ ).	0.6 – 5.8	3.11	1.4
8. Total alkalinity ( $\text{mg L}^{-1}$ ).	24.1 – 42.1	33.49	3.97
9. Chloride ion ( $\text{mg L}^{-1}$ ).	3.4 -7.9	5.94	0.95
10. Total hardness ( $\text{mg L}^{-1}$ ).	18.4 – 27.1	22.7	1.9
14. Ammonium-N ( $\text{mg L}^{-1}$ ).	0.008-0.028	0.016	0.005
12. Nitrite-N ( $\text{mg L}^{-1}$ ).	0.021-0.057	0.038	0.009
13. Nitrate-N ( $\text{mg L}^{-1}$ ).	0.006-0.014	0.009	0.002
11. Phosphate-P ( $\text{mg L}^{-1}$ ).	0.006-0.033	0.016	0.006



**Figure 4.2-1 Monthly variations of air (a) and water (b) temperature during first and second year of the study period (March 2007-February 2009).**



**Figure 4.2-2 Monthly variations of water velocity (a) and pH (b) of the hill stream water during first and second year of the study period (March 2007-February 2009).**

#### **4.2.1.4. Power (Puissance) of the hydrogen ion activity (pH)**

The pH value of surface water of hill stream Relli ranged from 7.3 to 8.3 with a mean value 7.8 ( $\pm 0.26$ ). Lowest pH value was recorded at RR-II in September 2007 and highest value at RR-III in May 2007. Monthly variations of pH explained the slow rise from March and touched peak in the month of May then gradually descended to be lowest in September again rise and reached peak in January (**Figure 4.2-2**).

#### **4.2.1.5. Specific Conductance**

The specific conductance of water of the stream Relli ranged from 52  $\mu\text{S cm}^{-1}$  to 99  $\mu\text{S cm}^{-1}$  with a mean value 77.49  $\mu\text{S cm}^{-1}$  ( $\pm 13.48$ ). Lowest conductivity was recorded at RR-I in July 2007 and highest at RR-III in May 2007. Monthly variations of specific conductance exhibited the slow rise from March and touched peak in the month of May then gradually descended to be lowest in July (2007-08) and August (2008-09) again rose (**Figure 4.2-3**).

#### **4.2.1.6. Dissolved oxygen (DO)**

The recorded of dissolved oxygen in the water of hill stream Relli ranged from 7.3  $\text{mg l}^{-1}$  to 11.9  $\text{mg l}^{-1}$  with a mean value 9.7  $\text{mg l}^{-1}$  ( $\pm 1.1$ ). Highest DO was documented at RR-I in December 2007 and lowest at RR-III in August 2008. Monthly variations of DO explained the slow descended from March to be lowest in the month of August then gradually ascended and touched peak in the month of December (**Figure 4.2-3**).

#### **4.2.1.7. Free Carbon dioxide (Free CO<sub>2</sub>)**

The free carbon dioxide in the stream water ranged from 0.6  $\text{mg l}^{-1}$  to 5.8  $\text{mg l}^{-1}$  with a mean value 3.1  $\text{mg l}^{-1}$  ( $\pm 1.4$ ). Lowest value of free CO<sub>2</sub> was recorded at RR-I in January 2008 and highest value at RR-III in September 2008. Monthly variations of free CO<sub>2</sub> exhibited the slow ascend from March to be highest in the month of July (2007-08) and August (2008-09) then gradually descended to be lowest in January (**Figure 4.2-4**).

#### **4.2.1.8. Total alkalinity**

The total alkalinity (always Bicarbonate Alkalinity) of the stream water ranged from 24.1  $\text{mg l}^{-1}$  to 42.1  $\text{mg l}^{-1}$  with a mean value 33.5  $\text{mg l}^{-1}$  ( $\pm 3.97$ ). Lowest value of total alkalinity was recorded at RR-I in July 2007 and highest value at RR-II in January 2009. Monthly variations of total alkalinity exhibited slow descend from March to be lowest in the month of July then gradually ascended to be highest in January (**Figure 4.2-4**).

#### **4.2.1.9. Chloride**

Chloride ion in the hill stream water ranged from 3.4  $\text{mg l}^{-1}$  to 7.9  $\text{mg l}^{-1}$  with a mean value 5.9  $\text{mg l}^{-1}$  ( $\pm 0.95$ ). Lowest value of chloride ion was recorded at RR-II in July 2007 and highest at RR-III in January 2009. Monthly variations of Chloride ion exhibited the

slow descend from March to be lowest in the month of July then gradually ascended to be highest in January (**Figure 4.2-5**).

#### **4.2.1.10. Total hardness**

In the stream water total hardness ranged from 18.4 mg L<sup>-1</sup> to 27.1 mg L<sup>-1</sup> with a mean value 22.7 mg L<sup>-1</sup> ( $\pm 1.9$ ). Lowest value of total hardness was recorded at RR-II in July 2007 and highest value at RR-II in January 2009. Monthly variations of total hardness exhibited the slow descend from March to be lowest in the month of July then gradually ascended to be highest in January (**Figure 4.2-5**).

#### **4.2.1.11. Ammonium-nitrogen (NH<sub>4</sub>-N)**

The ammonium nitrogen of the stream water ranged from 0.008 mg L<sup>-1</sup> to 0.028 mg L<sup>-1</sup> with a mean value 0.016 mg L<sup>-1</sup> ( $\pm 0.005$ ). Lowest value of NH<sub>4</sub>-N was recorded in January 2008(RR-I) and February 2008 (RR-II) and highest value at RR-III in September 2007. Monthly variations of NH<sub>4</sub>-N showed the slow rise from March and touched peak in the month of September then gradually descended to be lowest in February (**Figure 4.2-6**).

#### **4.2.1.12. Nitrite-nitrogen (NO<sub>2</sub>-N)**

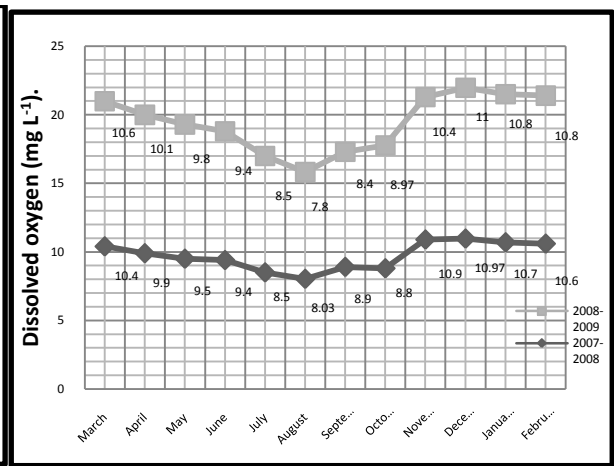
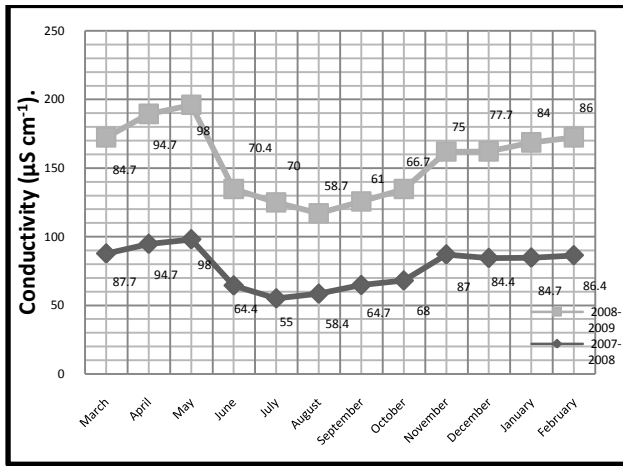
The amount of nitrite nitrogen of the stream water ranged from 0.006 mg L<sup>-1</sup> to 0.014 mg L<sup>-1</sup> with a mean value 0.009 mg L<sup>-1</sup> ( $\pm 0.002$ ). Lowest value of NO<sub>2</sub>-N was recorded in March' 07(RR-I), March' 08(RR-I & RR-III), February'08 (RR-II) and in January'08 (RR-III) and highest in September '07(RR-I) & September'08 (RR-I & RR-III) (Annex). Monthly variations of NO<sub>2</sub>-N showed the slow rise from March and touched peak in the month of September then gradually descended to be lowest in February and March (**Figure 4.2-6**).

#### **4.2.1.13. Nitrate-nitrogen (NO<sub>3</sub>-N)**

The amount of nitrate nitrogen of the stream water ranged from 0.021 mg L<sup>-1</sup> to 0.057 mg L<sup>-1</sup> with a mean value 0.038 mg L<sup>-1</sup> ( $\pm 0.009$ ). Lowest value of NO<sub>3</sub>-N was recorded at RR-I in January 2009 and highest value at RR-I in November 2007. Monthly variations of NO<sub>3</sub>-N showed slight rise from March to the month of April then gradually descended to be lowest in July and again ascended to be highest in the month of November (**Figure 4.2-7**).

#### **4.2.1.14. Phosphate-phosphorous (PO<sub>4</sub>-P)**

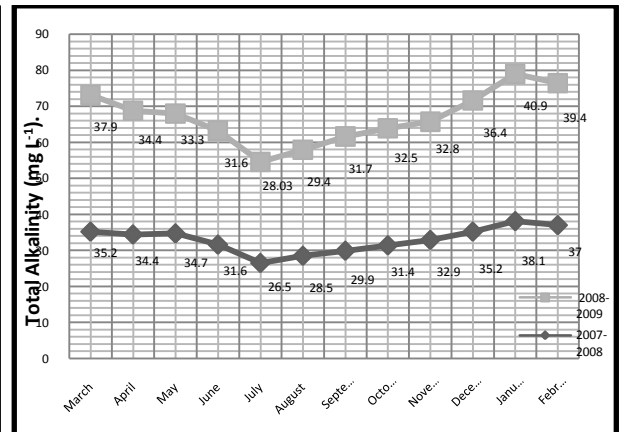
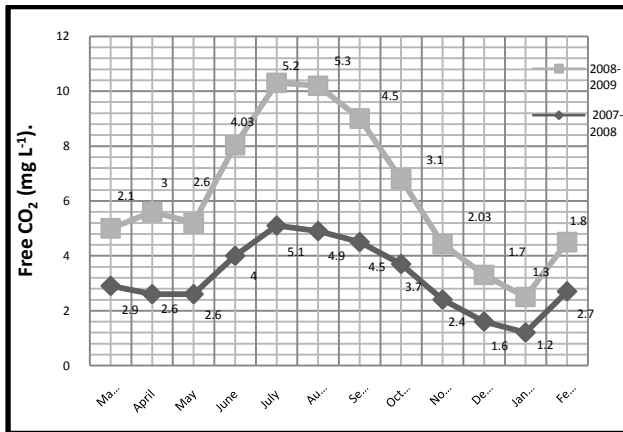
The amount of phosphate phosphorus in the stream water ranged from 0.006 mg L<sup>-1</sup> to 0.033 mg L<sup>-1</sup> with a mean value 0.016 mg L<sup>-1</sup> ( $\pm 0.006$ ). Lowest value of PO<sub>4</sub>-P was recorded at RR-I in January 2009 and highest value of PO<sub>4</sub>-P was found at RR-II in September 2007. Monthly variations of PO<sub>4</sub>-P showed the slow rise from March and touched peak in the month of September then gradually descended to be lowest in February (**Figure 4.2-7**).



(a)

(b)

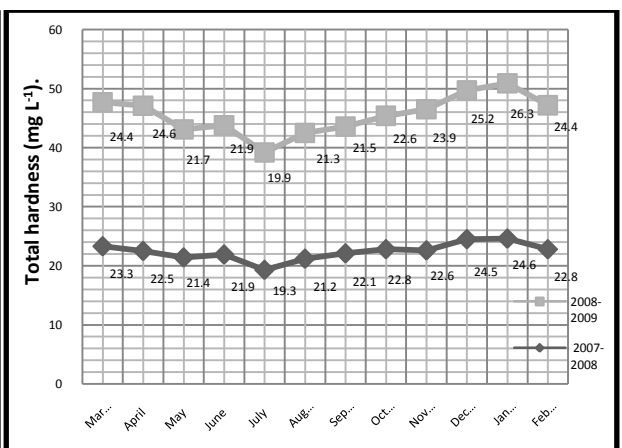
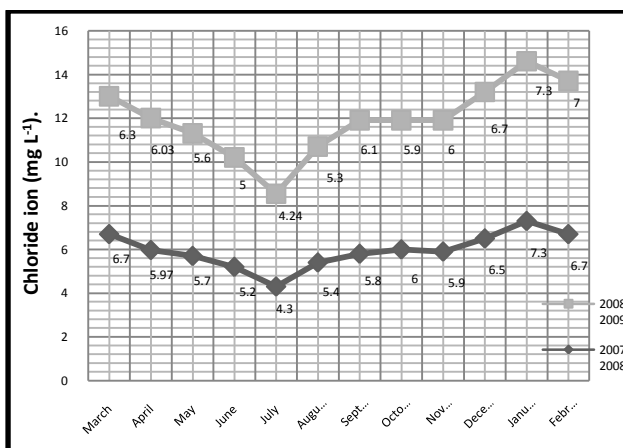
**Figure 4.2-3** Monthly variations of specific conductance (a) and dissolved oxygen (b) of the hill stream water during first and second year of the study period (March 2007-February 2009).



(a)

(b)

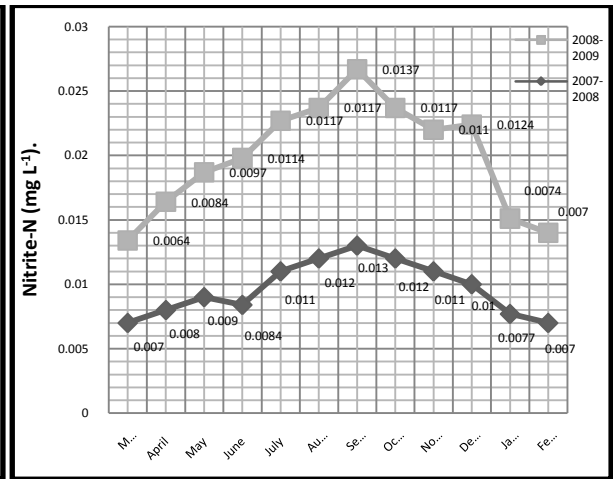
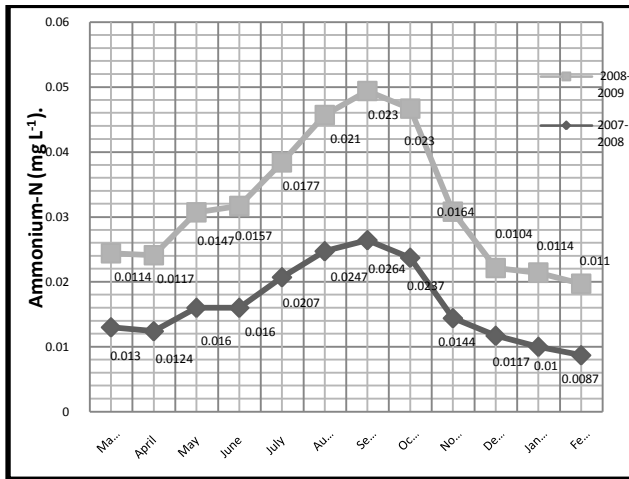
**Figure 4.2-4** Monthly variations of free CO<sub>2</sub> (a) and total alkalinity (b) of the hill stream water during first and second year of the study period (March 2007-February 2009).



(a)

(b)

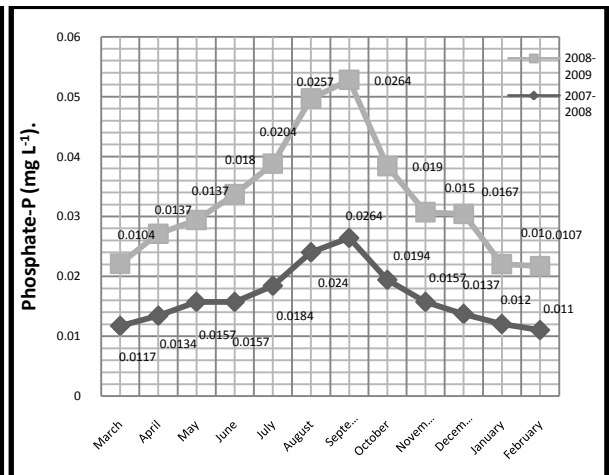
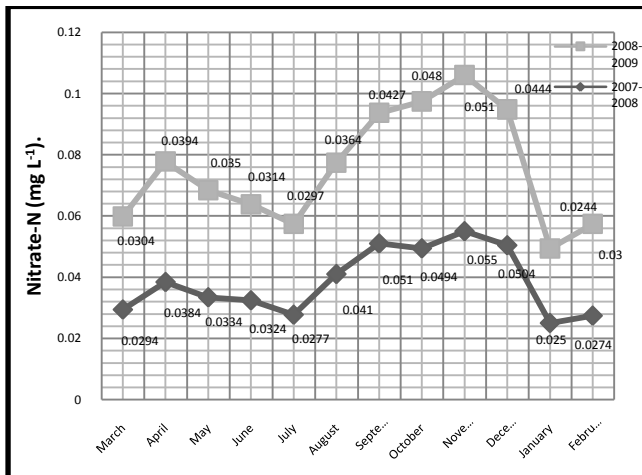
**Figure 4.2-5** Monthly variations of chloride (a) and total hardness (b) of the hill stream water first and second year of during the study period (March 2007-February 2009).



(a)

(b)

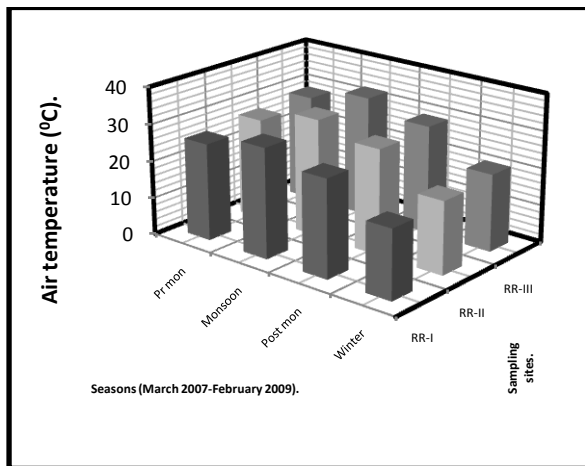
**Figure 4.2-6** Monthly variations of ammonium nitrogen (a) and nitrite nitrogen (b) of the hill stream water first and second year of during the study period (March 2007-February 2009).



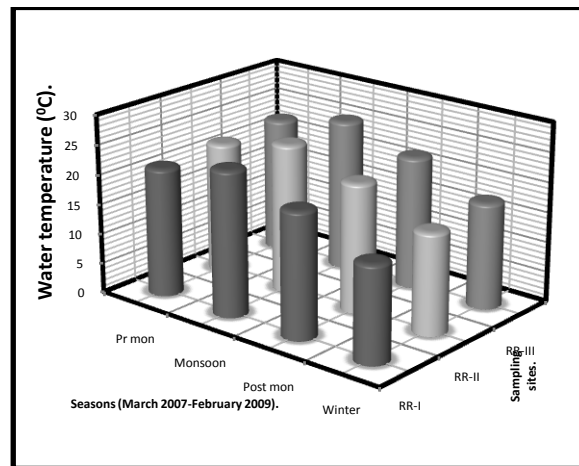
(a)

(b)

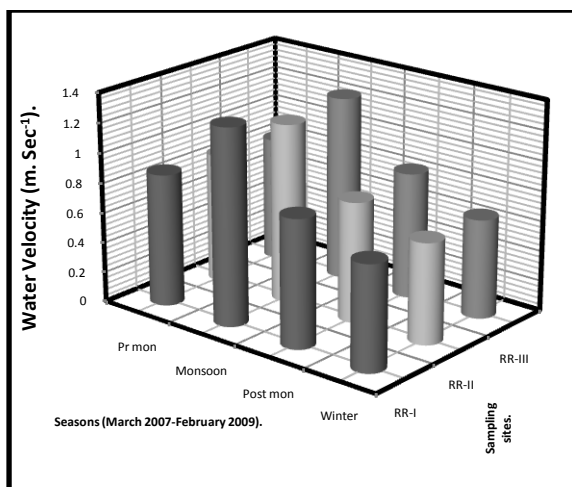
**Figure 4.2-7** Monthly variations of nitrate nitrogen (a) and phosphate phosphorus (b) of the hill stream water during first and second year of the study period (March 2007-February 2009).



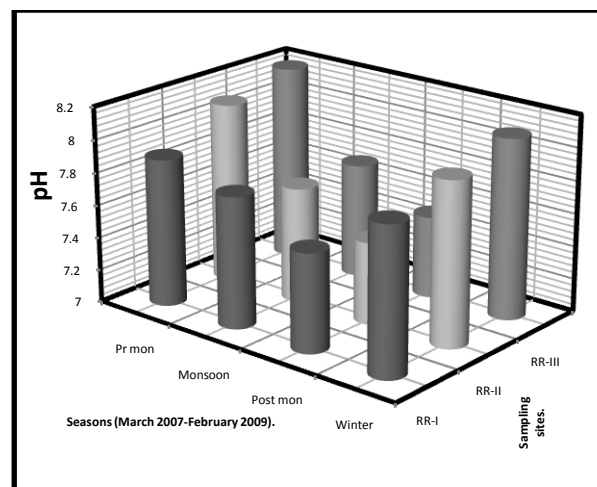
(a)



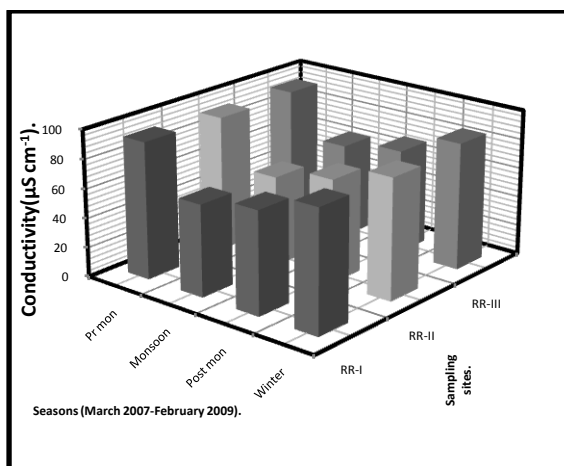
(b)



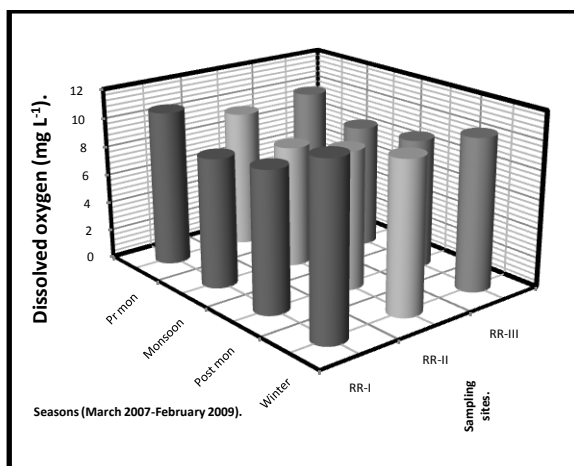
(c)



(d)

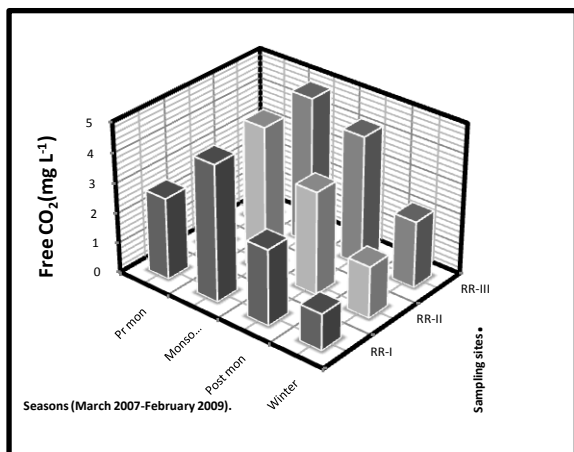


(e)

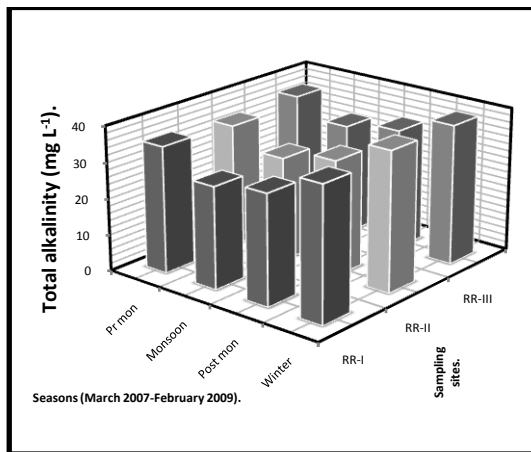


(f)

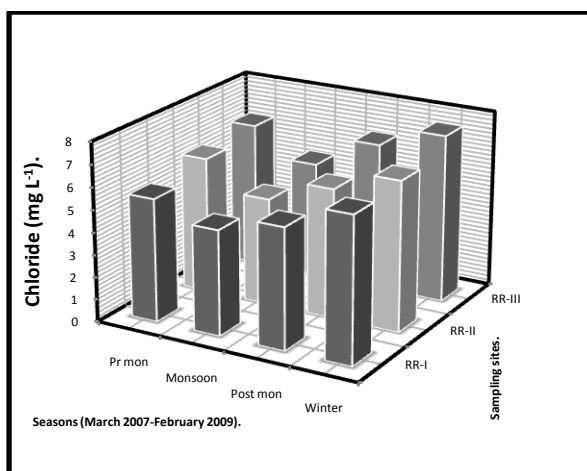
**Figure 4.2-8** Seasonal variations of air temperature (a), water temperature (b), water velocity (c), pH (d), specific conductance (e) and dissolved oxygen (f) in the three sampling sites of the hill stream water during the study period (March 2007-February 2009).



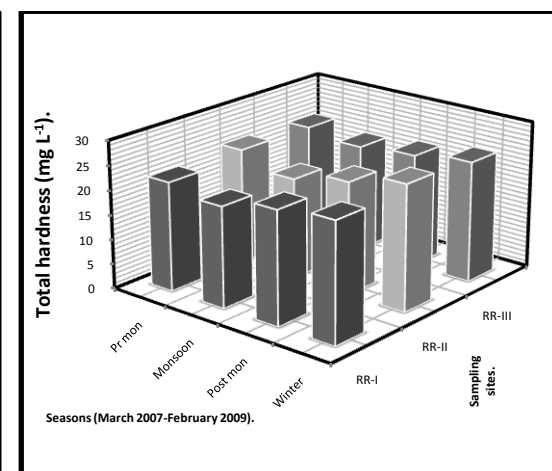
(g)



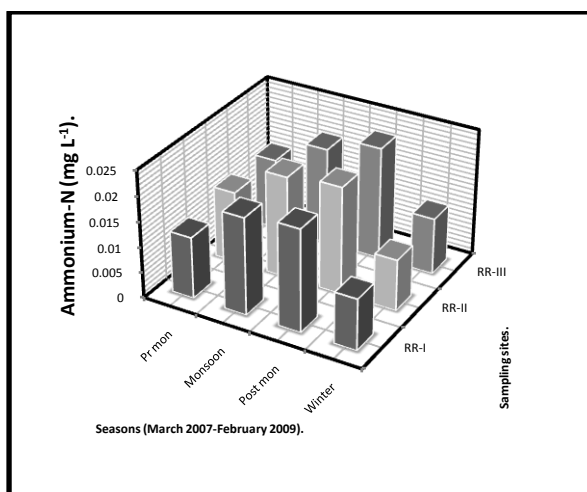
(h)



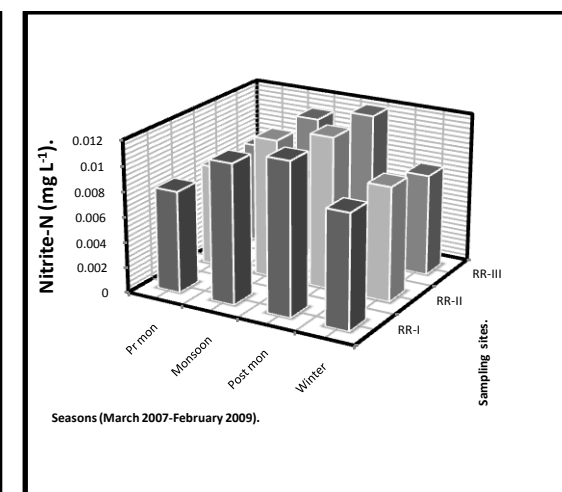
(i)



(j)

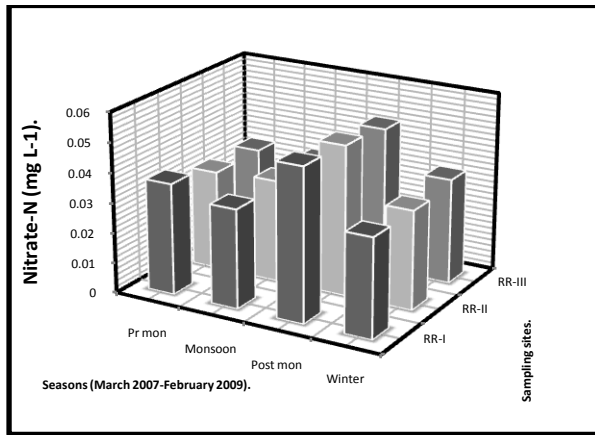


(k)

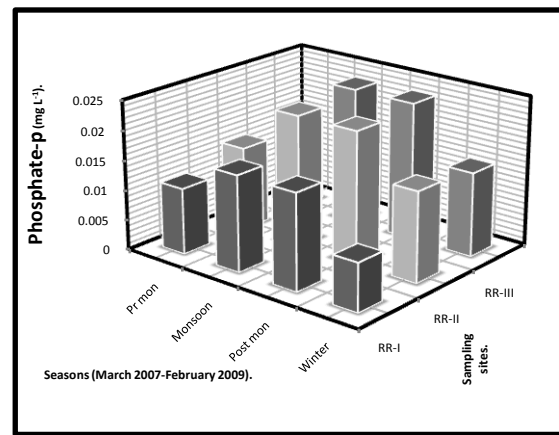


(l)

**Figure 4.2-9** Seasonal variations of free Carbon dioxide (g), total alkalinity (h), Chloride (i) total hardness (j), Ammonium-N (k) and nitrite-N (l) in the three sampling sites of the hill stream water during the study period (March 2007-February 2009).



(m)



(n)

**Figure 4.2-10** Seasonal variations of Nitrate-N (m) and phosphate-P (n) in the three sampling sites of the hill stream water during the study period (March 2007-February 2009).

**Table 4.2-2** Results of Test of Significance for Difference in Means (Fisher's t) of Seasonal Values of Physico-Chemical Parameters of Water Quality of the hill stream Relli During the Study Period (March 2007 to February 2009).

	pm/mon	pm/psm	pm/win	mon/psm	mon/win	psm/win
<b>Air temperature</b>	4.91*	0.22	10.09*	3.18*	14.71*	6.85*
<b>Water temperature</b>	6.74*	0.66	10.67*	4.08*	15.71*	5.56*
<b>Water velocity</b>	8.08*	0.64	8.25*	7.39*	12.46*	4.32*
<b>PH</b>	7.48*	10.40*	1.25	3.73*	6.72*	9.87*
<b>Conductivity</b>	13.90*	8.73*	5.44*	2.71*	10.55*	5.51*
<b>Dissolved oxygen</b>	5.79*	2.11**	3.24*	2.52*	9.34*	4.75*
<b>Free CO<sub>2</sub></b>	9.67*	2.14**	4.04*	3.94*	12.95*	4.70*
<b>Total alkalinity</b>	6.99*	4.38*	3.53*	3.22*	9.67*	7.55*
<b>Chloride</b>	4.91*	0.50	3.96*	4.68*	8.85*	4.72*
<b>Total hardness</b>	3.93*	0.78	3.17*	3.89*	7.90*	4.69*
<b>NH<sub>4</sub>-N</b>	6.16*	6.32*	4.42*	1.27	9.47*	8.80*
<b>NO<sub>2</sub>- N</b>	6.31*	9.26*	0.80	2.34*	3.82*	5.69*
<b>NO<sub>3</sub>-N</b>	0.72	9.19*	0.25	10.38*	0.18	5.73*
<b>PO<sub>4</sub>-P</b>	5.50*	4.54*	0.21	0.03	5.16*	4.37*

pm-pre monsoon; mon-monsoon; psm-post monsoon; win-winter.\*1%level significant, \*\*5%level significant.

### 4.2.2. Seasonal variations of water quality parameters

When data on monthly variations of water velocity, free CO<sub>2</sub>, air and water temperature were pooled into seasonal values, the monsoon showed the highest values and lowest in winter at all the sampling sites of the hill-stream Relli. On the contrary, seasonal variations of dissolved oxygen, total alkalinity, chloride ion and total hardness showed highest values in winter months and lowest values in monsoon months at all sites. pH of stream water shows lowest seasonal value in post monsoon months at all the sites and highest value in winter (RR-I), and pre monsoon (RR-II & III). Interestingly, variation of water conductivity showed highest value in pre-monsoon months and lowest in monsoon months at all sites. Seasonal dynamics of nutrients like PO<sub>4</sub>-P, NH<sub>4</sub>-N, NO<sub>2</sub>-N and NO<sub>3</sub>-N during the study period showed almost similar patterns. Highest values observed in post monsoon months and lowest values in pre monsoon and winter months. **Figure 4.2-8, 4.2-9 and 4.2-10** explains seasonal variations of physico-chemical water quality parameters in the three sampling sites during the study period.

Test of significance for difference in means (Fisher's t) was performed to understand whether the observed seasonal differences of physico-chemical parameters connote any real difference among groups. The null hypothesis for testing of differences between means is  $H_0: \mu_1 = \mu_2$ , where  $\mu_1$  is a mean of a variable in one season and  $\mu_2$  is a mean of same variable in other season. As  $H_a$  is two sided, a two tailed test for determining the rejection region at 1% level which comes to as under, using table of t-distribution for 34 degrees of freedom: R:  $t > 2.46$  and at 5% level it is: R:  $t > 1.70$ . The observed values of t for physico-chemical parameters in different seasons is presented in the **Table 4.2-2**, most of which fall in the rejection region and thus,  $H_0$  is rejected and concluded that seasonality affect physico-chemical factors of the river water.

### 4.2.3. Annual variations of water quality parameters

When data on monthly variations of physico-chemical parameters of water quality were pooled into annual values, the average values of air and water temperature, pH, total alkalinity, hardness, PO<sub>4</sub>-P and NO<sub>3</sub>-N were slightly higher in second year of study (March 2008- February 2009), but levels of water velocity, specific conductivity, free carbon dioxide, chloride, NH<sub>4</sub>-N and NO<sub>2</sub>-N were higher in first year of study (March 2007- February 2008). Dissolved oxygen showed no annual variation. Fisher's t were not significant except free CO<sub>2</sub> ( $|t|=1.74$ ,  $p < 0.05$ ), total alkalinity ( $|t|=1.89$ ,  $p < 0.05$ ), total hardness ( $|t|=2.19$ ,  $p < 0.05$ ), PO<sub>4</sub>-P ( $|t|=2.14$ ,  $p < 0.05$ ) and chloride ( $|t|=3.83$ ,  $p < 0.01$ ). **Table 4.2-3** showed the comparisons of annual mean values of physico-chemical parameters of water quality of the hill-stream Relli during two years of study period.

#### 4.2.4. Altitudinal variations of water quality parameters

Along the elevational gradient that is in three sampling sites, RR-I (704m), RR-II (566m) and RR-III (340m) average values of dissolved oxygen, conductivity and water velocity increased with the increase in altitude (RR-I > RR-II > RR-III) but, air and water temperature, pH, free carbon dioxide, total alkalinity, chloride and hardness decreased (RR-I < RR-II < RR-III). Nutrients (PO<sub>4</sub>-P, NH<sub>4</sub>-N, NO<sub>2</sub>-N and NO<sub>3</sub>-N) showed little or no fluctuations along the altitudinal gradient. Fisher's t were significant only in case of dissolved oxygen (between RR-I and RR-II, I and III, |t|=2.28, 2.19, p< 0.05), free CO<sub>2</sub> (I and III, |t|=2.25, p< 0.05), total alkalinity (I and III, |t|=1.94, p< 0.05), total hardness (I and III, |t|=2.06, p< 0.05), chloride (II and III, |t|=2.18, p< 0.05; I and III, |t|=3.76, p< 0.01). PO<sub>4</sub>-P was significant (between I and II, |t|=3.16, p< 0.01; I and III; |t|=3.22, p< 0.01). **Table 4.2-3** showed the comparisons of altitudinal mean values of physico-chemical parameters of water quality of the hill stream Relli during two years of study period.

#### 4.2.5. Correlation and Principal Component Analysis (PCA)

To examine individual relationship between physico-chemical variables, a Pearson correlation matrix was calculated. The numerical values of correlation coefficient are depicted in **Table 4.2-7** for all water quality parameters. Most of the calculated values depict some strong correlations. Pair having very high positive correlation between them shows the dependency of one parameter on the other while pair having very negative correlation between them shows inverse relation between them.

To extract the main tendencies of physico-chemical variables, a principal component analysis (PCA) was performed. In conjunction with the Kolmogorov–Smirnov test, it could be found (**Table 4.2-4**) that variables were normally distributed. To examine the suitability of these data for factor analysis, Kaiser–Meyer–Olkin (KMO) and Bartlett's tests were performed. KMO is a measure of sampling adequacy that indicates the proportion of variance which is common variance, i.e. which might be caused by underlying factors. High value (close to 1) generally indicates that factor analysis may be useful, if KMO test value is less than 0.6, factor analysis will not be useful (**Table 4.2-5**). Finally, PCA was applied to standardized data, and so the covariance matrix coincides with the correlation matrix. The data set of Z scores of the physico-chemical parameters satisfies Bartlett's Test of Sphericity. Bartlett's test of sphericity indicates whether correlation matrix is an identity matrix, which would indicate that variables are unrelated.

The significance level which is 0 (**Table 4.2-5**) in this study (less than 0.05) indicate that there are significance relationships among variables. At the same time, the data set also fulfills Kaiser-Meyer Measure of Sample Adequacy as KMO = 0.881 > 0.6. The KMO measures assess the extent persisting common variance that is inherent within the data set. Hence, it is possible to perform principal component analysis on the data set.

**Table 4.2-3 Mean Values ( $\pm$  standard deviation) of Physico-Chemical Parameters of Water Quality along the Altitudinal Gradient (n=24) of Relli and Comparisons of Mean ( $\pm$  standard deviation) Annual Values (n=36) During the two years of Study Period.**

Period of study	March 2007 – February 2009.			Annual variations	
Sampling sites	RR-I (704 m asl).	RR-II (566 m asl).	RR-III (340 m asl).	2007-08	2008-09
Physico-chemical parameters.					
1. Air temperature ( $^{\circ}$ C).	25.1 $\pm$ 4.9	26.8 $\pm$ 5.2	27.9 $\pm$ 5.2	26.4 $\pm$ 5.2	26.8 $\pm$ 5.2
2. Water temperature ( $^{\circ}$ C).	20.7 $\pm$ 3.6	21.4 $\pm$ 3.4	22.0 $\pm$ 3.3	21.2 $\pm$ 3.8	21.6 $\pm$ 3.1
3. Water velocity (m sec $^{-1}$ ).	0.94 $\pm$ 0.3	0.88 $\pm$ 0.2	0.89 $\pm$ 0.2	0.94 $\pm$ 0.2	0.87 $\pm$ 0.2
4. Hydrogen ion concentration (pH).	7.78 $\pm$ 0.2	7.83 $\pm$ 0.3	7.87 $\pm$ 0.3	7.83 $\pm$ 0.3	7.84 $\pm$ 0.3
5. Specific conductivity ( $\mu$ S cm $^{-1}$ ).	77.0 $\pm$ 13.8	76.5 $\pm$ 13.5	78.9 $\pm$ 13.6	77.8 $\pm$ 14.5	77.2 $\pm$ 12.6
6. Dissolved oxygen (mg L $^{-1}$ ).	10.2 $\pm$ 1.3	9.4 $\pm$ 0.96	9.5 $\pm$ 0.97	9.7 $\pm$ 1.1	9.7 $\pm$ 1.2
7. Free carbon dioxide (mg L $^{-1}$ ).	2.7 $\pm$ 1.4	3.0 $\pm$ 1.4	3.6 $\pm$ 1.2	3.2 $\pm$ 1.3*	3.0 $\pm$ 1.5*
8. Total alkalinity (mg L $^{-1}$ ).	32.6 $\pm$ 4.2	33.2 $\pm$ 4.2	34.7 $\pm$ 3.3	32.9 $\pm$ 3.7*	34.0 $\pm$ 4.2*
9. Chloride ion (mg L $^{-1}$ ).	5.5 $\pm$ 0.8	5.9 $\pm$ 0.9	6.5 $\pm$ 1.0	6.0 $\pm$ 0.96**	5.9 $\pm$ 0.97**
10. Total hardness (mg L $^{-1}$ ).	22.1 $\pm$ 1.8	23.0 $\pm$ 2.2	23.1 $\pm$ 1.5	22.4 $\pm$ 1.6*	23.1 $\pm$ 2.1*
11. Ammonium-N (mg L $^{-1}$ ).	0.015 $\pm$ 0.005	0.016 $\pm$ 0.005	0.016 $\pm$ 0.006	0.016 $\pm$ 0.006	0.015 $\pm$ 0.005
12. Nitrite-N (mg L $^{-1}$ ).	0.010 $\pm$ 0.002	0.010 $\pm$ 0.002	0.010 $\pm$ 0.002	0.009 $\pm$ 0.002	0.010 $\pm$ 0.002
13. Nitrate-N (mg L $^{-1}$ ).	0.038 $\pm$ 0.010	0.037 $\pm$ 0.010	0.037 $\pm$ 0.009	0.038 $\pm$ 0.011	0.037 $\pm$ 0.008
14. Phosphate-P (mg L $^{-1}$ ).	0.013 $\pm$ 0.005	0.018 $\pm$ 0.006	0.018 $\pm$ 0.006	0.016 $\pm$ 0.006*	0.017 $\pm$ 0.005*

\*\*Fisher's t significant at 0.01 level and \*Fisher's t significant at 0.05 level

**Table 4.2-4 Statistical Descriptive and Kolmogorov–Smirnov Normality Tests for the Physico-Chemical Variables Analysed.**

One-Sample Kolmogorov-Smirnov Test

	AT	WT	WV	PH	COND	DO	CO	TA	CL	HD	PO	NO3	NO2	NH4	
N	72	72	72	72	72	72	72	72	72	72	72	72	72	72	
Normal Parameters <sup>a</sup>	Mean	26.6292	21.3694	.9019	7.8319	77.4861	9.7139	3.1125	33.4847	5.9431	22.7639	.0165	.0376	.0099	.0160
	Std. Deviation	5.15849	3.44055	.24360	.26100	1.3484E1	1.14662	1.40210	3.97271	.95428	1.89598	.00604	.00956	.00229	.00538
Most Extreme Differences	Absolute	.140	.123	.138	.126	.131	.080	.102	.071	.073	.047	.140	.147	.168	.146
	Positive	.078	.071	.138	.118	.110	.080	.102	.071	.059	.047	.140	.147	.105	.146
	Negative	-.140	-.123	-.115	-.126	-.131	-.058	-.078	-.058	-.073	-.035	-.067	-.115	-.168	-.087
Kolmogorov-Smirnov Z	1.188	1.045	1.173	1.066	1.111	.680	.866	.605	.618	.398	1.185	1.244	1.427	1.238	
Asymp. Sig. (2-tailed)	.119	.225	.128	.206	.169	.745	.441	.858	.839	.997	.120	.090	.034	.093	

a. Test distribution is Normal.

(AT= Air temperature; WT= Water temperature; WV=Water velocity; pH= Power of hydrogen ion concentration; COND= conductivity; DO= Dissolved oxygen; FC= Free carbon dioxide; TA= Total alkalinity; CL= Chloride; Hard= Total hardness; PO<sub>4</sub> = Phosphate-phosphorous; NO<sub>3</sub>= Nitrate- nitrogen; NO<sub>2</sub>= Nitrite-nitrogen; NH<sub>4</sub>=Ammonium-nitrogen.)

**Table 4.2-5 KMO and Bartlett's Test of the Data Set**

Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.8805
Bartlett's Test of Sphericity	Approx. Chi-Square
	1085.248
	Degree of Freedom [df]
	91
	Level of Significance
	0.00

The information on communalities of the data set is provided in **Table 4.2-6**. Initial communalities are estimates of the variance in each variable accounted for by all components, whereas extraction communalities are estimates of the variance in each variable accounted for by the components in the component solution. Small values of extraction communalities of the variables are not well fit with the component solution. PCA ordination for physico-chemical factors on main factor plane is presented in **Figure 4.2-11**.

#### **4.2.5.1. Principal Component I (PC-I): More Physical and Nutrients, Less Chemical**

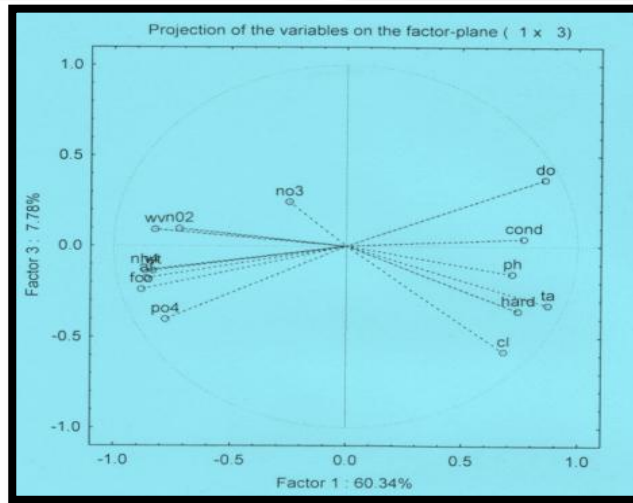
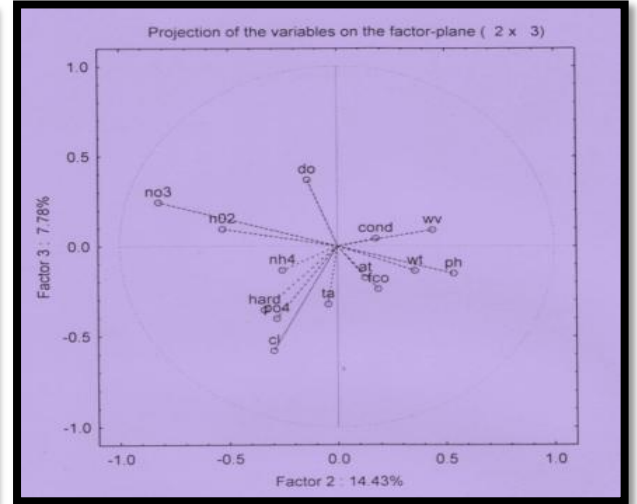
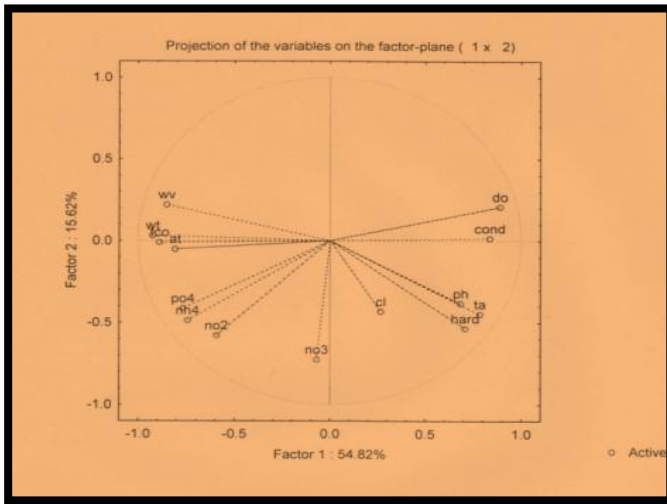
This component accounts for 60.3 per cent of the total variance of the original variables. The physical/nutrient parameters free carbon dioxide (FCO), ammonium nitrogen (NH<sub>4</sub>), air temperature (AT), water temperature (WT), water velocity (WV), phosphate phosphorous (PO<sub>4</sub>) and nitrite nitrogen (NO<sub>2</sub>) have high positive weights ranging from 0.72 to 0.88 with PCI and the chemical parameters total alkalinity (TA), dissolved oxygen (DO), conductivity (COND), total hardness (HARD), pH value (PH), chloride (CL) have high negative weights ranging from -0.68 to -0.87 with PCI. This suggests that the samples with higher score for this component have possessed more physical/nutrient parameters, and less chemical parameters. Hence, the physico-chemical quality of water of the stream Relli is mostly influenced by the greater presence of physical/nutrient parameters and less presence of chemical parameters.

#### **4.2.5.1. Principal Component II (PC-II): More Nutrients, Less Physical**

This component accounts for 14.4 per cent of the total variance of the original variables. Among the nutrient parameters nitrate nitrogen (NO<sub>3</sub>) has very high positive weight of 0.82 with PC2 and among the physical parameters water temperature (WT) and water velocity (WV) have relatively more negative weights of -0.36 and -0.44 respectively with this principal component. This indicates that the samples with higher score for this component have carried more NO<sub>3</sub> and relatively less physical parameters like WT and WV.

#### **4.2.5.1. Principal Component III (PC-III): PC III: More Chemical**

This component explains 7.8 per cent of the total variance of the original variables. Among the chemical parameters total alkalinity (TA), chloride (CL) and total hardness (HARD) have relatively high positive weights of 0.32, 0.58 and 0.35 respectively. This implies that a substantial number of samples associated with this component have relatively more amount of chemical parameters like TA, CL and HARD.



**Figure 4.2-11** PCA ordination for physico-chemical factors of Relli on main factor plane.

\*(at= Air temperature; wt= Water temperature; wv=Water velocity; ph= Power of hydrogen ion concentration; cond= conductivity; do= Dissolved oxygen; fco= Free carbon dioxide; ta= Total alkalinity; cl= Chloride; hard= Total hardness; po4= Phosphate-phosphorous; no3= Nitrate- nitrogen; no2= Nitrite-nitrogen; nh4=Ammonium-nitrogen.). o- active.

**Table 4.2-6 Interpretation and Eigenvalues of the Components, Component Loadings of the Variables and Extracted Communalities.**

Items	Principal Components			Communalities Extracted
	PC-I (more physical & nutrients Less chemicals).	PC-II (more nutrients , Less chemicals).	PC-III (more chemicals)	
AT (Air temperature).	<b>0.86</b>	-0.13	0.18	0.79
WT (Water temperature).	<b>0.83</b>	<b>-0.36</b>	0.14	0.84
WV (Water velocity).	<b>0.82</b>	<b>-0.44</b>	-0.09	0.88
PH (pH).	<b>-0.72</b>	-0.54	0.15	0.83
COND (conductivity).	<b>-0.77</b>	-0.18	-0.04	0.62
DO (Dissolved oxygen).	<b>-0.86</b>	0.14	-0.37	0.89
FCO (Free carbon dioxide).	<b>0.88</b>	-0.19	0.24	0.87
TA (Total alkalinity).	<b>-0.87</b>	0.04	<b>0.32</b>	0.87
CL (Chloride).	<b>-0.68</b>	0.30	<b>0.58</b>	0.89
HARD (Total hardness).	<b>-0.74</b>	0.34	<b>0.35</b>	0.79
PO <sub>4</sub> (Phosphate-phosphorous).	<b>0.78</b>	0.28	0.40	0.85
NH <sub>4</sub> (Ammonium-nitrogen).	<b>0.87</b>	0.26	0.13	0.83
NO <sub>2</sub> (Nitrite-nitrogen).	<b>0.72</b>	0.53	-0.10	0.81
NO <sub>3</sub> (Nitrate- nitrogen).	0.25	<b>0.82</b>	-0.24	0.80
<b>Eigen Value (Total Variance)</b>	<b>8.45</b>	<b>2.02</b>	<b>1.09</b>	
<b>(%) of Variance</b>	<b>60.3</b>	<b>14.4</b>	<b>7.8</b>	
<b>Cumulative (%)</b>	<b>60.3</b>	<b>74.8</b>	<b>82.5</b>	

**Table 4.2-7 Pearson's Correlation Coefficients Matrix for Physico-Chemical Parameters of Water Quality of the Hill-Stream Relli at the three Sites.**

	AT	WT	WV	PH	COND	DO	FCO	TA	CL	HARD	PO <sub>4</sub>	NH <sub>4</sub>	NO <sub>2</sub>	NO <sub>3</sub>
AT	1													
WT	0.892**	1												
WV	0.688**	0.763**	1											
PH	-0.455**	-0.354**	-0.398**	1										
COND	-0.481**	-0.497**	-0.602**	0.735**	1									
DO	-0.792**	-0.787**	-0.736**	0.452**	0.623**	1								
FCO	0.802**	0.804**	0.803**	-0.559**	-0.637**	-0.835**	1							
TA	-0.683**	-0.671**	-0.776**	0.622**	0.645**	0.656**	-0.682**	1						
CL	-0.563**	-0.610**	-0.721**	0.393**	0.443**	0.419**	-0.497**	0.745**	1					
HARD	-0.589**	-0.681**	-0.743**	0.395**	0.432**	0.555**	-0.648**	0.746**	0.736**	1				
PO <sub>4</sub>	0.691**	0.568**	0.462**	-0.606**	-0.627**	-0.751**	0.718**	-0.545**	-0.249*	-0.395**	1			
NH <sub>4</sub>	0.729**	0.651**	0.588**	-0.733**	-0.713**	-0.770**	0.690**	-0.683**	-0.428**	-0.531**	0.745**	1		
NO <sub>2</sub>	0.527**	0.389**	0.383**	-0.757**	-0.610**	-0.517**	0.501**	-0.633**	-0.400**	-0.369**	0.680**	0.691**	1	
NO <sub>3</sub>	0.195	-0.030	-0.168	-0.563**	-0.146	-0.030	0.012	-0.250*	-0.073	-0.024	0.326**	0.395**	0.574**	1

AT= Air temperature; WT= Water temperature; WV=Water velocity; pH= Power of hydrogen ion concentration; COND= conductivity; DO= Dissolved oxygen; FCO= Free carbon dioxide

TA= Total alkalinity; CL= Chloride; Hard= Total hardness; PO<sub>4</sub> = Phosphate-phosphorous; NO<sub>3</sub>= Nitrate- nitrogen; NO<sub>2</sub>= Nitrite-nitrogen; NH<sub>4</sub>=Ammonium-nitrogen.

\*\* Correlation is significant at the 0.01level (2-tailed); \* Correlation is significant at the 0.05 level (2-tailed).

## ***4.3. Diversity of Phytoplankton in the river Teesta***

---

### **4.3.1. Taxonomic Diversity and Relative Abundance**

A total of 47 genera belonging to five major groups were recorded during the study period in all four sampling sites. Bacillariophyceae was the most dominant group with 20 genera, followed by Chlorophyceae with 15 genera, Cyanophyceae with 7 genera, Euglenophyceae with 3 genera and Dinophyceae with 2 genera (**Table 4.3-1, 4.3-2 and Figure 4.3-1**).

The largest and most diverse group was the Bacillariophyceae (diatoms) which contributed about 82.2% of the total phytoplankton. *Navicula*, *Nitzschia*, *Synedra*, *Achnanthes*, *Diatoma*, *Amphora*, *Gomphonema* and *Cymbella* were the dominant genera among the diatoms and present almost throughout the study period. Other genera occurred irregularly. Taxonomic diversity and density was high during the winter months. Chlorophyceae (Green algae) contributed 8.4% of the total phytoplankton. The important genera of chlorophyceae recorded were *Closterium*, *Spirogyra*, *Ankistrodesmus*, *Chlorella* and *Crucigenia*. Cyanophyceae (blue-green algae) contributed 7.5 % of total phytoplankton and are mostly found during pre monsoon months. Euglenophyceae contributed 1.6% of total phytoplankton and represented by three genera which occurred irregularly. Dinophyceae contributed 0.6% of total phytoplankton and represented by two genera.

### **4.3.2. Monthly Variations of Density and Diversity Indices**

In the **Table 4.4-3** variations of density and diversity indices are summarized in all four sampling sites of the river Teesta during the study period.

#### **4.3.2.1. Phytoplankton density**

Recorded density of phytoplankton in the river Teesta ranged from 16 unit L<sup>-1</sup> to 137 unit L<sup>-1</sup> with a mean value 67.9 unit L<sup>-1</sup> ( $\pm 28.9$ ). Lowest density was recorded at TR-I during July 2008 and TR-III in August 2008. Highest density recorded at TR-IV during January 2009. Monthly variations (**Figure 4.3-2**) of phytoplankton density revealed a trend of gradual descend from the month of March and attained lowest value in July then ascended to touch peak in the month of January (2008-09) and February (2007-08). A small peak observed in the month of May.

**Table 4.3-1 Taxonomic Diversity and Relative Abundance of Phytoplankton in four sampling sites of river Teesta during the study period.**

Taxon/Genus	2007-2008				2008-2009			
	TR-I	TR-II	TR-III	TR-IV	TR-I	TR-II	TR-III	TR-IV
<b>CYANOPHYCEAE</b>								
1. <i>Anabaena sp</i>	-	+	+	+	-	+	+	+
2. <i>Merismopedia sp</i>	+	+	+	+	-	+	-	+
3. <i>Microcystis sp</i>	+	+	+	+	+	+	+	+
4. <i>Oscillatoria sp</i>	+	+	+	+	+	+	+	+
5. <i>Phormidium sp</i>	+	+	+	+	+	+	+	+
6. <i>Spirulina sp</i>	+	+	+	+	+	+	+	+
7. <i>Lyngbya sp</i>	-	+	-	+	-	-	+	+
<b>BACILLARIOPHYCEAE</b>								
8. <i>Navicula sp</i>	+++	+++	+++	+++	+++	+++	+++	++
9. <i>Surirella sp</i>	-	+	+	+	+	+	+	+
10. <i>Nitzschia sp</i>	++	++	+	+	++	+	++	++
11. <i>Synedra sp</i>	++	++	++	++	++	++	++	++
12. <i>Fragillaria sp</i>	+	+	+	+	+	+	+	+
13. <i>Cyclotella sp</i>	++	+	+	+	+	+	+	+
14. <i>Achnanthes sp</i>	++	+++	++	++	++	++	++	+
15. <i>Calones sp</i>	-	-	+	+	-	-	-	-
16. <i>Pinnularia sp</i>	-	+	+	+	-	+	+	+
17. <i>Eunotia sp</i>	+	+	+	+	+	+	+	+
18. <i>Diatoma sp</i>	++	++	++	+	++	++	++	+
19. <i>Amphora sp</i>	++	-	++	+	+	+	+	+
20. <i>Gomphonema sp</i>	+	++	++	++	+	+	+	++
21. <i>Hantzschia sp</i>	+	+	+	+	+	+	+	+
22. <i>Tabellaria sp</i>	-	-	-	-	-	-	+	+
23. <i>Melosira sp</i>	-	-	+	-	-	-	-	+
24. <i>Cymbella sp</i>	+++	+++	++	++	+++	+++	++	++
25. <i>Cocconeis sp</i>	-	+	+	+	-	+	+	+
26. <i>Epithemia sp</i>	-	-	-	+	-	-	+	-
27. <i>Rhopalodia sp</i>	-	-	-	+	-	-	-	+
<b>CHLOROPHYCEAE</b>								
28. <i>Chlorella sp</i>	+	+	+	+	-	+	+	+
29. <i>Chlorococcum sp</i>	+	+	+	+	+	+	+	+
30. <i>Tetraedron sp</i>	-	-	-	+	-	-	-	+
31. <i>Closterium sp</i>	+	-	+	+	+	+	+	+
32. <i>Cosmarium sp</i>	-	+	-	-	-	-	-	+
33. <i>Desmidium sp</i>	-	-	-	+	-	-	-	+
34. <i>Hydrodictyon sp</i>	+	-	-	+	-	+	+	-
35. <i>Spirogyra sp</i>	+	+	+	+	+	+	+	+
36. <i>Zygnema sp</i>	+	-	-	-	+	+	+	+
37. <i>Oocystis sp</i>	+	+	+	+	+	+	+	+
38. <i>Ankistrodesmus sp</i>	+	-	+	+	+	+	+	+
39. <i>Scenedesmus sp</i>	-	+	-	-	-	-	+	+
40. <i>Crucigenia sp</i>	+	-	-	+	+	+	+	+
41. <i>Ulothrix sp</i>	-	+	+	+	-	-	+	+
42. <i>Mougeota sp</i>	+	+	+	+	-	-	+	-
<b>EUGLENOPHYCEAE</b>								
43. <i>Euglena sp</i>	+	+	+	+	-	-	+	+
44. <i>Phacus sp</i>	+	+	+	+	+	+	+	+
45. <i>Trachelomonas sp</i>	+	-	+	+	+	+	+	+
<b>DINOPHYCEAE</b>								
46. <i>Ceratium sp</i>	-	+	+	+	-	+	+	+
47. <i>Glenodinium sp</i>	-	+	+	+	-	+	+	+

\*(-) absent, (+) upto 5%, (++) upto 10%, (+++) above 10%.

#### **4.3.2.2. Number of Phytoplankton Genera**

Documented variations of number of phytoplankton genera in the river ranged from 09 to 32 with a mean value 21.1 ( $\pm 5.5$ ). Lowest number of genera was recorded at TR-I during July 2007 and 2008. Highest number of genera recorded at RR-IV during January 2008. Monthly variations (**Figure 4.3-2**) of number of phytoplankton genera exhibited a trend of gradual descend from the month of March and attained lowest value in July then ascended to touch peak in the month of January (2008-09) and February (2007-08). A small peak observed in the month of May in 2007-08.

#### **4.3.2.3. Shannon-Wiener Diversity Index (H')**

Evaluated values of Shannon-Wiener Diversity Index (H') in the river Teesta ranged from 2.924 bits per individual to 4.654 bits per individual with an average 3.962 bits per individual ( $\pm 0.401$ ). Lowest value of diversity index was found in July 2008 at TR-II and highest value of species diversity index was found in April 2008 at TR-IV. Monthly variations (**Figure 4.3-3**) of phytoplankton diversity index exhibited a style of gradual descend from the month of March and attained lowest value in July then ascended to touch peak in the month of January (2008-09) and March (2007-08).

#### **4.3.2.4. Phytoplankton Evenness Index**

Assessed variations of phytoplankton evenness index (J') ranged from 0.856 to 0.956 with an average 0.914 ( $\pm 0.02$ ). Lowest evenness index was found in January 2009 (TR-I). Highest species evenness index was evidenced in July 2008 (TR-I) and August 2008 (TR-II). Monthly variations (**Figure 4.3-3**) of phytoplankton evenness index exhibited a fluctuating trend. In 2007-08 three small peaks were observed in the months of April, June and September but in 2008-09 similar small peaks were found in the months of April, August and December.

#### **4.3.2.5. Margalef's Richness Index**

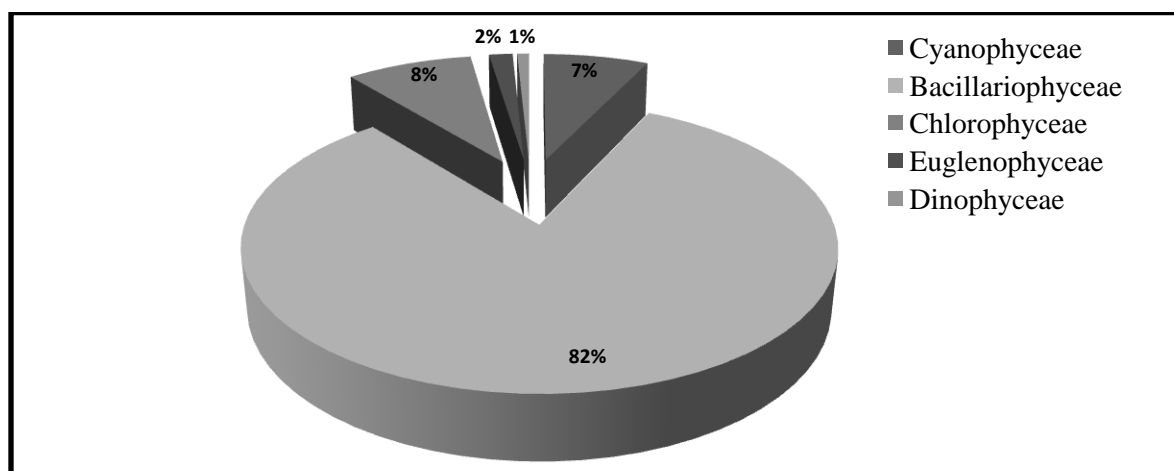
Projected values of phytoplankton species richness index (d) ranged from 2.52 to 6.56 with an average 4.82 ( $\pm 0.9$ ). Lowest richness index was found in July 2007 (TR-I) and highest species richness index was found in April 2008 (TR-IV). Monthly variations (**Figure 4.3-4**) of phytoplankton species richness index exhibited a trend of gradual descend from the month of March and attained lowest value in July then ascended to touch peak in the month of January (2008-09) and March (2007-08). A small peak observed in the month of May in 2007-08.

#### **4.3.2.6. Index of Dominance**

Monthly variation of index of dominance ( $\lambda$ ) ranges from 0.046 to 0.160 with an average 0.081 ( $\pm 0.02$ ). Lowest value of index of dominance was found in April 2008 (TR-IV) and highest value of index of dominance was found in July 2008 (TR-II).

**Table 4.3-2** Percent Composition of Phytoplankton Groups in four sampling sites of river Teesta during the study period.

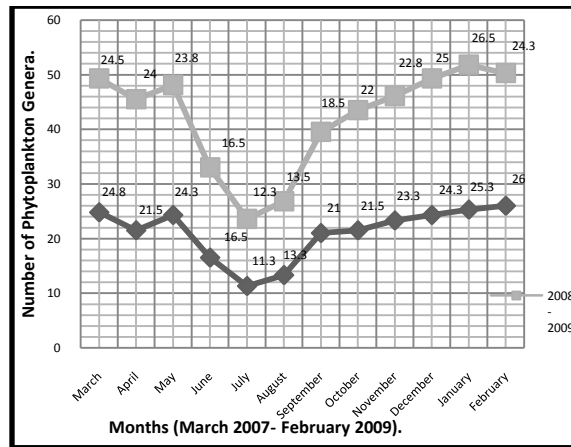
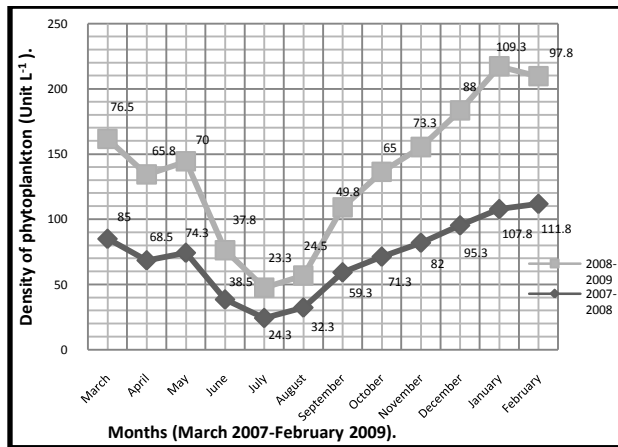
Taxon	2007-2008				2008-2009			
	TR-I	TR-II	TR-III	TR-IV	TR-I	TR-II	TR-III	TR-IV
CYANOPHYCEAE	4.7%	7.4%	7.1%	7.2%	5.4%	9.0%	7.3%	8.3%
BACILLARIOPHYCEAE	87.5%	80.6%	81.8%	82.1%	83.5%	79.0%	82.1%	81.5%
CHLOROPHYCEAE	6.7%	9.0%	8.6%	7.6%	8.8%	10.2%	9.0%	7.9%
EUGLENOPHYCEAE	1.1%	1.4%	1.8%	2.3%	2.3%	1.3%	0.9%	1.6%
DINOPHYCEAE	-----	1.6%	0.7%	0.8%	-----	0.5%	0.7%	0.8%



**Figure 4.3-1** Percent Composition of different Phytoplankton Groups in the River Teesta.

**Table 4.3-3** Summary of Phytoplankton Density and Diversity Indices of (showing the Range and Mean  $\pm$  Standard Deviation) of the river Teesta (n=96) during the study period.

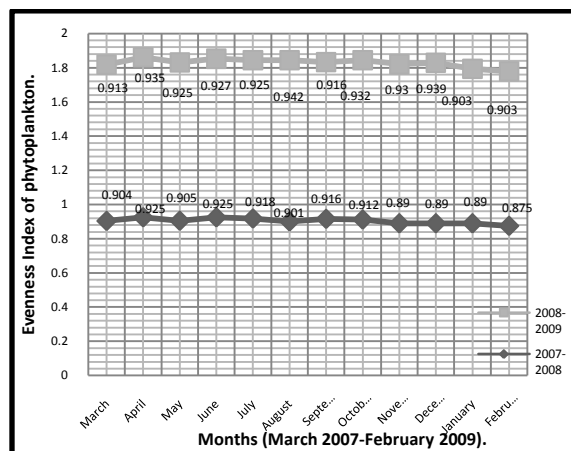
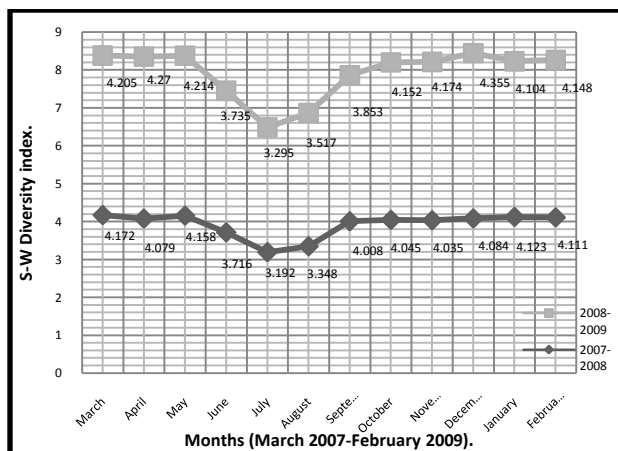
Period of study	March 2007 – February 2009		
	Range	Mean	S.D. ( $\pm$ ).
<b>Diversity indices</b>			
1. Density (Unit L <sup>-1</sup> ).	16-137	67.9	28.9
2. Number of genera (S).	09-32	21.1	5.5
3. Species diversity index (H').	2.92-4.65	3.96	0.40
4. Species evenness Index (J').	0.856-0.956	0.914	0.02
5. Species Richness Index (d).	2.517-6.563	4.82	0.92
6. Species dominance Index ( $\lambda$ ).	0.046-0.160	0.081	0.02



(a)

(b)

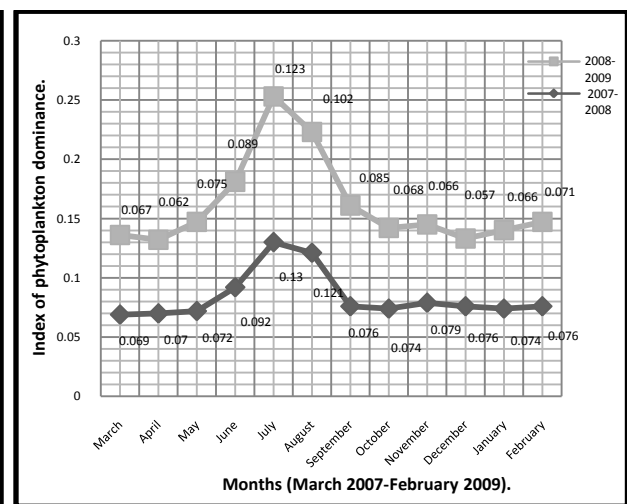
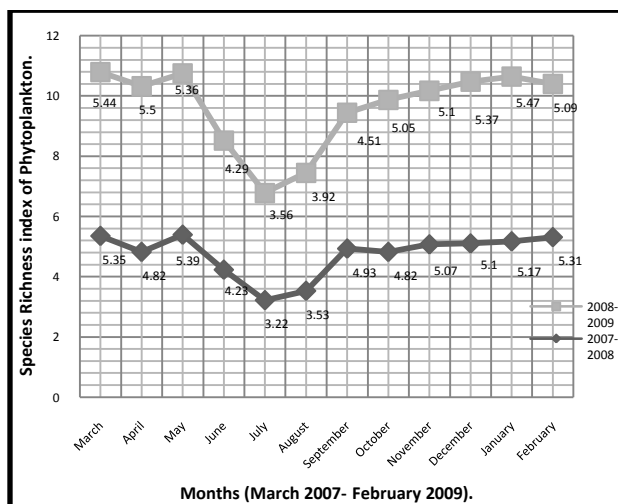
**Figure 4.3-2** Monthly variations of phytoplankton density (a) and number of genera (b) in the river Teesta during the study period.



(a)

(b)

**Figure 4.3-3** Monthly variations of Shannon-Wiener Diversity Index (a) and Evenness Index (b) of phytoplankton in the river Teesta during the study period.



(a)

(b)

**Figure 4.3-4** Monthly variations of Margalef's Richness Index (a) and Dominance Index (b) of phytoplankton in the river Teesta during the study period.

Monthly variations (**Figure 4.3-4**) of phytoplankton species dominance index exhibited a trend of gradual ascend from the month of March and attained highest value in July then descended to be lowest in the month of December (2008-09) and March (2007-08). A small peak observed in the month of May in 2007-08.

### 4.3.3. Similarity Index (Sorensen's Coefficient of Community)

**Table 4.3-4** shows the similarity index of phytoplankton at all sampling sites in the Teesta river. Highest similarity index (0.923) was recorded in between TR-III (07-08) and TR-IV (07-08). The lowest value of similarity index (0.678) was found in between TR-I (08-09) and TR-II (07-08).

### 4.3.4. Seasonal Variations of Density and Diversity indices

When data on monthly variations of phytoplankton density and number of genera was pooled into seasonal values, the monsoon showed the lowest value and highest in winter months at all the sampling sites of the river Teesta. Seasonal variations of Shannon-Wiener diversity index of phytoplankton showed the highest value in pre-monsoon months (TR-I & IV) and in winter months (TR-II & III) and lowest value in monsoon months at all sites. Highest seasonal value of Margalef's richness index of phytoplankton observed in pre-monsoon months (TR-I, III and IV) and in winter months at TR-II but lowest value found in monsoon months at all the sites. On the contrary, highest seasonal value of dominance index observed in monsoon months at all the sites but, lowest value found in pre monsoon months (TR-I, TR-II & TR-III), post monsoon months (TR-III) and in winter months at TR-IV. Interestingly, Seasonal variations of evenness index of phytoplankton showed the highest value in pre monsoon (TR-IV), monsoon (TR-I & TR-III) and post monsoon (TR-II) months but, lowest value found in winter months at all sites. **Figure 4.3-5, 4.3-6** and **4.3-7** explains seasonal variations of density and diversity indices of phytoplankton in four sampling sites during the study period.

Test of significance for difference in means (Fisher's t) was performed to understand whether the observed seasonal differences of density and diversity indices of phytoplankton connote any real difference among groups. The null hypothesis for testing of differences between means is  $H_0: \mu_1 = \mu_2$ , where  $\mu_1$  is a mean of a variable in one season and  $\mu_2$  is a mean of same variable in other season. As  $H_a$  is two sided, a two tailed test for determining the rejection region at 1% level which comes to as under, using table of t-distribution for 34 degrees of freedom: Critical Region:  $|t| \geq 2.46$  and at 5% level it is: Critical Region:  $|t| \geq 1.70$ . The observed values of t for physico-chemical parameters in different seasons is presented in the **Table 4.3-5**, most of which fall in the rejection region and thus,  $H_0$  is rejected and concluded that seasonality affect density and diversity of phytoplankton of the river water.

#### 4.3.5. Annual Variations of Density and Diversity indices

When data on monthly variations of density and diversity indices of phytoplankton were pooled into annual values, the average values of phytoplankton density, Shannon-Wiener Diversity Index and dominance index were found to be slightly higher in the first year of study (March 2007-February 2008) than the second year (March 2008-February 2009). On the contrary, average value of number of phytoplankton genera, evenness index and Margalef's richness index was found to be slightly higher in the second year of study (March 2008-February 2009) than the first year (March 2007-February 2008).

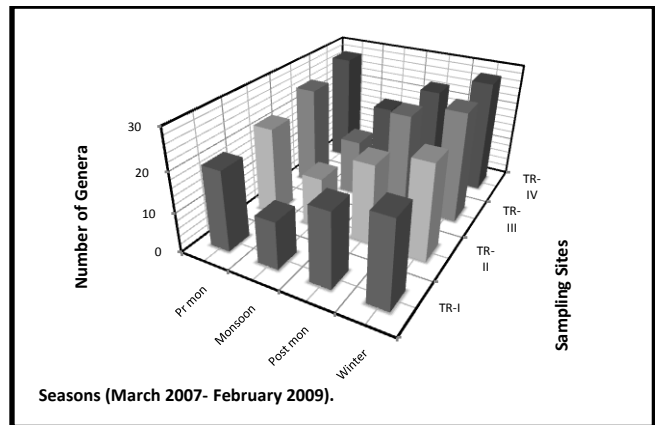
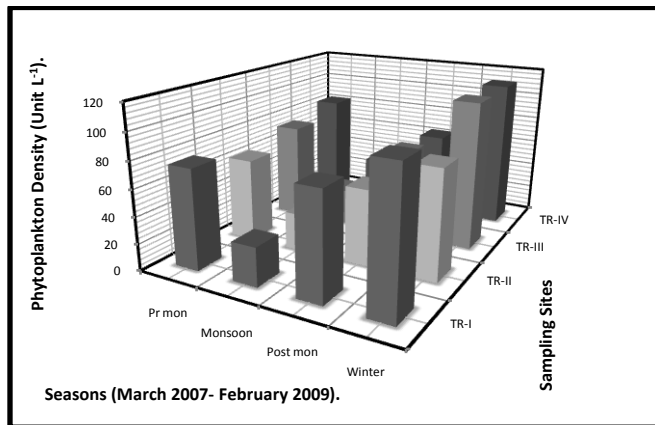
Fisher's t were not significant except evenness index ( $|t|=4.44$ ,  $p < 0.01$ ). **Table 4.3-6** showed the comparisons of annual mean values of density and diversity indices of phytoplankton in the river Teesta during two years of study period.

#### 4.3.6. Altitudinal Variations of Density and Diversity indices

Along the elevational gradient that is in four sampling sites such as TR-I (224m), TR-II (216m), TR-III (168m) and TR-IV (147m) of the river Teesta average values of number of phytoplankton genera, Shannon-Wiener diversity index, evenness index and Margalef's richness index demonstrated a trend of increment from up to downstream. On the contrary, average value of index of dominance showed a tendency of increment with the increase of altitude. Interestingly, average values of phytoplankton density along the altitudinal gradient of the Teesta demonstrated a peculiar pattern ( $57.3 \text{ unit L}^{-1}$  in TR-II)  $<$  ( $69.8 \text{ unit L}^{-1}$  in TR-III)  $<$  ( $71.4 \text{ unit L}^{-1}$  in TR-I)  $<$  ( $73.3 \text{ unit L}^{-1}$  in TR-IV). Fisher's t were significant in case of density (I and II, II and IV,  $|t|=1.86$ ,  $2.06$ ,  $p < 0.05$ ), number of genera (I and III, I and IV and II and IV, ( $|t|=3.34$ ,  $4.41$ ,  $3.09$ ,  $p < 0.01$ ); II and III,  $|t|=2.10$ ,  $p < 0.01$ ), diversity index (I and III, I and IV, II and IV,  $|t|=3.70$ ,  $5.20$ ,  $3.05$ ,  $p < 0.01$ ; I and II, II and III,  $|t|=1.92$ ,  $1.72$ ,  $p < 0.05$ ), evenness (I and III,  $|t|=1.85$ ,  $p < 0.05$ ; I and IV,  $|t|=3.03$ ,  $p < 0.01$ ), richness index (I and II, I and III, I and IV, II and III, II and IV,  $|t|=2.91$ ,  $5.67$ ,  $6.86$ ,  $2.48$ ,  $3.54$ ,  $p < 0.01$ ) and dominance index (I and III, I and IV, II and IV,  $|t|=2.74$ ,  $5.05$ ,  $2.49$ ,  $p < 0.01$ ). **Table 4.3-6** showed the comparisons of altitudinal mean values of density and diversity indices of phytoplankton in the river Teesta during two years of study period.

#### 4.3.7. Density and Diversity Indices of Phytoplankton and Water Quality

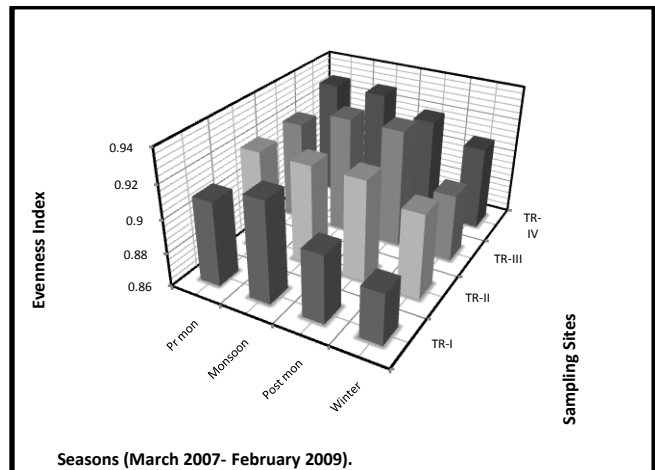
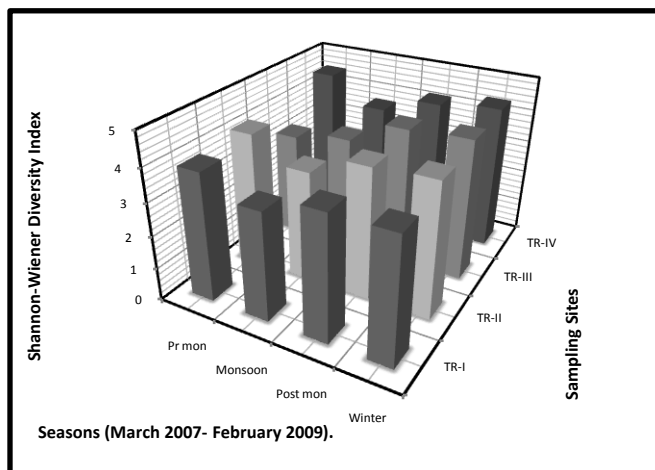
To examine individual relationship between Density and Diversity Indices of Phytoplankton and Physico-Chemical variables, a Pearson Correlation matrix was calculated. The numerical values of correlation coefficient are depicted in **Table 4.3-8** for all the variables. Most of the calculated values depict some strong correlations. Pair having very high positive correlation between them shows the dependency of one parameter on the other while pair having very negative correlation between them shows inverse relation between them.



(a)

(b)

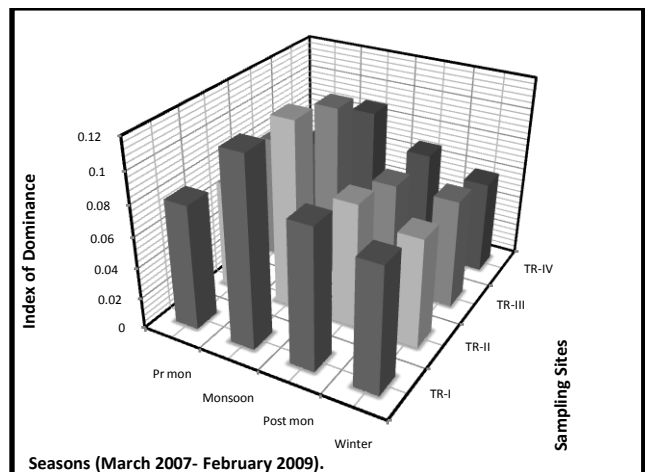
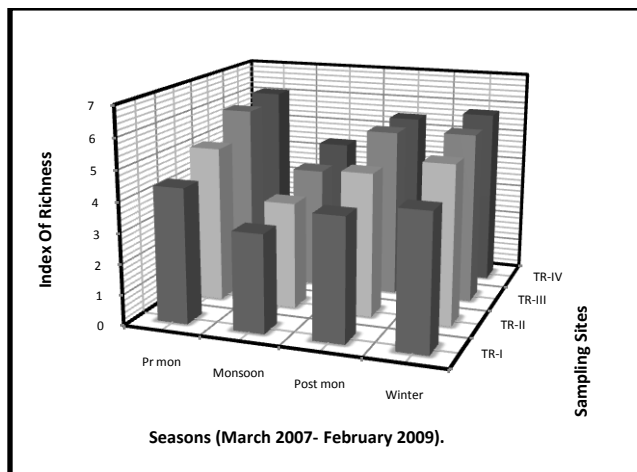
**Figure 4.3-5** Seasonal variations of phytoplankton density (a) and number of genera (b) in the four sampling sites of the river Teesta during the study period.



(a)

(b)

**Figure 4.3-6** Seasonal variations of Shannon-Wiener Diversity Index (a) and Evenness Index (b) of phytoplankton in the four sampling sites of the river Teesta during the study period.



(a)

(b)

**Figure 4.3-7** Seasonal variations of Margalef's Richness Index (a) and Dominance Index (b) of phytoplankton in the four sampling sites of the river Teesta during the study period.

**Table 4.3-5 Results of Test of Significance for Difference in Means (Fisher's t) of Seasonal Values of Density and Diversity Indices of Phytoplankton in the hill stream Relli During the Study Period (March 2007 to February 2009).**

	pm/mon	pm/psm	pm/win	mon/psm	mon/win	psm/win
1. Density (Unit L <sup>-1</sup> ).	14.468*	1.695	6.34*	10.265*	17.055*	7.159*
2. Number of genera (S).	9.92*	2.329**	1.426	8.033*	11.816*	3.934*
3. Species diversity index (H').	8.402*	1.981**	0.361	6.774*	7.376*	1.382
4. Species evenness Index (J').	0.922	0.307	2.491*	1.204	3.235*	2.194**
5. Species Richness Index (R).	7.079*	1.877**	0.285	5.336*	7.358*	1.739**
6. Species dominance Index (λ).	7.341*	1.502	0.141	6.228*	7.074*	1.284

pm-pre monsoon; mon-monsoon; psm-post monsoon; win-winter.\*1%level significant, \*\*5%level significant.

**Table 4.3-6 Mean Values (± standard deviation) of Density and Diversity Indices of Phytoplankton along the Altitudinal Gradient (n=24) of Teesta and Comparisons of Mean (± standard deviation) Annual Values (n=48) During the two years of Study Period.**

Period of study	March 2007 – February 2009.				Annual variations	
	TR-I	TR-II	TR-III	TR-IV	2007-08	2008-09
1. Density (Unit L <sup>-1</sup> ).	71.4±29.1	57.3±21.5	69.8±32.6	73.3±30.4	70.8±28.8	65.1±29.1
2. Number of Genera (S).	17.9±4.1	19.6±4.6	22.8±5.6	24.1±5.4	21.1±5.5	21.1±5.4
3. Shannon-Wiener diversity index (H').	3.685±0.3	3.885±0.4	4.073±0.4	4.204±0.3	3.922±0.4	4.002±0.4
4. Evenness Index (J').	0.903±0.03	0.915±0.03	0.915±0.02	0.924±0.02	0.904±0.02**	0.924±0.02**
5. Margalef's Richness index (R).	4.014±0.6	4.617±0.8	5.195±0.8	5.437±0.8	4.745±0.9	4.887±0.9
6. Dominance Index (λ).	0.093±0.02	0.085±0.03	0.075±0.02	0.069±0.02	0.084±0.02	<b>0.077±0.02</b>

\*\*Fisher's t significant at 0.01 level

**Table 4.3-4 Similarity Index Variations at Different Sampling Sites in Teesta river during the Study Period.**

	2007-2008				2008-2009			
	TR-I	TR-II	TR-III	TR-IV	TR-I	TR-II	TR-III	TR-IV
TR-I (07-08)	1	0.699	0.819	0.806	0.893	0.907	0.812	0.778
TR-II(07-08)		1	0.870	0.827	<b>0.678</b>	0.806	0.862	0.854
TR-III (07-08)			1	<b>0.923</b>	0.775	0.886	0.880	0.872
TR-IV(07-08)				1	0.736	0.869	0.889	0.881
TR-I (08-09)					1	0.867	0.800	0.756
TR-II(08-09)						1	0.877	0.869
TR-III(08-09)							1	0.914
TR-IV(08-09)								1

The regression analysis showed causal relationship between physico-chemical variables (Independent or explanatory variables) and variables of phytoplankton density and diversity indices (Dependant or regressand variables). Three Principal Components obtained for physico-chemical parameters in the hill stream were used as independent variables to understand the trend of control over phytoplankton density and diversity (**Table 4.3-7**). Causal relationship as obtained in the regression analysis has been summarized below.

#### 4.3.7.1. Density of Phytoplankton

$$Dens_i = 67.948 + -17.136 PC1_i + 19.376 PC2_i$$

$$SE = (1.34) \quad (1.35) \quad (1.35)$$

$$t\text{-value} = 50.633^* \quad -12.703^* \quad 14.363^*$$

$$R^2 = 0.798; \bar{R}^2 = 0.794; F_{2,93} = 183.82^*$$

The  $\bar{R}^2$  value of 0.794 indicates that about 79.4% variation in the density of phytoplankton in the river Teesta is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component I (PC1) has significant negative influence and principal component II (PC2) has significant positive impact on the phytoplankton density of the river. Hence, in one hand density of phytoplankton will increase in the augmented values of dissolved oxygen and specific conductance and the decreased values of water temperature, free carbon dioxide, Phosphate phosphorous, ammonium nitrogen, nitrite nitrogen and nitrate nitrogen in the river water. On the other hand increased values of pH, Total alkalinity, chloride and total hardness escalate the density of phytoplankton in the stream when water velocity is less.

#### 4.3.7.2. Number of Genera of Phytoplankton

$$NOG_i = 21.094 + -2.389 PC1_i + 3.472 PC2_i$$

$$SE = (0.36) \quad (0.36) \quad (0.36)$$

$$t\text{-value} = 58.857^* \quad -6.631^* \quad 9.637^*$$

$$R^2 = 0.595; \bar{R}^2 = 0.587; F_{2,93} = 68.42^*$$

The  $\bar{R}^2$  value of 0.587 indicates that about 58.7% variation in the number of phytoplankton genera in the stream is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component II (PC2) has significant positive impact on the number of phytoplankton genera. Hence, number of phytoplankton genera will increase if the value of pH, total alkalinity, chloride and hardness of the river water increases and the value of water velocity decreases. The principal component I (PC1) has significant negative influence on the number of phytoplankton genera. Hence, number of phytoplankton genera will increase in

the augmented values of dissolved oxygen and specific conductance and the decreased values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen, nitrite nitrogen and nitrate nitrogen in the stream water.

#### 4.3.7.3. Shannon-Wiener Diversity Index of Phytoplankton

$$SDI_i = 3.962 + (-0.121) PC1_i + 0.235 PC2_i$$

SE	= (0.03)	(0.03)	(0.03)
t-value	= 127.173*	-3.855*	7.488*

$$R^2 = 0.433; \bar{R}^2 = 0.420; F_{2, 93} = 35.465^*$$

The  $\bar{R}^2$  value of 0.420 indicates that about 42% variation in the diversity index of phytoplankton in the stream is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component II (PC2) has significant positive impact on the phytoplankton diversity index. Hence, the index will increase if the value of pH, total alkalinity, chloride and hardness of the river water increases when water velocity is less. The principal component I (PC1) has significant negative influence on the phytoplankton diversity index. Hence, index will soar in the augmented values of dissolved oxygen and specific conductance and the decreased values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen, nitrite nitrogen and nitrate nitrogen in the stream water.

#### 4.3.7.4. Evenness Index of Phytoplankton

$$Even_i = 0.914 + 0.007 PC1_i + (-0.004) PC2_i$$

SE	= (0.002)	(0.002)	(0.002)
t-value	= 399.963*	3.019*	-1.850**

$$R^2 = 0.119; \bar{R}^2 = 0.100; F_{2, 93} = 6.268^*$$

The  $\bar{R}^2$  value of 0.100 indicates that about 10% variation of the evenness index of phytoplankton in the stream is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component I (PC1) has significant positive influence on the phytoplankton evenness index. Hence, the index will soar in the augmented values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen, nitrite nitrogen and nitrate nitrogen in the stream water when there is less dissolved oxygen and specific conductance. The principal component II (PC2) has significant (6% level) negative impact on the phytoplankton evenness index. Hence, the index will increase with the decreased values of pH, total alkalinity, chloride and hardness and increased value of water velocity in the river water.

#### 4.3.7.5. Species Richness Index of Phytoplankton

$$Rich_i = 4.816 + -0.273 PC1_i + 0.486 PC2_i$$

$$SE = (0.08) \quad (0.08) \quad (0.08)$$

$$t\text{-value} = 63.51^* \quad -3.603^* \quad 6.407^*$$

$$R^2 = 0.367; \bar{R}^2 = 0.354; F_{2, 93} = 27.016^*$$

The  $\bar{R}^2$  value of 0.354 indicates that about 35.4% variation in the species richness index of phytoplankton in the stream is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component II (PC2) has significant positive impact on the phytoplankton diversity index. Hence, the index will increase if the value of pH, total alkalinity, chloride and hardness of the river water increases when water velocity is less. The principal component I (PC1) has significant negative influence on the phytoplankton diversity index. Hence, index will soar in the augmented values of dissolved oxygen and specific conductance and the decreased values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen, nitrite nitrogen and nitrate nitrogen in the stream water.

#### 4.3.7.6. Species Dominance Index of phytoplankton

$$Domi_i = 0.081 + 0.007 PC1_i + -0.014 PC2_i$$

$$SE = (0.002) \quad (0.002) \quad (0.002)$$

$$t\text{-value} = 46.099^* \quad 4.226^* \quad -7.762^*$$

$$R^2 = 0.457; \bar{R}^2 = 0.445; F_{2, 93} = 39.059^*$$

The  $\bar{R}^2$  value of 0.445 indicates that about 44.5% variation in the species dominance index of phytoplankton in the stream is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component I (PC1) has significant positive influence on the phytoplankton evenness index. Hence, the index will soar in the augmented values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen, nitrite nitrogen and nitrate nitrogen in the stream water when there is less dissolved oxygen and specific conductance. The principal component II (PC2) has significant negative impact on the phytoplankton evenness index. Hence, the index will increase with the decreased values of pH, total alkalinity, chloride and hardness and increased value of water velocity in the river water.

**Table 4.3-7 Physico-Chemical Water Quality Determinants of phytoplankton diversity: OLS Estimation.**

Independent Variables	Density		Number of genera		SDI		Evenness		Richness		Dominance	
	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value
Intercept	67.948	50.633*	21.094	58.857*	3.962	127.173*	0.914	399.963*	4.816	63.510*	0.081	46.099*
PCI: More physical & nutrient and less chemical	-17.136	-12,703*	-2.389	-6.631*	-0.121	-3.855*	0.007	3.019*	-0.273	-3.603*	0.007	4.226*
PCII: More Chemical and less physical.	19.376	14.363*	3.472	9.637*	0.235	7.488*	-0.004	-1.850**	0.486	6.407*	-0.014	-7.762*
R square	0.798		0.595		0.433		0.275		0.367		0.457	
Adjusted R square	0.794		0.587		0.420		0.259		0.354		0.445	
F <sub>2, 93</sub> -value (ANOVA)	183.82*		68.42*		35.465*		17.59*		27.016*		39.059*	

\*=> Significant at 1% level of Significance; \*\*=> Significant at 6% level of Significance.

**Table 4.3-8 Pearson's Correlation Coefficients Matrix for Phytoplankton Density and Diversity Indices and Water Quality Parameters of the river Teesta.**

	AT	WT	WV	PH	COND	DO	FCO	TA	CL	HARD	PO4	NO3	NO2	NH4
<b>DENSP</b>	-0.598**	-0.788**	-0.858**	0.646**	0.714**	0.785**	-0.792**	0.842**	0.278**	0.676**	-0.590**	-0.008	-0.508**	-0.579**
<b>NOGP</b>	-0.323**	-0.654**	-0.849**	0.540**	0.601**	0.616**	-0.678**	0.818**	0.196**	0.663**	-0.455**	0.051	-0.411**	-0.466**
<b>SDIP</b>	-0.187	-0.551**	-0.768**	0.447**	0.489**	0.478**	-0.549**	0.707**	0.167	0.594**	-0.348**	0.139	-0.310**	-0.348**
<b>EVENP</b>	0.362**	0.264**	0.251**	-0.136	-0.372**	-0.338**	0.368**	-0.281**	-0.142	-0.115	0.261**	0.063	0.212*	0.214*
<b>RICHP</b>	-0.145	-0.496**	-0.712**	0.424**	0.451**	0.450**	-0.515**	0.691**	0.134	0.568**	-0.314**	0.059	-0.307**	-0.342**
<b>DOMIP</b>	0.265**	0.613**	0.766**	-0.466**	-0.501**	-0.526**	0.559**	-0.699**	-0.134	-0.580**	0.352**	-0.166	0.319**	0.345**

AT= Air temperature; WT= Water temperature; WV=Water velocity; pH= Power of hydrogen ion concentration; COND= conductivity; DO= Dissolved oxygen; FC= Free carbon dioxide;TA= Total alkalinity; CL= Chloride; Hard= Total hardness; PO<sub>4</sub> = Phosphate-phosphorous; NO<sub>3</sub>= Nitrate- nitrogen; NO<sub>2</sub>= Nitrite-nitrogen; NH<sub>4</sub>=Ammonium-nitrogen; DENSP= Phytoplankton density;

NOGP= Number of phytoplankton genera; SDIP= Diversity index of phytoplankton; EVENP= Evenness index of phytoplankton; RICHP= Richness index of phytoplankton; DOMIP=Dominance index.

\*\* Correlation is significant at the 0.01 level (2-tailed); \* Correlation is significant at the 0.05 level (2-tailed).

## ***4.4. Diversity of Phytoplankton in the hill stream Relli***

---

### **4.4.1. Taxonomic Diversity and Relative abundance**

A total of 34 genera belonging to four major groups were recorded during the study period in all three sampling sites. Bacillariophyceae was the most dominant group with 16 genera, followed by Chlorophyceae with 11 genera, Cyanophyceae with 5 genera and Euglenophyceae with only 2 genera (**Table 4.4-1, 4.4-2 and Figure 4.4-1**).

The largest and most diverse group was the Bacillariophyceae (diatoms) which contributed about 78.2% of the total phytoplankton. *Navicula*, *Nitzschia*, *Synedra*, *Achnanthes*, *Diatoma*, *Amphora*, *Gomphonema* and *Cymbella* were the dominant genera among the diatoms and were present almost throughout the study period. Other genera occurred irregularly. Taxonomic diversity and density was high during the winter months.

Chlorophyceae (Green algae) contributed 10.44% of the total phytoplankton. The important genera of chlorophyceae recorded were *Closterium*, *Spirogyra*, *Ankistrodesmus*, *Chlorella* and *Crucigenia*. Cyanophyceae (blue-green algae) contributed 9.62 % of total phytoplankton and are mostly found during pre monsoon months. Euglenophyceae were contributed by 1.74% of total phytoplankton and represented by two genera which occurred irregularly.

### **4.4.2. Monthly Variations of Density and Diversity Indices**

In the **Table 4.4-3** variations of density and diversity indices are summarized in all three sampling sites of the hill stream Relli during the study period.

#### **4.4.2.1. Phytoplankton Density**

Observed density of phytoplankton in the hill stream ranged from 16 unit L<sup>-1</sup> to 91 unit L<sup>-1</sup> with a mean value 48.6 unit L<sup>-1</sup> ( $\pm 18.5$ ). Lowest density was recorded at RR-II during July 2008 and highest was found at RR-III during December 2008. Monthly variations of phytoplankton density revealed a trend of gradual descend from the month of March to attain lowest value in July and then ascended to touch peak in the month of December (2007-08) and January (2008-09) (**Figure 4.4-2**).

**Table 4.4-1 Taxonomic Diversity and Relative Abundance of Phytoplankton in three sampling sites of the hill stream Relli during the study period.**

Taxon/Genus	2007-2008			2008-2009		
	RR-I	RR-II	RR-III	RR-I	RR-II	RR-III
<b>CYANOPHYCEAE</b>						
1. <i>Merismopedia sp</i>	-	+	+	-	+	+
2. <i>Microcystis sp</i>	+	+	+	+	+	+
3. <i>Oscillatoria sp</i>	+	+	+	+	+	+
4. <i>Phormidium sp</i>	+	+	+	+	+	+
5. <i>Spirulina sp</i>	+	+	+	+	+	+
<b>BACILLARIOPHYCEAE</b>						
6. <i>Navicula sp</i>	+++	+++	+++	+++	++	+++
7. <i>Surirella sp</i>	-	+	+	+	+	+
8. <i>Nitzschia sp</i>	++	++	++	++	+	++
9. <i>Synedra sp</i>	++	++	++	++	+	++
10. <i>Fragillaria sp</i>	+	+	+	+	+	+
11. <i>Cyclotella sp</i>	+	+	+	+	++	++
12. <i>Achnanthes sp</i>	++	++	++	++	++	++
13. <i>Pinnularia sp</i>	-	+	-	-	+	+
14. <i>Eunotia sp</i>	+	-	+	+	-	-
15. <i>Diatoma sp</i>	++	++	++	++	++	++
16. <i>Amphora sp</i>	+	+	+	+	++	++
17. <i>Gomphonema sp</i>	++	++	++	++	+	++
18. <i>Hantzschia sp</i>	+	-	-	+	-	+
19. <i>Tabellaria sp</i>	-	+	+	-	+	-
20. <i>Melosira sp</i>	+	-	+	+	-	+
21. <i>Cymbella sp</i>	+++	++	+++	++	++	++
<b>CHLOROPHYCEAE</b>						
22. <i>Chlorococcum sp</i>	-	-	+	+	+	+
23. <i>Closterium sp</i>	+	+	+	+	+	+
24. <i>Cosmarium sp</i>	+	+	+	-	-	+
25. <i>Desmidium sp</i>	-	-	-	-	+	+
26. <i>Spirogyra sp</i>	+	+	+	+	+	+
27. <i>Zygnema sp</i>	-	-	+	-	+	+
28. <i>Oocystis sp</i>	-	-	+	-	-	+
29. <i>Ankistrodesmus sp</i>	+	+	-	-	+	+
30. <i>Chlorella sp</i>	+	+	+	+	+	+
31. <i>Scenedesmus sp</i>	-	-	+	+	-	-
32. <i>Crucigenia sp</i>	+	+	+	+	+	+
<b>EUGLENOPHYCEAE</b>						
33. <i>Euglena sp</i>	+	+	+	+	+	+
34. <i>Phacus sp</i>	+	+	+	+	+	+

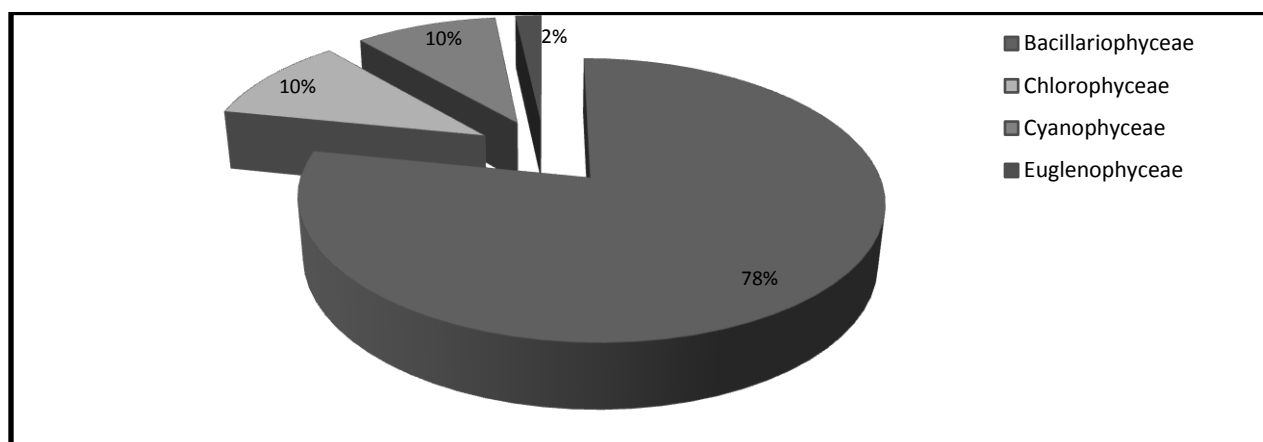
\*(-) absent, (+) upto 5%, (++) upto 10%, (+++) above 10%.

**Table 4.4-2** Percent Composition of Phytoplankton Groups in three sampling sites of the hill stream Relli during the study period.

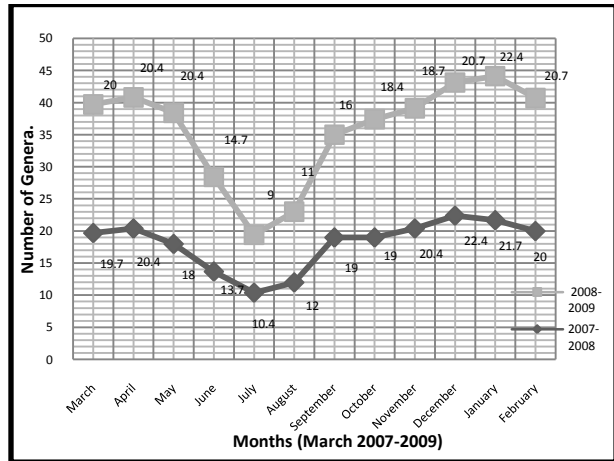
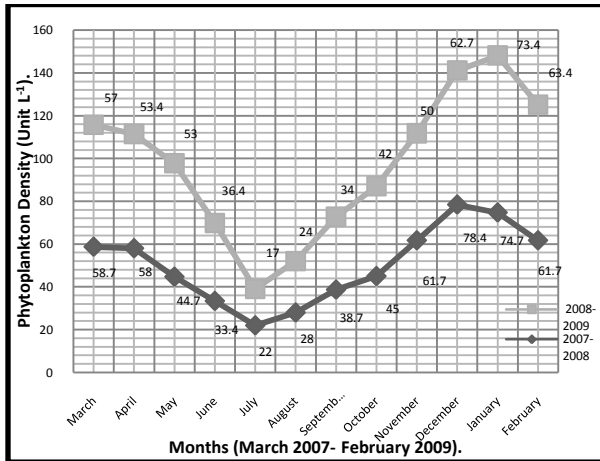
Taxon	2007-2008			2008-2009		
	RR-I	RR-II	RR-III	RR-I	RR-II	RR-III
CYANOPHYCEAE	8.6%	10.3%	8.2%	9.7%	11.8%	9.0%
BACILLARIOPHYCEAE	80.4%	76.5%	81.3%	78.8%	73.6%	78.7%
CHLOROPHYCEAE	9.2%	11.2%	9.1%	9.9%	12.6%	10.7%
EUGLENOPHYCEAE	1.8%	2.0%	1.4%	1.5%	2.0%	1.6%

**Table 4.4-3** Summary of Phytoplankton Density and Diversity Indices (showing the Range and Mean  $\pm$  Standard Deviation) of the hill stream Relli (n=72) during the study period.

Period of study	March 2007 – February 2009		
	Range	Mean	S.D. ( $\pm$ ).
<b>Diversity indices</b>			
1. Density (Unit L <sup>-1</sup> ).	16-91	48.6	18.5
2. Number of genera (S).	8-25	17.8	4.2
3. Species diversity index (H').	2.91-4.34	3.87	0.4
4. Species evenness Index (J').	0.91-0.98	0.94	0.02
5. Species Richness Index (d).	2.23-5.37	4.35	0.75
6. Species dominance Index ( $\lambda$ ).	0.057-0.152	0.081	0.03



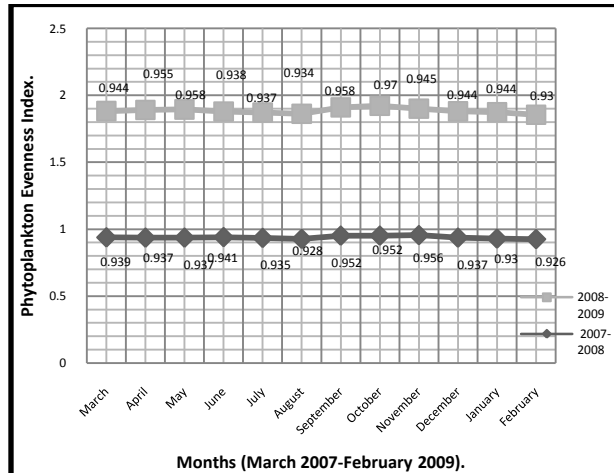
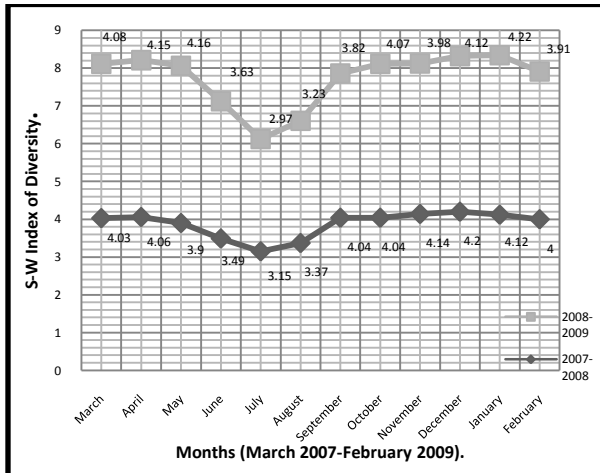
**Figure 4.4-1** Percent Composition of Phytoplankton Groups in the hill-stream Relli.



(a)

(b)

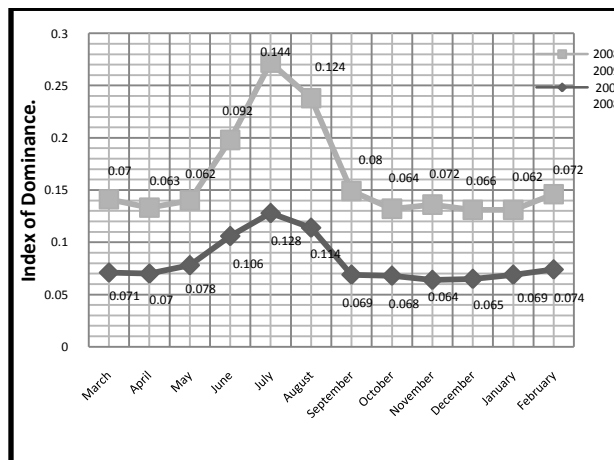
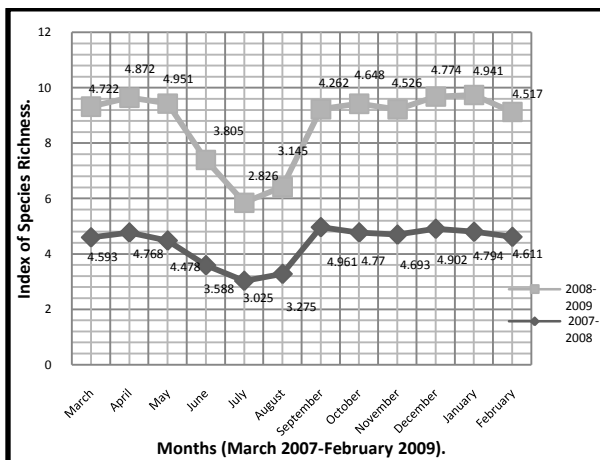
**Figure 4.4-2** Monthly variations of phytoplankton density (a) and number of genera (b) in the hill stream Relli during the study period.



(a)

(b)

**Figure 4.4-3** Monthly variations of Shannon-Wiener Diversity Index (a) and Evenness Index (b) of phytoplankton in the hill stream Relli during the study period.



(a)

(b)

**Figure 4.4-4** Monthly variations of Margalef's Richness Index (a) and Dominance Index (b) of phytoplankton in the hill stream Relli during the study period.

#### **4.4.2.2. Number of Phytoplankton Genera**

Recorded number of phytoplankton genera in the hill stream Relli ranged from 08 to 25 with a mean value 17.8 ( $\pm 4.2$ ). Lowest number of genera was recorded at RR-II during August, 2007 and highest number of genera recorded at RR-III during January 2009. Monthly variations of number of phytoplankton genera revealed a style of gradual descend from the month of April to reach lowest value in July and then ascended to touch peak in the month of December (2007-08) and January (2008-09) (**Figure 4.4-2**).

#### **4.4.2.3. Shannon-Wiener Diversity Index**

Estimated phytoplankton diversity index ( $H'$ ) in the stream ranged from 2.91 bits per individual to 4.34 bits per individual with an average of 3.87 bits per individual ( $\pm 0.39$ ). Lowest value of diversity index was found in June 2007 at RR-I and highest value in January 2009 at RR-III. Monthly variations of phytoplankton diversity index revealed a tendency of gradual descend from the month of April to reach lowest value in July and then ascended to touch peak in the month of December (2007-08) and January (2008-09) (**Figure 4.4-3**).

#### **4.4.2.4. Phytoplankton Evenness Index**

Projected evenness index ( $J'$ ) of phytoplankton in the stream ranged from 0.906 to 0.980 with an average 0.942 ( $\pm 0.02$ ). Lowest evenness index was found in April 2007 (RR-III) and highest species evenness index was found in October 2008 (RR-II). Monthly variations of phytoplankton evenness index exhibited small peak in May (2008-09) and June (2007-08) then another peak in the month of November (2007-08) and October (2008-09) (**Figure 4.4-3**).

#### **4.4.2.5. Margalef's Richness Index**

Assessed phytoplankton richness index in the stream ranged from 2.23 to 5.37 with an average 4.35 ( $\pm 0.75$ ). Lowest richness index was found in August 2007 (RR-II) and highest value was found in January'09 (RR-III). Monthly variations of phytoplankton richness index revealed a style of gradual descend from the month of April to reach lowest value in July and then ascended to touch peak in the month of September in 2007-08. But in 2008-09 the index moves down from May and became lowest in July and then touched peak in January (**Figure 4.4-4**).

#### **4.4.2.6. Index of Dominance**

Evaluated values of phytoplankton Dominance Index ranged from 0.057 to 0.152 with an average 0.081 ( $\pm 0.025$ ). Lowest value of Index of Dominance was found in November 2007 (RR-II) and May 2008 (RR-III) and highest value was found in June 2007 (RR-I). Monthly variations of phytoplankton dominance index revealed a style of gradual ascend from the month

of April to reach highest value in July then descend down in the month of September in 2007-08. But in 2008-09 the index moved upward from May and became highest in July and then moved downwards to be lowest in January (**Figure 4.4-4**).

#### **4.4.3. Similarity Index (Sorensen's Coefficient of Community)**

**Table 4.4-4** shows the Similarity Index of phytoplankton at all sampling sites in the stream. Highest similarity index 0.926 was recorded in between RR-II (07-08) and RR-II (08-09). The lowest value of similarity index (0.793) was found in between RR-I (07-08) and RR-II (08-09)

#### **4.4.4. Seasonal Variations of Density and Diversity indices**

When data on monthly variations of phytoplankton density was pooled into seasonal values, the monsoon showed the lowest value and highest in winter months at all the sampling sites of the hill-stream Relli. But, seasonal variation of number of phytoplankton genera demonstrated highest value in winter months (at all the sites) and pre monsoon at (RR-II). Lowest value observed in monsoon at all the sites. Highest seasonal value of Shannon-Wiener Diversity Index and Margalef's Richness Index was found in pre-monsoon months (RR-II) and in winter months (RR-I & III) and lowest value in monsoon months at all the sites. On the contrary, highest seasonal value of Index of Phytoplankton Dominance was observed in monsoon months at all the sites, whereas, lowest value found in pre monsoon months at RR-II and in winter months at RR-I and RR-III. Interestingly, seasonal variations of evenness index of phytoplankton exhibited highest value in post-monsoon months at all sites. Lowest value found in monsoon months (RR-II) and in winter months at RR-I and RR-III. **Figure 4.4-5, 4.4-6 and 4.2-7** explains seasonal variations of density and diversity indices of phytoplankton in three sampling sites during the study period.

Test of significance for difference in means (Fisher's t) was performed to understand whether the observed seasonal differences of density and diversity indices of phytoplankton connote any real difference among groups. The null hypothesis for testing of differences between means is  $H_0: \mu_1 = \mu_2$ , where  $\mu_1$  is a mean of a variable in one season and  $\mu_2$  is a mean of same variable in other season. As  $H_a$  is two sided, a two tailed test for determining the rejection region at 1% level which comes to as under, using table of t-distribution for 34 degrees of freedom: R:  $t > 2.46$  and at 5% level it is: R:  $t > 1.70$ . The observed values of t for physico-chemical parameters in different seasons is presented in the **Table 4.4-5**, most of which fall in the rejection region and thus,  $H_0$  is rejected and concluded that seasonality affect density and diversity of phytoplankton of the stream water.

#### **4.4.5. Annual Variations of Density and Diversity indices**

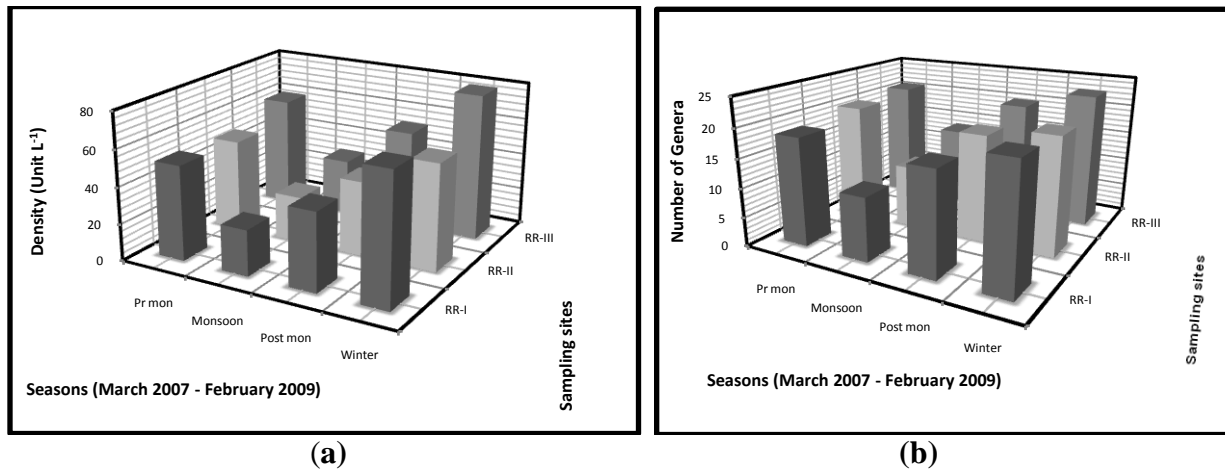
When data on monthly variations of density and diversity indices of phytoplankton were pooled into annual values, the average values of phytoplankton density, number of phytoplankton genera, Shannon-Wiener Diversity Index and Margalef's Richness Index were found to be slightly higher in the first year of study (March 2007-February 2008) than the second year (March 2008-February 2009). On the contrary, average value of phytoplankton evenness index was found to be slightly higher in the second year of study (March 2008-February 2009) than the first year (March 2007-February 2008). Interestingly, average value of Phytoplankton Dominance Index showed no annual variation. Values of Fisher t were not significant. **Table 4.4-6** showed the comparisons of annual mean values of density and diversity indices of phytoplankton in the hill-stream Relli during two years of study period.

#### **4.4.6. Altitudinal Variations of Density and Diversity Indices**

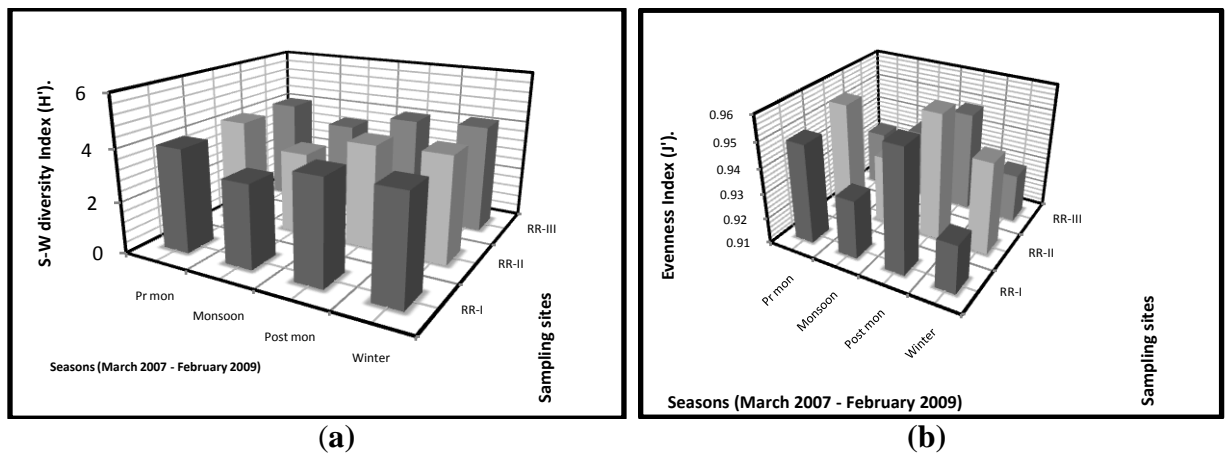
Along the elevational gradient that is in three sampling sites, RR-I (704m), RR-II (566m) and RR-III (340m), average values number of phytoplankton genera and Margalef's Richness Index exhibited increment from up to downwards. On the contrary, average values of Index of Phytoplankton Dominance demonstrated gradual decrease downwards. Average values of phytoplankton density and Shannon-Wiener Diversity Index of phytoplankton along the altitudinal gradient demonstrated a trend of increment from up to downwards except at the RR-II. Average values of phytoplankton evenness index along the altitudinal gradient of the stream demonstrated gradual decrease downwards except at the RR-II. Fisher's t were significant for density (II and III,  $|t|=2.29$ ,  $p < 0.05$ ), number of genera (I and III, II and III,  $|t|=2.04$ ,  $1.70$ ,  $p < 0.05$ ), evenness (II and III,  $|t|=2.63$ ,  $p < 0.01$ ) and richness (I and III,  $|t|=2.02$ ,  $p < 0.05$ ). **Table 4.4-6** showed the comparisons of altitudinal mean values of density and diversity indices of phytoplankton in the hill-stream Relli during two years of study period.

#### **4.4.7. Density and Diversity Indices of Phytoplankton and Water Quality**

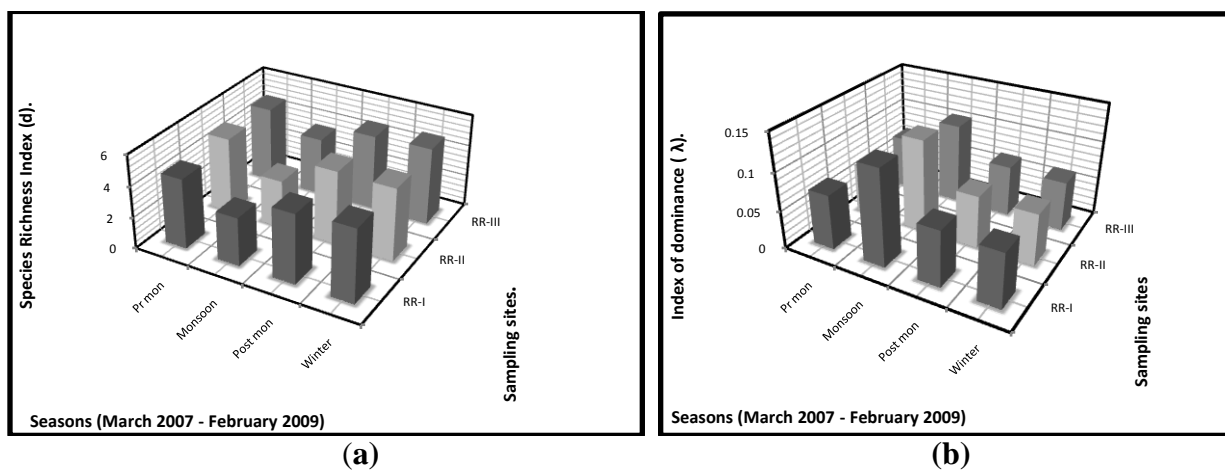
To examine individual relationship between Density and Diversity Indices of Phytoplankton and Physico-Chemical variables, a Pearson Correlation matrix was calculated. The numerical values of correlation coefficient are depicted in **Table 4.4-7** for all the variables. Most of the calculated values depict some strong correlations. Pair having very high positive correlation between them shows the dependency of one parameter on the other while pair having very negative correlation between them shows inverse relation between them.



**Figure 4.4-5** Seasonal variations of phytoplankton density (a) and number of genera (b) in the three sampling sites of the hill stream water during the study period.



**Figure 4.4-6** Seasonal variations of Shannon-Wiener diversity Index (a) and Evenness Index (b) of phytoplankton in the three sampling sites of the hill stream water during the study period.



**Figure 4.4-7** Seasonal variations of Margalef's Richness Index (a) and Index of Dominance (b) of phytoplankton in the three sampling sites of the hill stream water during the study period

**Table 4.4-4 Values of Similarity Index of Phytoplankton between different sampling sites in the hill stream during two years of study period.**

	2007-2008			2008-2009		
	RR-I	RR-II	RR-III	RR-I	RR-II	RR-III
RR-I (07-08)	1	0.863	0.837	0.902	<b>0.793</b>	0.858
RR-II(07-08)		1	0.858	0.808	<b>0.926</b>	0.843
RR-III(07-08)			1	0.893	0.862	0.853
RR-I(08-09)				1	0.815	0.843
RR-II(08-09)					1	0.882
RR-III(08-09)						1

**Table 4.4-5 Results of Test of Significance for Difference in Means (Fisher's t) of Seasonal Values of density and diversity indices of phytoplankton in the hill stream Relli During the Study Period (March 2007 to February 2009).**

	pm/mon	pm/psm	pm/win	mon/psm	mon/win	psm/win
1. Density (Unit L <sup>-1</sup> ).	9.031*	2.363**	4.008*	5.138*	11.924*	5.679*
2. Number of genera (S).	9.659*	1.949**	2.677*	7.672*	11.342*	4.259*
3. Species diversity index (H').	9.04*	0.98	0.595	8.272*	8.812*	1.377
4. Species evenness Index (J').	1.738**	1.79**	1.604	4.586*	0.048	3.977*
5. Species Richness Index (R).	8.626*	0.758	0.272	7.681*	8.973*	1.028
6. Species dominance Index (λ).	7.919*	0.216	0.368	7.796*	8.202*	0.596

pm-pre monsoon; mon-monsoon; psm-post monsoon; win-winter.\*1%level significant, \*\*5%level significant.

**Table 4.4-6 Mean Values (± standard deviation) of Density and Diversity Indices of Phytoplankton along the Altitudinal Gradient (n=24) of Relli and Comparisons of Mean (± standard deviation) Annual Values (n=36) During the two years of Study Period.**

Period of study	March 2007 – February 2009.			Annual variations	
	RR-I (704 m asl).	RR-II (566 m asl).	RR-III (340 m asl).	2007-08	2008-09
1. Density (Unit L <sup>-1</sup> ).	47.1±19.0	43.3±14.1	55.6±20.5	50.4±19.4	46.9±17.8
2. Number of Genera (S).	16.9±4.1	17.3±4.1	19.4±4.2	18.0±4.3	17.7±4.2
3. Shannon-Wiener diversity index (H').	3.778±0.4	3.686±0.4	3.966±0.36	3.879±0.38	3.862±0.4
4. Evenness Index (J').	0.942±0.019	0.949±0.017	0.936±0.014	0.939±0.018	0.946±0.016
5. Margalef's Richness Index (R).	4.15±0.72	4.33±0.80	4.57±0.69	4.37±0.77	4.33±0.73
6. Dominance Index (λ).	0.085±0.027	0.081±0.027	0.077±0.022	0.081±0.024	0.081±0.027

The regression analysis showed causal relationship between physico-chemical variables (Independent or explanatory variables) and variables of phytoplankton density and diversity indices (Dependant or regressand variables). Three Principal Components obtained for physico-chemical parameters in the hill stream were used as independent variables to understand the trend of control over phytoplankton density and diversity (**Table 4.4-8**). Causal relationship as obtained in the regression analysis has been summarized below.

#### 4.4.7.1. Density of Phytoplankton

$$\begin{aligned}
 \text{Dens}_i &= 48.639 + -9.869 \text{ PC1}_i + 12.643 \text{ PC2}_i + 3.187 \text{ PC3}_i \\
 \text{SE} &= (1.05) \quad (1.06) \quad (1.06) \quad (1.06) \\
 \text{t-value} &= 46.172^* \quad -9.303^* \quad 11.918^* \quad -3.005^* \\
 R^2 &= 0.777; \bar{R}^2 = 0.768; F_{3, 68} = 79.207^*
 \end{aligned}$$

The  $\bar{R}^2$  value of 0.777 indicates that about 77.7 per cent variation in the density of phytoplankton in the hill stream Relli is explained by the principal components. Since the F-statistic is significant at one per cent level of significance and therefore, the estimated regression model fits the data quite well. The principal component I (PC1) and III (PC3) has significant negative influence and principal component II (PC2) has significant positive impact on the phytoplankton density of the stream. Hence, in one hand density of phytoplankton will increase in the augmented values of dissolved oxygen, total alkalinity, total hardness, chloride ion, pH, nitrate nitrogen and specific conductance and the decreased values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen and nitrite nitrogen in the stream water. On the other hand decreased values of Total alkalinity, chloride and total hardness related to increased density of phytoplankton in the stream.

#### 4.4.4.2. Number of Phytoplankton Genera

$$\begin{aligned}
 \text{NOG}_i &= 17.847 + -1.845 \text{ PC1}_i + 3.159 \text{ PC2}_i + -0.284 \text{ PC3}_i \\
 \text{SE} &= (0.25) \quad (0.25) \quad (0.25) \quad (0.25) \\
 \text{t-value} &= 70.801^* \quad -7.270^* \quad 12.446^* \quad -1.120 \\
 R^2 &= 0.754; \bar{R}^2 = 0.744; F_{3, 68} = 69.670^*
 \end{aligned}$$

The  $\bar{R}^2$  value of 0.744 indicates that about 74.4 per cent variation in the number of phytoplankton genera in the stream is explained by the principal components. Since the F-statistic is significant at one per cent level of significance and therefore, the estimated regression model fits the data quite well. The principal component II (PC2) has significant positive impact on the number of phytoplankton genera. Hence, number of phytoplankton genera will increase if

the value of nitrate nitrogen increases and the values of water velocity and water temperature decrease. The principal component I (PC1) has significant negative influence on the number of phytoplankton genera. Hence, number of phytoplankton genera will increase in the augmented values of dissolved oxygen, total alkalinity, total hardness, chloride ion, pH, specific conductance and the decreased values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen and nitrite nitrogen in the stream water.

#### 4.4.4.3. Shannon-Wiener Diversity Index

$$SDI_i = 3.870 + -0.151 PC1_i + 0.276 PC2_i + -0.015 PC3_i$$

SE	= (0.027)	(0.027)	(0.027)	(0.027)
t-value	= 143.099*	-5.558*	10.149*	0.537

$$R^2 = 0.664; \bar{R}^2 = 0.649; F_{3, 68} = 44.730^*$$

The  $\bar{R}^2$  value of 0.649 indicates that about 64.9 per cent variation in the diversity index of phytoplankton in the stream is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component II (PC2) has significant positive impact on the diversity index of phytoplankton. Hence, diversity index of phytoplankton will increase if the value of nitrate nitrogen increases and the values of water velocity and water temperature decrease. The principal component I (PC1) has significant negative influence on the diversity index of phytoplankton. Hence, diversity index of phytoplankton will increase in the augmented values of dissolved oxygen, total alkalinity, total hardness, chloride ion, pH, specific conductance and the decreased values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen and nitrite nitrogen in the stream water.

#### 4.4.4.4. Evenness Index of phytoplankton

$$Even_i = 0.943 + -0.0005 PC1_i + 0.0004 PC2_i + 0.0058 PC3_i$$

SE	= (0.002)	(0.002)	(0.002)	(0.002)
t-value	= 485.191*	-0.266	0.231	2.960*

$$R^2 = 0.115; \bar{R}^2 = 0.076; F_{3, 68} = 2.962^*$$

The  $\bar{R}^2$  value of 0.076 indicates that about 7.6 per cent variation of the evenness index of phytoplankton in the stream is explained by the principal components. Since the F-statistic is significant at three per cent level of significance and therefore, the estimated regression model fits the data quite well. The principal component III has significant positive impact on the evenness index of phytoplankton. Hence, evenness index of phytoplankton will increase if the value of total alkalinity, total hardness and chloride increase in the stream water.

#### 4.4.4.5. Richness Index of Phytoplankton:

$$\begin{aligned} Rich_i &= 4.352 + -0.254 PC1_i + 0.517 PC2_i + 0.025 PC3_i \\ SE &= (0.057) \quad (0.057) \quad (0.057) \quad (0.057) \\ t\text{-value} &= 76.285^* \quad -4.420^* \quad 8.995^* \quad 0.432 \\ R^2 &= 0.597; \bar{R}^2 = 0.579; F_{3, 68} = 33.542^* \end{aligned}$$

The  $\bar{R}^2$  value of 0.579 indicates that about 57.9 % variation in the species richness index of phytoplankton in the stream is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component II (PC2) has significant positive impact on the species richness index of phytoplankton. Hence, species richness index of phytoplankton will increase if the value of nitrate nitrogen increases and the values of water velocity and water temperature decrease. The principal component I (PC1) has significant negative influence on the species richness index of phytoplankton. Hence, species richness index of phytoplankton will increase in the augmented values of dissolved oxygen, total alkalinity, total hardness, chloride ion, pH, specific conductance and the decreased values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen and nitrite nitrogen in the stream water.

#### 4.4.4.6. Dominance Index of Phytoplankton:

$$\begin{aligned} Domi_i &= 0.081 + 0.010 PC1_i + -0.017 PC2_i + -0.002 PC3_i \\ SE &= (0.002) \quad (0.002) \quad (0.002) \quad (0.002) \\ t\text{-value} &= 43.294^* \quad 5.332^* \quad -9.056^* \quad -1.026 \\ R^2 &= 0.621; \bar{R}^2 = 0.604; F_{3, 68} = 37.165^* \end{aligned}$$

The  $\bar{R}^2$  value of 0.604 indicates that about 60.4% variation in the species dominance index of phytoplankton in the stream is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component I (PC1) has significant positive influence on the species dominance index of phytoplankton. Hence, the dominance index of phytoplankton will increase in the augmented values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen, and nitrite nitrogen and in the decreased values of dissolved oxygen, total alkalinity, total hardness, chloride ion, pH, specific conductance in the stream water. The principal component II (PC2) has significant negative impact on the species dominance index of phytoplankton. Hence, dominance index of phytoplankton will increase if the value of nitrate nitrogen decreases and the values of water velocity and water temperature increase in the stream water

**Table 4.4-7 Pearson's Correlation Coefficients Matrix for Phytoplankton Density and Diversity Indices and Water Quality of the Relli**

	AT	WT	WV	PH	COND	DO	FCO	TA	CL	HARD	PO4	NO3	NO2	NH4
DENSP	-0.691**	-0.773**	-0.840**	0.535**	0.644**	0.727**	-0.721**	0.762**	0.773**	0.689**	-0.499**	0.000	-0.527**	-0.650**
NOGP	-0.556**	-0.667**	-0.848**	0.448**	0.658**	0.638**	-0.690**	0.726**	0.784**	0.728**	-0.407**	0.126	-0.411**	-0.501**
SDIP	-0.456**	-0.585**	-0.833**	0.362**	0.598**	0.547**	-0.659**	0.639**	0.710**	0.680**	-0.330**	0.230	-0.300*	-0.391**
EVENP	0.136	0.063	-0.154	-0.214	-0.030	-0.097	-0.089	-0.082	-0.108	0.031	0.093	0.363**	0.242*	0.203
RICHP	-0.406**	-0.532**	-0.776**	0.320**	0.585**	0.515**	-0.592**	0.607**	0.689**	0.660**	-0.307**	0.208	-0.276*	-0.345**
DOMIP	0.430**	0.548**	0.826**	-0.323**	-0.567**	-0.539**	0.654**	-0.619**	-0.655**	-0.648**	0.321**	-0.265*	0.266*	0.355*

AT= Air temperature; WT= Water temperature; WV=Water velocity; pH= Power of hydrogen ion concentration; COND= conductivity; DO= Dissolved oxygen; FC= Free carbon dioxide  
 TA= Total alkalinity; CL= Chloride; Hard= Total hardness; PO<sub>4</sub> = Phosphate-phosphorous; NO<sub>3</sub>= Nitrate- nitrogen; NO<sub>2</sub>= Nitrite-nitrogen; NH<sub>4</sub>=Ammonium-nitrogen; DENSP=  
 Phytoplankton density;

NOGP= Number of phytoplankton genera; SDIP= Diversity index of phytoplankton; EVENP= Evenness index of phytoplankton; RICHP= Richness index of phytoplankton;  
 DOMIP=Dominance index.

\*\* Correlation is significant at the 0.01 level (2-tailed); \* Correlation is significant at the 0.05 level (2-tailed).

**Table 4.4-8 Physico-chemical Water Quality Determinants of phytoplankton diversity: OLS Estimation.**

Independent Variables	Density		Number of genera		SDI		Evenness		Richness		Dominance	
	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value
Intercept	48.639	46.172*	17.847	70.801*	3.871	143.10*	0.943	485.19*	4.352	76.29*	0.081	43.29*
PCI: More physical & nutrient and less chemical	-0.532	-9.303*	-0.437	-7.270*	-0.391	-5.558*	-0.030	-0.266	-0.340	-4.420*	0.398	5.332*
PCII: More nutrients, less physical.	0.682	11.918*	0.748	12.446*	0.714	10.149*	0.026	0.231	0.693	8.995*	-0.676	-9.056*
PCIII: More chemical	-0.172	-3.005*	-0.067	-1.120	0.038	0.537	0.338	2.960*	0.033	0.432	-0.077	-0.027*
R square	0.778		0.755		0.664		0.116		0.597		0.621	
Adjusted R square	0.768*		0.744		0.649		0.077		0.579		0.604	
F <sub>3, 68</sub> -value (ANOVA)	79.207*		69.670*		44.780*		2.962		33.542*		37.165*	

\*=> Significant at 1% level of Significance; \*\*=> Significant at 2% level of Significance; \*\*\*=> Significant at 5% of Significance.

## ***4.5 Diversity of Zooplankton in the Teesta River***

---

### **4.5.1. Taxonomic Diversity and Relative Abundance**

In the present investigation, a total of 22 zooplankton genera were recorded in the Teesta river comprising, 7 genera of protozoa, 8 genera of rotifer, 3 genera of copepod and 4 genera of cladocera (**Table 4.5-1 and 4.5-2**). Rotifers were abundantly found group of zooplankton at all sites it ranges from 43.6% to 57.6% with an average 51.6% ( $\pm 4.3$ ). Occurrence of protozoa ranges from 14.2% to 25.8% with an average 17.5% ( $\pm 3.5$ ), Copepod ranges from 11.1% to 16.8% with an average 13.3% ( $\pm 2.0$ ) and cladocera ranges from 14.3% to 21.2% with an average 17.6% ( $\pm 2.2$ ). Thus, in all four sites of the Teesta river abundance of different groups of zooplankton followed the pattern of Rotifers > Cladocera > Protozoa > Copepoda. *Brachionus sp*, *Keratella sp*, *Lecane sp* (Rotifera) and *Bosmina sp* (Cladocera) are abundantly found zooplankton at all the sites (**Table 4.5-1 and Figure 4.5-1**).

### **4.5.2. Monthly Variations of Density and Diversity Indices**

In the **Table 4.5-3** variations of density and diversity indices of zooplankton are summarized in all four sampling sites of the river Teesta during the study period.

#### **4.5.2.1. Zooplankton Density**

Documented density of zooplankton in the river Teesta ranged from 05 Org. L<sup>-1</sup> to 34 Org. L<sup>-1</sup> with a mean value 17.5 Org. L<sup>-1</sup> ( $\pm 6.6$ ). Lowest density was recorded in July 2007 (TR-I), July 2008 (TR-I & II). Highest density recorded at RR-III during February 2008. Monthly variations of zooplankton density revealed a trend of gradual descend from the month of February and attained lowest value in July then ascended to touch peak in the month of February (2007-08) and January and February (2008-09). A small peak observed in the month of May in both the year of study (**Figure 4.5-2**).

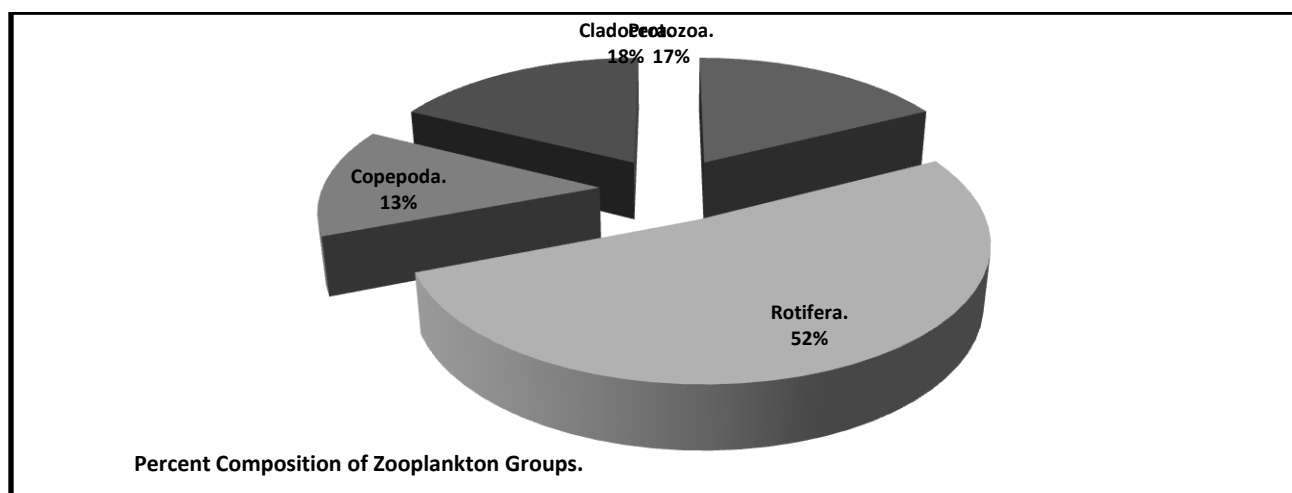
#### **4.5.2.2. Number of Zooplankton Genera**

Recorded number of zooplankton genera in the river ranged from 03 to 14 with a mean value 9.6 ( $\pm 2.5$ ). Lowest number of genera was recorded in July 2008 (TR-II). Highest number of genera recorded during January 2008 (TR-IV) and in February 2008 (TR-III). Monthly variations of number of zooplankton genera revealed a trend of gradual descend from the month of March and attained lowest value in July then ascended to touch peak in the month of February (2007-08) and January and February (2008-09). A small peak observed in the month of May (2007-08) and in April (2008-09) (**Figure 4.5-2**).

**Table 4.5-1 Taxonomic Diversity and Relative Abundance of Zooplankton in four sampling sites of the river Teesta during the study period.**

Taxon	2007-2008				2008-2009			
	TR-I	TR-II	TR-III	TR-IV	TR-I	TR-II	TR-III	TR-IV
<b>PROTOZOA</b>								
1. <i>Diffugia sp</i>	++	+	+	+	-	+	+	+
2. <i>Arcella sp</i>	+	+	+	+	+	+	+	+
3. <i>Centropyxis sp</i>	+	+	+	++	+	+	+	++
4. <i>Loxodes sp</i>	+	+	-	+	+	+	+	-
5. <i>Oxytricha sp</i>	+	-	+	-	-	-	-	+
6. <i>Colpoda sp</i>	+	+	+	+	++	+	++	+
7. <i>Paramecium sp</i>	+	+	-	+	-	-	+	+
<b>ROTIFERA</b>								
8. <i>Brachionus sp</i>	+++	+++	+++	+++	+++	+++	+++	+++
9. <i>Keratella sp</i>	++	+++	+++	+++	+++	+++	+++	+++
10. <i>Lecane sp</i>	++	++	++	++	+++	++	++	++
11. <i>Filina sp</i>	+	++	-	+	-	+	+	-
12. <i>Polyarthra sp</i>	+	++	++	+++	++	+++	++	++
13. <i>Asplanchna sp</i>	+	++	++	-	-	-	-	+
14. <i>Testudinella sp</i>	+	-	-	-	-	++	+	+
15. <i>Lepadella sp</i>	-	-	+	+	-	-	-	-
<b>COPEPODA</b>								
16. <i>Cyclops sp</i>	+	++	+	+	++	+	++	++
17. <i>Diatomus sp</i>	-	-	-	+	-	-	+	-
18. <i>Nauplius</i>	+	++	++	++	++	++	++	++
<b>CLADOCERA</b>								
19. <i>Daphnia sp</i>	+	+	+	+	-	+	+	+
20. <i>Moina sp</i>	++	+	+	+	++	+	+	++
21. <i>Bosmina sp</i>	++	++	++	++	+++	++	++	++
22. <i>Simocephalus sp</i>	-	+	+	-	-	+	-	+

\*Absent (-), < 5% (+), <10% (++) , above 10% (+++).



**Figure 4.5-1 Percent Composition of Zooplankton Groups in the river Teesta.**

**Table 4.5-2 Percent Composition of Zooplankton Groups in four sampling sites of river Teesta during the study period.**

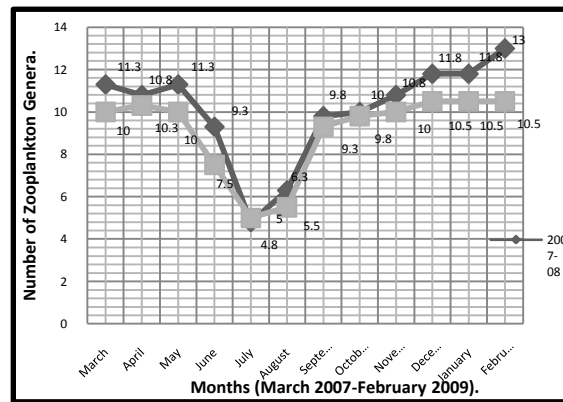
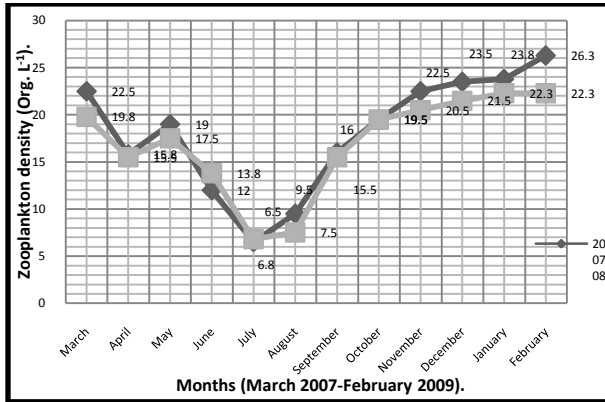
Taxon	2007-2008				2008-2009			
	TR-I	TR-II	TR-III	TR-IV	TR-I	TR-II	TR-III	TR-IV
<b>PROTOZOA.</b>	25.8%	14.2%	16.4%	17.3%	16.6%	16.4%	17.3%	16.1%
<b>ROTIFERA.</b>	43.6%	54.8%	57.6%	50.6%	50.7%	55.5%	50.8%	50.0%
<b>COPEPODA.</b>	11.8%	12.3%	11.7%	14.3%	15.6%	11.1%	16.7%	12.7%
<b>CLADOCERA.</b>	18.8%	18.7%	14.3%	17.8%	17.1%	17.5%	15.2%	21.2%

**Table 4.5-3 Summary of Zooplankton Density and Diversity Indices of (showing the Range and Mean  $\pm$  Standard Deviation) of the River Teesta (n=96) during the study period.**

Period of study	March 2007 – February 2009		
	Range	Mean	S.D. ( $\pm$ ).
<b>Diversity indices</b>			
<b>1. Density (Org. L<sup>-1</sup>).</b>	<b>05-34</b>	<b>17.5</b>	<b>6.6</b>
<b>2. Number of genera (S).</b>	<b>03-14</b>	<b>9.6</b>	<b>2.5</b>
<b>3. Species diversity index (H').</b>	<b>1.371-3.679</b>	<b>3.066</b>	<b>0.5</b>
<b>4. Species evenness Index (J').</b>	<b>0.865-0.983</b>	<b>0.960</b>	<b>0.02</b>
<b>5. Species Richness Index (R).</b>	<b>1.243-4.236</b>	<b>3.022</b>	<b>0.6</b>
<b>6. Species dominance Index (<math>\lambda</math>).</b>	<b>0.075-0.440</b>	<b>0.136</b>	<b>0.06</b>

**Table 4.5-4 Similarity Index Variations at Different Sampling Sites in Teesta river during the Study Period.**

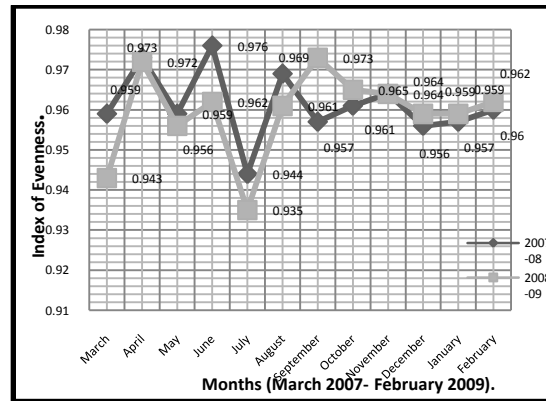
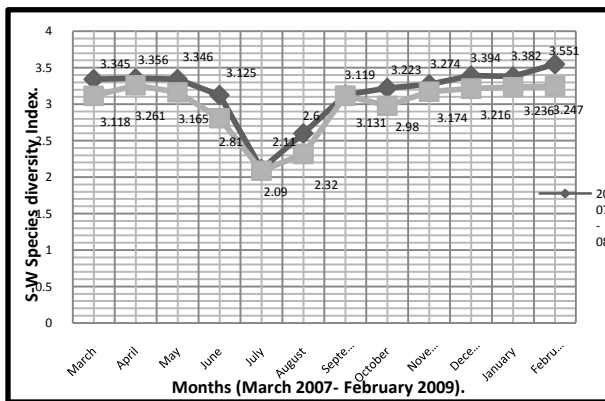
	2007-2008				2008-2009			
	TR-I	TR-II	TR-III	TR-IV	TR-I	TR-II	TR-III	TR-IV
TR-I (07-08)	1	0.919	0.834	0.865	0.774	0.889	0.919	0.919
TR-II(07-08)		1	0.857	0.889	0.800	0.917	0.889	0.889
TR-III (07-08)			1	0.800	0.759	0.824	0.743	0.914
TR-IV(07-08)				1	0.800	0.857	<b>0.945</b>	0.778
TR-I (08-09)					1	0.828	0.800	<b>0.734</b>
TR-II(08-09)						1	0.914	0.857
TR-III(08-09)							1	0.834
TR-IV(08-09)								1



(a)

(b)

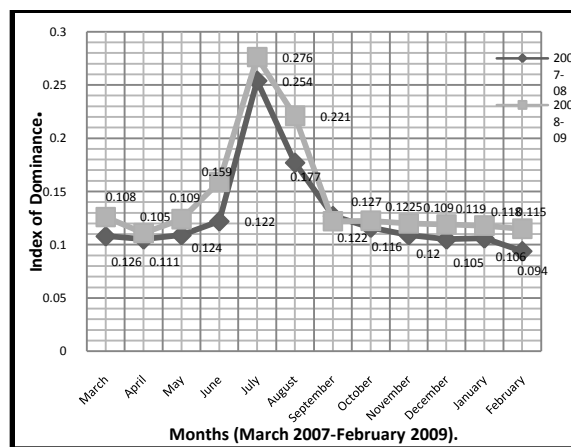
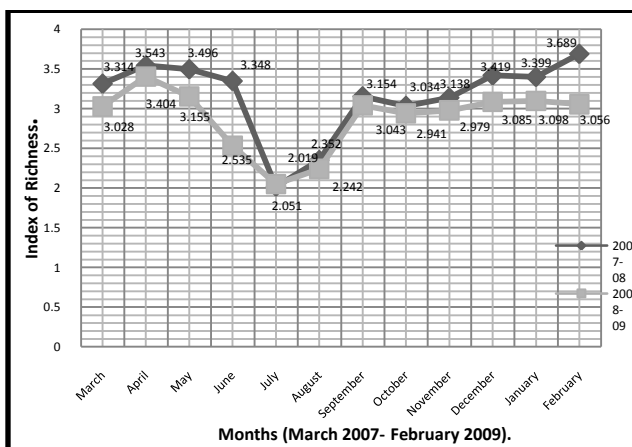
**Figure 4.5-2** Monthly variations of zooplankton density (a) and number of genera (b) in the river Teesta during the study period.



(a)

(b)

**Figure 4.5-3** Monthly variations of Shannon-Wiener Diversity Index (a) and Evenness Index (b) of zooplankton in the river Teesta during the study period.



(a)

(b)

**Figure 4.5-4** Monthly variations of Margalef's Richness Index (a) and Dominance Index (b) of zooplankton in the river Teesta during the study period.

#### **4.5.2.3. Shannon -Wiener Diversity Index**

Assessed values of Shannon-Wiener species diversity index (H') for zooplankton genera in the river ranged from 1.371 bits individual-1 to 3.679 bits individual-1 with an average of 3.066 bits individual-1 ( $\pm 0.5$ ). Lowest value of Shannon-Wiener species diversity index of zooplankton was recorded in July 2008 (TR-II). Highest number of genera recorded at TR-III during February 2008. Monthly variations of values of diversity index revealed a trend of gradual descend from the month of March and attained lowest value in July then ascended to touch peak in the month of February in both the year of study. A small peak observed in the month of May in both years (**Figure 4.5-3**).

#### **4.5.2.4. Zooplankton Evenness Index**

Projected values of evenness index for zooplankton in the river Teesta ranged from 0.865 to 0.983 with an average 0.960 ( $\pm 0.02$ ). Highest value for the index was found in June 2007 (TR-I) and lowest value was found in July 2008 (TR-II). Monthly variations of evenness index revealed an erratic trend. In 2007-08 gradual descend from highest value in the month of June and attained lowest value in July then rose again. Similarly, in 2008-09 lowest point found in the month of July and highest point in September. Though, other small peaks and sinks were also observed in both the years (**Figure 4.5-3**).

#### **4.5.2.5. Zooplankton Richness Index**

Estimated values of richness index for zooplankton in the river ranged from 1.243 to 4.236 with an average 3.022 ( $\pm 0.575$ ). Lowest value was found in July 2008 (TR-II) and highest value found in May 2007 (RR-I). Monthly variations of values of richness index revealed a trend of gradual descend from the month of April and attained lowest value in July then ascended to touch peak in the month of January (2008-09) and February (2007-08). Though other small peaks and sinks observed in both the years (**Figure 4.5-4**).

#### **4.5.2.6. Index of Dominance**

Evaluated index of dominance of zooplankton in the river ranged from 0.075 to 0.440 with an average 0.136 ( $\pm 0.06$ ). Lowest value of index of dominance was found in March 2008 (TR-III) and highest value of index of dominance was found in July 2008 (TR-II). Monthly variations of values of the dominance index revealed a trend of gradual ascend from the month of April and attained highest value in July then descended to touch lowest value in the month of April (2008-09) and February (2007-08) (**Figure 4.5-4**).

### 4.5.3. Similarity Index (Sorensen's Coefficient of Community)

**Table 4.5-4** shows the similarity index of zooplankton at all sampling sites in the Teesta river. Highest similarity index (0.945) was recorded in between TR-IV (07-08) and TR-III (08-09). The lowest value of similarity index (0.734) was found in between TR-I (08-09) and TR-IV (08-09).

### 4.5.4. Seasonal Variations of Density and Diversity indices

When data on monthly variations of zooplankton density was pooled into seasonal values, highest value observed in winter months (TR-II, III and IV) and in post monsoon (TR-I). Lowest value found in monsoon months at all the sites of the river Teesta. Highest seasonal value of Shannon-Wiener diversity index and Margalef's richness index observed in pre-monsoon months (TR-I & II) and in winter months at TR-III & IV but, lowest seasonal value found in monsoon months at all the sampling sites. On the contrary, highest seasonal value of index of dominance observed in monsoon months at all the sites. Lowest value found in pre monsoon months at TR-I and II and in winter months at TR-III & IV. Seasonal variation of number of genera showed highest value in winter months at TR-II, III and IV and in pre monsoon at TR-I and lowest in monsoon months at all the sampling sites. Interestingly, seasonal variations of evenness index of zooplankton showed highest value in monsoon months at TR-I & TR-III and in post monsoon months at TR-II & IV. Lowest value found in post monsoon months (TR-I), monsoon months (TR-II & IV), pre monsoon (TR-III), and in winter months at TR-I. **Figure 4.5-5, 4.5-6 and 4.5-7** explains seasonal variations of density and diversity indices of zooplankton in three sampling sites during the study period.

Test of significance for difference in means (Fisher's t) was performed to understand whether the observed seasonal differences of density and diversity indices of zooplankton connote any real difference among groups. The null hypothesis for testing of differences between means is  $H_0: \mu_1 = \mu_2$ , where  $\mu_1$  is a mean of a variable in one season and  $\mu_2$  is a mean of same variable in other season. As  $H_a$  is two sided, a two tailed test for determining the rejection region at 1% level which comes to as under, using table of t-distribution for 34 degrees of freedom: Critical Region:  $|t| \geq 2.46$  and at 5% level it is:  $|t| \geq 1.70$ . The observed values of t for zooplankton density and diversity in different seasons is presented in the **Table 4.5-5**, most of which fall in the rejection region and thus,  $H_0$  is rejected and concluded that seasonality affect density and diversity of zooplankton of the river water.

### 4.5.5. Annual Variations of Density and Diversity indices

When data on monthly variations of density and diversity indices of zooplankton were pooled into annual values, the average values of zooplankton density, number of zooplankton genera, Shannon-Wiener Diversity Index and Margalef's richness index were found to be

slightly higher in the first year of study (March 2007-February 2008) than those observed in second year (March 2008-February 2009). On the contrary, average value of zooplankton evenness index and dominance index was found to be slightly higher in the second year of study (March 2008-February 2009) than those found in first year (March 2007-February 2008). Fisher's t were significant for number of genera ( $|t|=1.92$ ,  $p < 0.05$ ), diversity index ( $|t|=1.90$ ,  $p < 0.05$ ) and richness index ( $|t|=2.37$ ,  $p < 0.05$ ). **Table 4.5-6** showed the comparisons of annual mean values of density and diversity indices of zooplankton in the river Teesta during two years of study period.

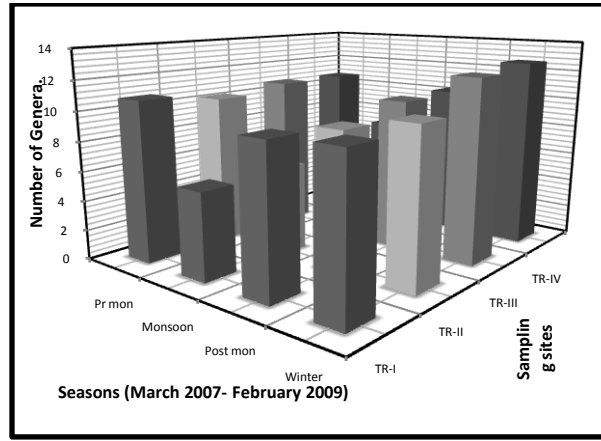
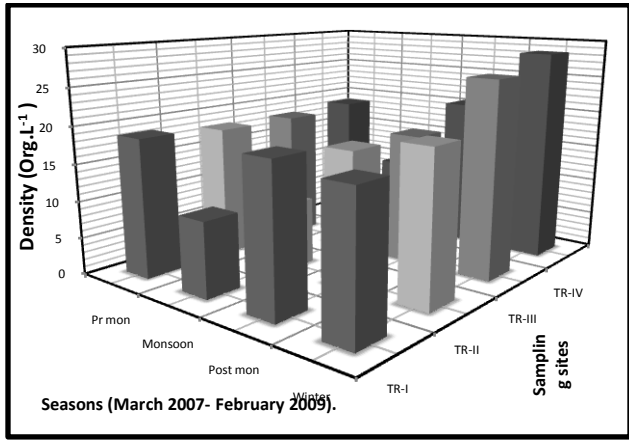
#### **4.5.6. Altitudinal Variations of Density and Diversity indices**

Along the elevational gradient that is in four sampling sites such as TR-I (224m), TR-II (216m), TR-III (168m) and TR-IV (147m) of the river Teesta average values of zooplankton density, number of zooplankton genera, Shannon-Wiener Diversity Index and Margalef's Richness Index exhibited a trend of gradual increment from upstream to downstream except in site TR-II. On the contrary, average values of index of dominance along the altitudinal gradient of the river demonstrated a trend of decrease from upstream to the downstream except in site TR-II. Interestingly, average values of evenness index along the altitudinal gradient of the river demonstrated a peculiar trend ( $0.954$  in TR-II  $<$   $0.957$  in TR-IV  $<$   $0.964$  in TR-III  $<$   $0.966$  in TR-I). Values of fisher's t were significant for number of genera (II and IV,  $|t|=1.88$ ,  $p < 0.05$ ), diversity index (II and IV,  $|t|=1.76$ ,  $p < 0.05$ ), evenness index (I and II, I and IV, II and III, III and IV,  $|t|=2.26, 2.39, 1.91, 1.84$ ,  $p < 0.05$ ) and richness index (II and III, III and IV,  $|t|=1.86, 1.93$ ,  $p < 0.05$ ). **Table 4.5-6** showed the comparisons of altitudinal mean values of density and diversity indices of zooplankton in the river Teesta during two years of study period.

#### **4.5.7. Density and Diversity Indices of Zooplankton and Water Quality**

To examine individual relationship between Density and Diversity Indices of zooplankton and Physico-Chemical variables for water quality, a Pearson Correlation matrix was calculated. The numerical values of correlation coefficient are depicted in **Table 4.5-8** for all the variables. Most of the calculated values depict some strong correlations. Pair having very high positive correlation between them shows the dependency of one parameter on the other while pair having very negative correlation between them shows inverse relation between them.

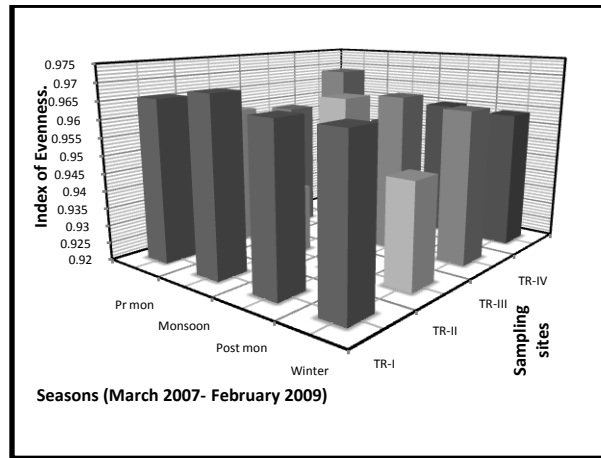
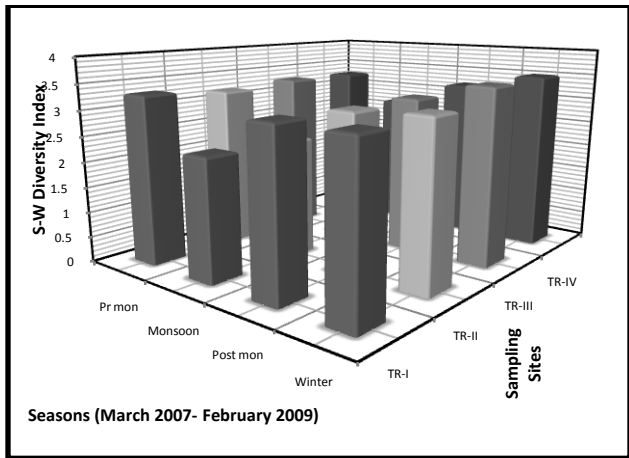
The regression analysis showed causal relationship between physico-chemical variables (Independent or explanatory variables) and variables of zooplankton density and diversity indices (Dependant or regressand variables). Two Principal Components obtained for physico-chemical parameters in the river were used as independent variables to understand the trend of control over zooplankton density and diversity (**Table 4.5-7**). Causal relationship as obtained in the regression analysis has been summarized.



(a)

(b)

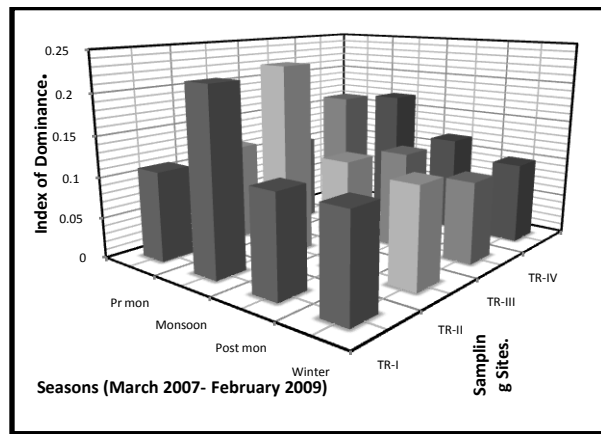
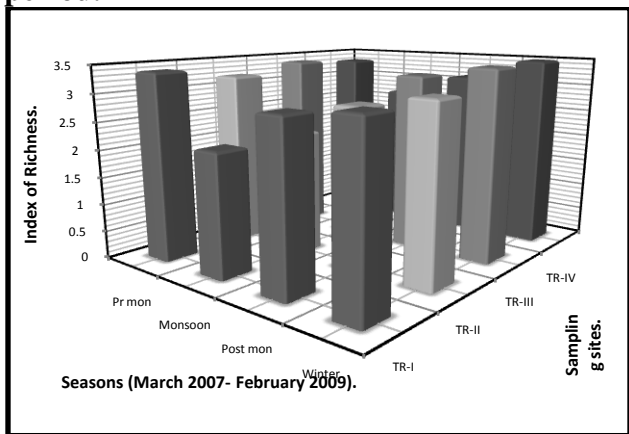
**Figure 4.5-5** Seasonal variations of zooplankton density (a) and number of genera (b) in the four sampling sites of the river Teesta during the study period.



(a)

(b)

**Figure 4.5-6** Seasonal variations of Shannon-Wiener Diversity Index (a) and Evenness Index (b) of zooplankton in the four sampling sites of the river Teesta during the study period.



(a)

(b)

**Figure 4.5-7** Seasonal variations of Margalef's Richness Index (a) and Dominance Index (b) of zooplankton in the four sampling sites of the river Teesta during the study period.

**Table 4.5-5 Results of Test of Significance for Difference in Means (Fisher's t) of Seasonal Values of Density and Diversity Indices of Zooplankton in the river Teesta During the Study Period (March 2007 to February 2009).**

	pm/mon	pm/psm	pm/win	mon/psm	mon/win	psm/win
1. Density (Unit L <sup>-1</sup> ).	7.865*	0.5	3.634*	8.096*	10.173*	3.126*
2. Number of genera (S).	8.855*	1.762**	1.621	6.998*	8.671*	2.866*
3. Species diversity index (H').	7.00*	1.753**	1.096	5.591*	7.217*	2.457*
4. Species evenness Index (J').	0.421	0.916	0.355	1.106	0.219	1.777**
5. Species Richness Index (R).	6.091*	2.588*	0.263	4.309*	5.543*	2.056**
6. Species dominance Index (λ).	5.438*	1.118	0.727	5.146*	5.674*	1.866**

pm-pre monsoon; mon-monsoon; psm-post monsoon; win-winter.\*1%level significant, \*\*5%level significant.

**Table 4.3-6 Mean Values (± standard deviation) of Density and Diversity Indices of Zooplankton along the Altitudinal Gradient (n=24) of Teesta river and Comparisons of Mean (± standard deviation) Annual Values (n=48) During the two years of Study Period.**

Period of study	March 2007 – February 2009.				Annual variations	
Sampling sites	TR-I	TR-II	TR-III	TR-IV	2007-08	2008-09
1. Density (Unit L <sup>-1</sup> ).	16.5±5.9	16.3±5.5	17.6±7.5	19.5±7.3	18.1±6.7	16.9±6.5
2. Number of Genera (S).	9.1±2.7	8.9±2.4	9.9±2.6	10.3±2.3	10.0±2.5*	9.1±2.4*
3. Shannon-Wiener diversity index (H').	2.998±0.5	2.962±0.5	3.120±0.4	3.184±0.4	3.153±0.4*	2.979±0.5*
4. Evenness Index (J').	0.966±0.01	0.954±0.02	0.964±0.01	0.957±0.01	0.961±0.01	0.959±0.02
5. Margalef's Richness Index (R).	2.906±0.7	2.862±0.6	3.159±0.5	3.160±0.5	3.159±0.6*	2.885±0.6*
6. Dominance Index (λ).	0.143±0.06	0.150±0.07	0.126±0.04	0.125±0.04	0.127±0.05	0.144±0.06

\*Fisher's t significant at 0.05 level

#### 4.5.7.1. Density of Zooplankton

$$\begin{aligned} \text{Dens}_i &= 17.458 + -2.714 \text{ PC1}_i + 4.603 \text{ PC2}_i \\ \text{SE} &= (0.40) \quad (0.41) \quad (0.41) \\ \text{t-value} &= 43.248^* \quad -6.689^* \quad 11.344^* \\ R^2 &= 0.651; \bar{R}^2 = 0.643; F_{2, 93} = 86.707^* \end{aligned}$$

The  $\bar{R}^2$  value of 0.643 indicates that about 64.3% variation in the density of zooplankton in the river Teesta is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component I (PC1) has significant negative influence and principal component II (PC2) has significant positive impact on the zooplankton density of the river. Hence, in one hand density of zooplankton will increase in the augmented values of dissolved oxygen and specific conductance and the decreased values of water temperature, free carbon dioxide, Phosphate phosphorous, ammonium nitrogen, nitrite nitrogen and nitrate nitrogen in the stream water. On the other hand increased values of pH, Total alkalinity, chloride and total hardness escalate the density of zooplankton in the stream when water velocity is less.

#### 4.5.7.2. Number of Genera of Zooplankton

$$\begin{aligned} \text{NOG}_i &= 9.552 + -1.091 \text{ PC1}_i + 1.493 \text{ PC2}_i \\ \text{SE} &= (0.17) \quad (0.18) \quad (0.18) \\ \text{t-value} &= 54.828^* \quad -6.227^* \quad 8.525^* \\ R^2 &= 0.545; \bar{R}^2 = 0.535; F_{2, 93} = 55.727^* \end{aligned}$$

The  $\bar{R}^2$  value of 0.535 indicates that about 53.5% variation in the number of zooplankton genera in the stream is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component II (PC2) has significant positive impact on the number of zooplankton genera. Hence, number of zooplankton genera will increase if the value of pH, total alkalinity, chloride and hardness of the river water increases and the value of water velocity decreases. The principal component I (PC1) has significant negative influence on the number of zooplankton genera. Hence, number of zooplankton genera will increase in the augmented values of dissolved oxygen and specific conductance and the decreased values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen, nitrite nitrogen and nitrate nitrogen in the stream water.

#### 4.5.7.3. Shannon-Weiner Diversity Index

$$\begin{aligned}SDI_i &= 3.066 + -0.184 PC1_i + 0.250 PC2_i \\SE &= (0.034) \quad (0.034) \quad (0.034) \\t\text{-value} &= 90.030^* \quad -5.362^* \quad 7.292^* \\R^2 &= 0.468; \bar{R}^2 = 0.457; F_{2,93} = 40.966^*\end{aligned}$$

The  $\bar{R}^2$  value of 0.457 indicates that about 45.7% variation in the diversity index of zooplankton in the stream is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component II (PC2) has significant positive impact on the zooplankton diversity index. Hence, the index will increase if the value of pH, total alkalinity, chloride and hardness of the river water increases when water velocity is less. The principal component I (PC1) has significant negative influence on the zooplankton diversity index. Hence, index will soar in the augmented values of dissolved oxygen and specific conductance and the decreased values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen, nitrite nitrogen and nitrate nitrogen in the stream water.

#### 4.5.7.4. Evenness Index of Zooplankton

$$\begin{aligned}Even_i &= 0.960 + 0.0002 PC1_i + 0.0014 PC2_i \\SE &= (0.002) \quad (0.002) \quad (0.002) \\t\text{-value} &= 564.474^* \quad 0.111 \quad 0.792 \\R^2 &= 0.007; \bar{R}^2 = -0.015; F_{2,93} = 0.319\end{aligned}$$

The  $\bar{R}^2$  value of -0.015 indicates that variation of the evenness index of zooplankton in the stream cannot be explained by the principal components. Since the F-statistic is not significant therefore, the estimated regression model does not fit the data quite well.

#### 4.5.7.5. Margalef's Richness Index

$$\begin{aligned}Rich_i &= 3.022 + -0.216 PC1_i + 0.237 PC2_i \\SE &= (0.049) \quad (0.050) \quad (0.050) \\t\text{-value} &= 61.941^* \quad -4.357^* \quad 4.778^* \\R^2 &= 0.310; \bar{R}^2 = 0.295; F_{2,93} = 20.907^*\end{aligned}$$

The  $\bar{R}^2$  value of 0.295 indicates that about 29.5% variation in the species richness index of zooplankton in the stream is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component II (PC2) has significant positive impact on the zooplankton diversity index. Hence, the index will increase if the value of pH, total alkalinity, chloride and hardness of the river water increases when water velocity is less. The principal component I

(PC1) has significant negative influence on the zooplankton diversity index. Hence, index will soar in the augmented values of dissolved oxygen and specific conductance and the decreased values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen, nitrite nitrogen and nitrate nitrogen in the stream water.

#### 4.5.7.6. Index of Dominance

$$Domi_i = 0.136 + 0.019 PC1_i + -0.03 PC2_i$$

$$SE = (0.004) \quad (0.004) \quad (0.004)$$

$$t\text{-value} = 30.972^* \quad 4.289^* \quad -6.803^*$$

$$R^2 = 0.410; \bar{R}^2 = 0.398; F_{2, 93} = 32.340^*$$

The  $\bar{R}^2$  value of 0.398 indicates that about 39.8% variation in the species dominance index of zooplankton in the stream is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component I (PC1) has significant positive influence on the zooplankton evenness index. Hence, the index will soar in the augmented values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen, nitrite nitrogen and nitrate nitrogen in the stream water when there is less dissolved oxygen and specific conductance. The principal component II (PC2) has significant negative impact on the zooplankton evenness index. Hence, the index will increase with the decreased values of pH, total alkalinity, chloride and hardness and increased value of water velocity in the river water.

**Table 4.5-7 Physico-Chemical Determinants of Zooplankton Diversity in Teesta River: OLS Estimation.**

Independent Variables	Density		Number of genera		SDI		Evenness		Richness		Dominance	
	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value
Intercept	17.458	43.248*	9.552	54.828*	3.066	90.030*	0.960	564.474*	3.022	61.941*	0.136	30.972*
PCI: More physical & nutrient and less chemical	-2.714	-6.689*	-1.091	-6.227*	-0.184	-5.362*	0.0002	0.111	-0.216	-4.357*	0.019	4.289*
PCII: More Chemical and less physical.	4.603	11.344*	1.493	8.525*	0.250	7.292*	0.0014	0.792	0.237	4.778*	-0.03	-6.803*
R square	0.651		0.545		0.468		0.007		0.310		0.410	
Adjusted R square	0.643		0.535		0.457		- 0.015		0.295		0.398	
F <sub>2, 93</sub> -value (ANOVA)	86.707*		55.727*		40.966*		0.319		20.907*		32.340*	

\*=> **Significant at 1% level of Significance.**

**Table 4.5-8 Pearson's Correlation Coefficients Matrix for Zooplankton Density and Diversity Indices and Water Quality of the river Teesta.**

	AT	WT	WV	PH	COND	DO	FCO	TA	CL	HARD	PO4	NO3	NO2	NH4
DENSZ	<b>-0.457**</b>	<b>-0.66**</b>	<b>-0.794**</b>	<b>0.599**</b>	<b>0.628**</b>	<b>0.642**</b>	<b>-0.679**</b>	<b>0.807**</b>	<b>0.277**</b>	<b>0.674**</b>	<b>-0.469**</b>	<b>0.14</b>	<b>-0.341**</b>	<b>-0.457**</b>
NOGZ	<b>-0.395**</b>	<b>-0.641**</b>	<b>-0.792**</b>	<b>0.471**</b>	<b>0.61**</b>	<b>0.627**</b>	<b>-0.657**</b>	<b>0.725**</b>	<b>0.191</b>	<b>0.573**</b>	<b>-0.435**</b>	<b>0.149</b>	<b>-0.442**</b>	<b>-0.442**</b>
SDIZ	<b>-0.371**</b>	<b>-0.623**</b>	<b>-0.755**</b>	<b>0.411**</b>	<b>0.553**</b>	<b>0.575**</b>	<b>-0.623**</b>	<b>0.669**</b>	<b>0.15</b>	<b>0.513**</b>	<b>-0.4**</b>	<b>0.181</b>	<b>-0.446**</b>	<b>-0.389**</b>
EVENZ	<b>-0.08</b>	<b>-0.103</b>	<b>-0.065</b>	<b>0.03</b>	<b>0.068</b>	<b>0.014</b>	<b>-0.083</b>	<b>-0.009</b>	<b>-0.041</b>	<b>0.029</b>	<b>0.041</b>	<b>0.206*</b>	<b>-0.141</b>	<b>0.111</b>
RICHZ	<b>-0.277**</b>	<b>-0.508**</b>	<b>-0.635**</b>	<b>0.297**</b>	<b>0.475**</b>	<b>0.5**</b>	<b>-0.511**</b>	<b>0.533**</b>	<b>0.09</b>	<b>0.397**</b>	<b>-0.329**</b>	<b>0.132</b>	<b>-0.449**</b>	<b>-0.355**</b>
DOMIZ	<b>0.331**</b>	<b>0.572**</b>	<b>0.718**</b>	<b>-0.388**</b>	<b>-0.525**</b>	<b>-0.529**</b>	<b>0.591**</b>	<b>-0.62**</b>	<b>-0.126</b>	<b>-0.502**</b>	<b>0.331**</b>	<b>-0.231*</b>	<b>0.412**</b>	<b>0.308**</b>

AT= Air temperature; WT= Water temperature; WV=Water velocity; pH= Power of hydrogen ion concentration; COND= conductivity; DO= Dissolved oxygen; FC= Free carbon dioxide;TA= Total alkalinity; CL= Chloride; Hard= Total hardness; PO<sub>4</sub> = Phosphate-phosphorous; NO<sub>3</sub>= Nitrate- nitrogen; NO<sub>2</sub>= Nitrite-nitrogen; NH<sub>4</sub>=Ammonium-nitrogen; DENSZ= Zooplankton density;

NOGZ= Number of zooplankton genera; SDIZ= Diversity index of zooplankton; EVENZ= Evenness index of zooplankton; RICHZ= Richness index of zooplankton; DOMIZ=Dominance index.

**\*\* Correlation is significant at the 0.01 level (2-tailed); \* Correlation is significant at the 0.05 level (2- tailed).**

## ***4.6 Diversity of Zooplankton in the Hill Stream Relli***

---

### **4.6.1. Taxonomic diversity and Relative abundance**

In the present study a total of 18 zooplankton genera were recorded in the hill-stream Relli, comprising 8 genera of protozoa, 5 genera of rotifer, 3 genera of copepod and two genera of cladocera (**Table 4.6-1**).

Rotifers were abundantly found group of zooplankton at all sites it ranges from 49.3% to 58.9% with an average 55.9% ( $\pm 3.2$ ). Occurrence of protozoa ranges from 14.1% to 21.62% with an average 18.5% ( $\pm 2.8$ ), Copepod ranges from 10.8% to 18.1% with an average 15.9% ( $\pm 2.7$ ) and cladocera ranges from 8.3% to 12.1% with an average 10.6% ( $\pm 1.4$ ). Thus, at all sites of Relli abundance of Rotifers > Protozoa > Copepods > Cladocera. *Brachionus sp*, *Keratella sp*, *Lecane sp* (Rotifera) and *Bosmina sp* (Cladocera) are abundantly found zooplankton at all sites (**Table 4.6-2 and Figure 4.6-1**).

### **4.6.2. Monthly Variations of Density and Diversity Indices**

In the **Table 4.6-3** variations of density and diversity indices of zooplankton are summarized in all three sampling sites of the hill stream Relli during the study period.

#### **4.6.2.1. Zooplankton density**

Documented densities of zooplankton in the hill-stream were ranged from 03 Org. L<sup>-1</sup> to 14 Org. L<sup>-1</sup> with a mean value of 7.1 Org. L<sup>-1</sup> ( $\pm 2.7$ ). Lowest density was recorded in June 2007 (RR-I) July 2007 (RR-I & II), July 2008 (RR-I & II), August 2007 (RR-II), and August 2008 (RR-II). Highest density recorded at RR-III during December 2007 and January 2009. Monthly variations (**Figure 4.6-2**) of zooplankton density revealed a trend of gradual descend from the month of March and attained lowest value in July then again ascended to touch peak in the month of December (2007-08) and January (2008-09).

#### **4.6.2.2. Number of Zooplankton Genera**

Recorded number of zooplankton genera ranged from 02 to 09 with a mean value 5.2 ( $\pm 1.8$ ). Lowest number of genera was recorded in June 2007 (RR-I), July 2007 (RR-I & II), August 2007 (RR-II) and August 2008 (RR-I & II). Highest number of genera recorded at RR-III during December 2007. Monthly variations (**Figure 4.6-2**) of number of zooplankton genera revealed a trend of gradual descend from the month of March and attained lowest value in July (2007-08) and August (2008-09) then again ascended to touch peak in the month of December (2007-08) and January (2008-09).

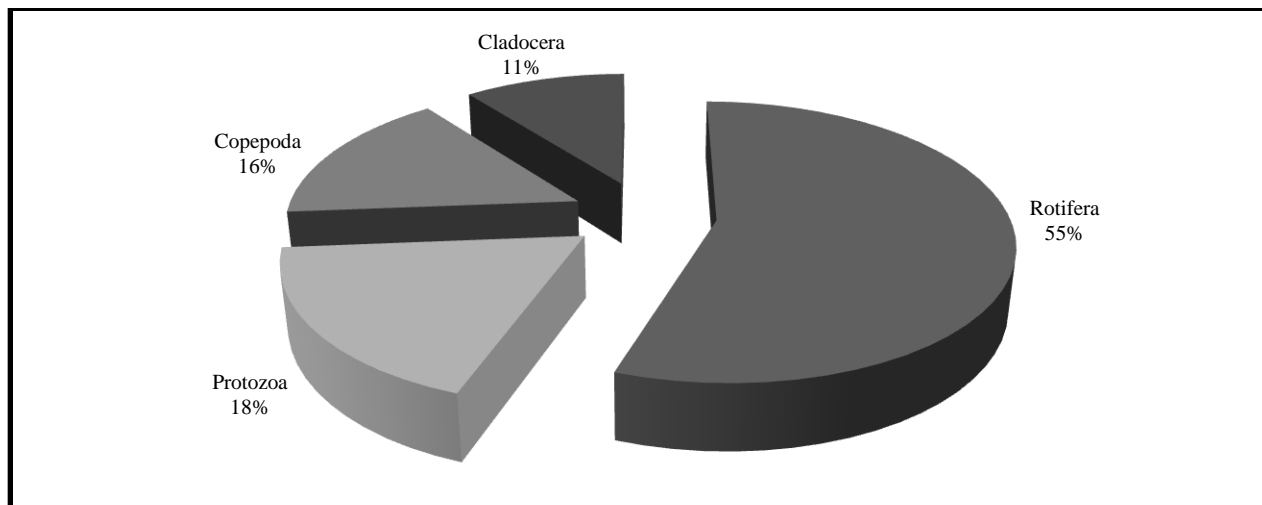
**Table 4.6-1 Taxonomic Diversity and Relative Abundance of Zooplankton in three sampling sites of the hill stream Relli during the study period.**

Taxon	2007-2008			2008-2009		
	RR-I	RR-II	RR-III	RR-I	RR-II	RR-III
<b>PROTOZOA</b>						
1. <i>Diffugia sp</i>	++	++	+	+	+	+
2. <i>Arcella sp</i>	+	-	+	+	-	+
3. <i>Centropyxis sp</i>	++	++	+	+	+	++
4. <i>Loxodes sp</i>	-	+	-	+	-	+
5. <i>Euplotes sp</i>	-	-	-	-	+	-
6. <i>Colpoda sp</i>	++	++	+	+	+	+
7. <i>Chilodinella sp</i>	-	+	-	+	-	+
8. <i>Paramoecium sp</i>	-	-	+	-	+	-
<b>ROTIFERA</b>						
9. <i>Brachionus sp</i>	+++	+++	+++	+++	+++	+++
10. <i>Keratella sp</i>	+++	+++	+++	+++	+++	+++
11. <i>Lecane sp</i>	+++	++	+++	+++	+++	+++
12. <i>Filina sp</i>	-	++	++	-	-	+++
13. <i>Polyarthra sp</i>	++	-	-	-	++	-
<b>COPEPODA</b>						
14. <i>Cyclops sp</i>	++	++	++	+	++	++
15. <i>Diaptomus sp</i>	-	+	+	+	-	++
16. <i>Nauplius</i>	++	++	++	++	++	++
<b>CLADOCERA</b>						
17. <i>Moina sp</i>	+	-	+	-	++	-
18. <i>Bosmina sp</i>	++	+++	++	+++	+++	++

\*Absent (-), < 5% (+), <10% (++) , above 10% (+++).

**Table 4.6-2 Percent Composition of Zooplankton Groups in three sampling sites of the hill-stream Relli during the study period.**

Taxon	2007-2008			2008-2009		
	RR-I	RR-II	RR-III	RR-I	RR-II	RR-III
<b>PROTOZOA.</b>	<b>21.62%</b>	<b>20.7%</b>	<b>17.1%</b>	<b>19.7%</b>	<b>14.1%</b>	<b>17.7%</b>
<b>ROTIFERA.</b>	<b>55.4%</b>	<b>49.3%</b>	<b>55.2%</b>	<b>54.3%</b>	<b>58.9%</b>	<b>56.2%</b>
<b>COPEPODA.</b>	<b>12.1%</b>	<b>11.6%</b>	<b>10.1%</b>	<b>11.1%</b>	<b>16.6%</b>	<b>8.3%</b>
<b>CLADOCERA.</b>	<b>10.8%</b>	<b>18.1%</b>	<b>17.1%</b>	<b>14.8%</b>	<b>10.2%</b>	<b>17.7%</b>



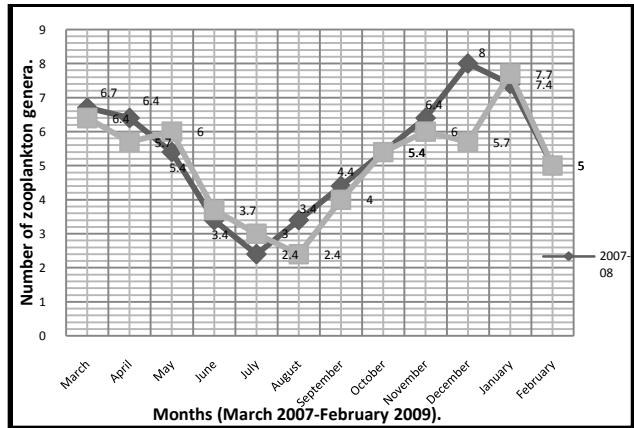
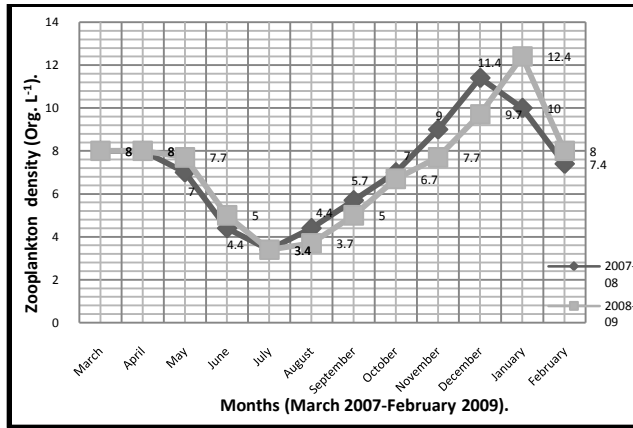
**Figure 4.6-1** Percent Composition of Zooplankton Groups in the hill-stream Relli.

**Table 4.6-3** Summary of Zooplankton Density and Diversity Indices of (showing the Range and Mean  $\pm$  Standard Deviation) of the hill stream Relli (n=72) during the study period.

Period of study	March 2007 – February 2009		
	Range	Mean	S.D. ( $\pm$ ).
<b>Diversity indices</b>			
<b>1. Density (Org. L<sup>-1</sup>).</b>	<b>03-14</b>	<b>7.1</b>	<b>2.6</b>
<b>2. Number of genera (S).</b>	<b>02-09</b>	<b>5.2</b>	<b>1.8</b>
<b>3. Species diversity index (H').</b>	<b>0.918-3.039</b>	<b>2.184</b>	<b>0.6</b>
<b>4. Species evenness Index (J').</b>	<b>0.896-0.998</b>	<b>0.955</b>	<b>0.02</b>
<b>5. Species Richness Index (R).</b>	<b>0.315-3.186</b>	<b>1.962</b>	<b>0.7</b>
<b>6. Species dominance Index (<math>\lambda</math>).</b>	<b>0.133-0.556</b>	<b>0.255</b>	<b>0.11</b>

**Table 4.6-4** Similarity Index Variations at Different Sampling Sites in the hill-stream Relli during the Study Period.

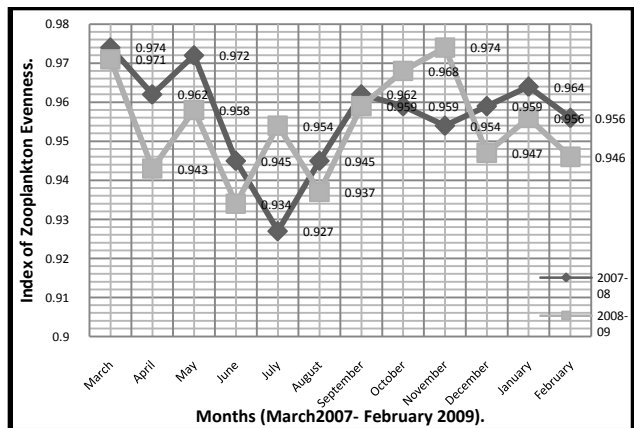
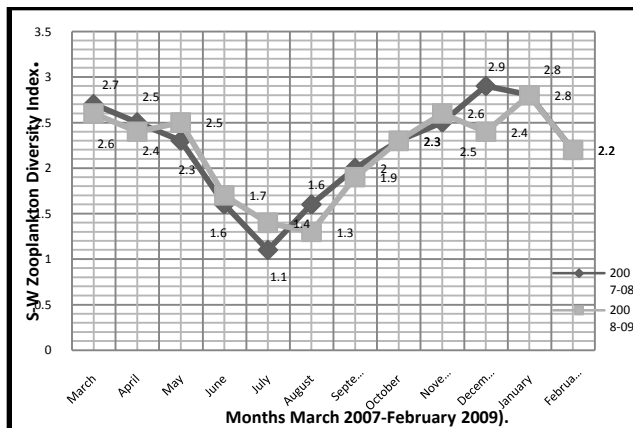
	2007-2008			2008-2009		
	RR-I	RR-II	RR-III	RR-I	RR-II	RR-III
RR-I (07-08)	1	0.720	0.846	0.800	0.880	0.769
RR-II(07-08)		1	0.815	0.923	0.692	<b>0.963</b>
RR-III(07-08)			1	0.815	0.815	0.857
RR-I(08-09)				1	0.692	0.963
RR-II(08-09)					1	<b>0.667</b>
RR-III(08-09)						1



(a)

(b)

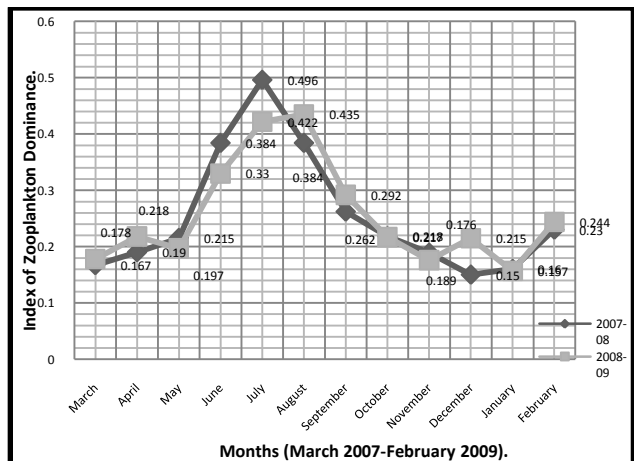
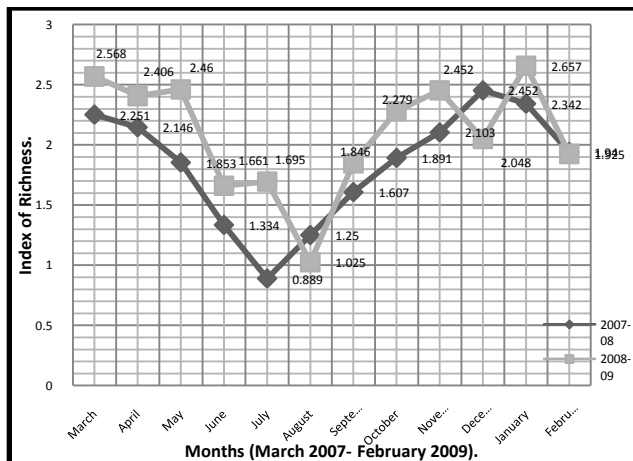
**Figure 4.6-2** Monthly variations of zooplankton density (a) and number of genera (b) in the hill stream Relli during the study period.



(a)

(b)

**Figure 4.6-3** Monthly variations of Shannon-Wiener Diversity Index (a) and Evenness Index (b) of zooplankton in the hill stream Relli during the study period.



(a)

(b)

**Figure 4.6-4** Monthly variations of Margalef's Richness Index (a) and Dominance Index (b) of zooplankton in the hill stream Relli during the study period.

### **4.6.2.3. Shannon -Weiner diversity index**

Estimated values of Shannon-Wiener species diversity index ( $H'$ ) for zooplankton genera ranged from 0.918 bits individual<sup>-1</sup> to 3.039 bits individual<sup>-1</sup> with an average 2.184 bits individual<sup>-1</sup>( $\pm 0.559$ ). Lowest value of Shannon-Wiener species diversity index ( $H'$ ) of zooplankton was recorded in June 2007 (RR-I), July 2007(RR-I & II), August 2007 (RR-II), July 2008 (RR-I) and August 2008 (RR- II). Highest number of genera recorded at RR-III during December 2007. Monthly variations (**Figure 4.6-3**) of number of zooplankton genera revealed a trend of gradual descend from the month of March and attained lowest value in July (2007-08) and August (2008-09) then again ascended to touch peak in the month of December (2007-08) and January (2008-09).

### **4.6.2.4. Zooplankton Evenness Index**

Evaluated values of evenness index ( $J'$ ) for zooplankton ranged from 0.896 to 0.998 with an average 0.955 ( $\pm 0.021$ ). Lowest evenness index was found in June 2008 (RR-III) and highest species evenness index was found in May 2007 (RR-I) and July 2008 (RR-II). Monthly variations (**Figure 4.6-3**) of evenness index revealed an erratic trend. In 2007-08 gradual descend from highest value in the month of March and attained lowest value in July then rose again. Similarly, in 2008-09 lowest point found in the month of June and highest point in November. Though, other small peaks and sinks were also observed in both the years.

### **4.6.2.5. Margalef's Richness Index**

Estimated values of richness index ( $R$ ) for zooplankton ranged from 0.32 to 3.19 with an average 1.962 ( $\pm 0.7$ ). Lowest richness index was found in July 2007 (RR-I) and highest species richness index was found in April 2007 (RR-II). Monthly variations (**Figure 4.6-4**) of species richness index for zooplankton revealed a trend of gradual descend from the month of March and attained lowest value in July (2007-08) and August (2008-09) then again ascended to touch peak in the month of December (2007-08) and January (2008-09). Though, other small peaks and sinks were also observed in 2008-09.

### **4.6.2.6. Index of dominance**

Projected values of index of dominance for zooplankton in the stream ranged from 0.133 to 0.556 with an average 0.255 ( $\pm 0.11$ ). Lowest value of index of dominance was found in December 2007 (RR-III) and highest value of index of dominance was found in June 2007 (RR-I), July 2007 (RR-I & RR-II), July 2008 (RR-I) August'07 (RR-II) and August 2008 (RR-II). Monthly variations (**Figure 4.6-4**) of dominance index for zooplankton

revealed a trend of gradual ascend from the month of March and attained highest value in the month of July (2007-08) and August (2008-09). But, then descended to attain lowest value in the month of December (2007-08) and January (2008-09).

#### **4.6.3. Similarity Index (Sorensen's Coefficient of Community)**

**Table 4.6-4** shows the similarity index of zooplankton at all sampling sites in the Relli. Highest similarity index 0.963 was recorded in between RR-II (07-08) and RR-III (08-09). The lowest value of similarity index (0.667) was found in between RR-II (08-09) and RR-III (08-09).

#### **4.6.4. Seasonal Variations of Density and Diversity indices**

When data on monthly variations of zooplankton density was pooled into seasonal values, the monsoon showed the lowest value and highest in winter months at all the sampling sites of the hill-stream Relli. Highest seasonal value of number of zooplankton genera observed in winter months at all the sites and in pre monsoon at RR-I but, lowest value found in monsoon at all the sites. Seasonal variations of richness index of zooplankton showed the highest value in pre-monsoon months (RR-I & II) and winter months at RR-III. Lowest value found in monsoon months at all the sites. On the contrary, seasonal variations of index of dominance exhibited the highest value monsoon months at all the sites. Lowest value found in pre monsoon months at RR-I & II and in winter months at RR-III. Highest seasonal value of Shannon-Wiener diversity index exhibited highest value in pre-monsoon months (RR-I) and in winter months (RR-II & III) and lowest value in monsoon months at all the sites. Interestingly, seasonal variations of evenness index of zooplankton showed the highest value in pre monsoon months at RR-I & RR-II and in post monsoon months at RR-III. Lowest value found in monsoon months at all the sites. **Figure 4.6-5, 4.6-6 and 4.6-7** explains seasonal variations of density and diversity indices of zooplankton in three sampling sites during the study period.

Test of significance for difference in means (Fisher's t) was performed to understand whether the observed seasonal differences of density and diversity indices of zooplankton connote any real difference among groups. The null hypothesis for testing of differences between means is  $H_0: \mu_1 = \mu_2$ , where  $\mu_1$  is a mean of a variable in one season and  $\mu_2$  is a mean of same variable in other season. As  $H_a$  is two sided, a two tailed test for determining the rejection region at 1% level which comes to as under, using table of t-distribution for 34 degrees of freedom: Critical Region:  $|t| \geq 2.46$  and at 5% level it is: Critical Region:  $|t| \geq 1.70$ . The observed values of t for zooplankton density and diversity indices in different seasons is

presented in the **Table 4.6-5**, most of which fall in the rejection region and thus,  $H_0$  is rejected and concluded that seasonality affect density and diversity of zooplankton of the stream water.

#### **4.6.5. Annual Variations of Density and Diversity indices**

When data on monthly variations of density and diversity indices of zooplankton were pooled into annual values, the average values of zooplankton density, number of zooplankton genera, Shannon-Wiener Diversity Index and evenness index were found to be slightly higher in the first year of study (March 2007-February 2008) than the second year (March 2008-February 2009). On the contrary, average value of zooplankton richness index and dominance index was found to be slightly higher in the second year of study (March 2008-February 2009) than the first year (March 2007-February 2008). Fisher's t was only significant for evenness index ( $|t|=1.83$ ,  $p < 0.05$ ). **Table 4.6-6** showed the comparisons of annual mean values of density and diversity indices of zooplankton in the hill-stream Relli during two years of study period.

#### **4.6.6. Altitudinal Variations of Density and Diversity indices**

Along the elevational gradient that is in three sampling sites, RR-I (704m), RR-II (566m) and RR-III (340m), average values number of zooplankton genera, Shannon-Wiener Diversity Index and Margalef's Richness Index exhibited gradual increment from up to downwards. Average values of density along the altitudinal gradient demonstrated a peculiar pattern ( $6.5 \text{ Org. L}^{-1}$  in RR-I =  $6.5 \text{ Org. L}^{-1}$  in RR-II <  $8.4 \text{ Org. L}^{-1}$  in RR-III). On the contrary, average values of evenness index along the altitudinal gradient of the stream exhibited a reverse pattern ( $0.957$  in RR-I =  $0.957$  in RR-II >  $0.952$  in RR-III). Interestingly, average values of index of dominance along the altitudinal gradient of the stream exhibited gradual decrease from upstream to downstream. Average values of zooplankton evenness index along the altitudinal gradient of the stream demonstrated gradual decrease downwards except at the RR-II. Values of Fisher's t were significant for density (I and III, II and IV,  $|t|=2.48$ ,  $2.47$ ,  $p < 0.01$ ), number of genera (I and III, II and IV,  $|t|=1.95$ ,  $1.73$ ,  $p < 0.05$ ), diversity index (I and III,  $|t|=1.81$ ,  $p < 0.05$ ), richness index (I and II, II and III,  $|t|=2.82$ ,  $4.55$ ,  $p < 0.01$ ) and dominance index (I and III,  $|t|=1.70$ ,  $p < 0.05$ ). **Table 4.6-6** showed the comparisons of altitudinal mean values of density and diversity indices of zooplankton in the hill-stream Relli during two years of study period.

#### 4.6.7. Density and Diversity Indices of Zooplankton and Water Quality

To examine individual relationship between Density and Diversity Indices of zooplankton and Physico-Chemical variables, a Pearson Correlation matrix was calculated. The numerical values of correlation coefficient are depicted in **Table 4.6-8** for all the variables. Most of the calculated values depict some strong correlations. Pair having very high positive correlation between them shows the dependency of one parameter on the other while pair having very negative correlation between them shows inverse relation between them.

**Table 4.6-5 Results of Test of Significance for Difference in Means (Fisher's t) of Seasonal Values of density and diversity indices of zooplankton in the hill stream Relli During the Study Period (March 2007 to February 2009).**

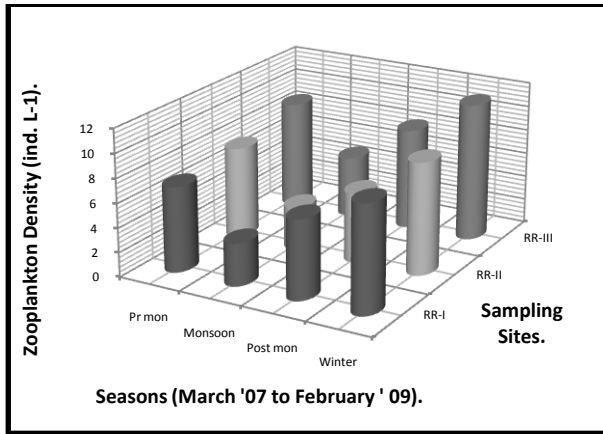
	pm/mon	pm/psm	pm/win	mon/psm	mon/win	psm/win
1. Density (Unit L <sup>-1</sup> ).	8.498*	1.659	3.05*	5.507*	9.49*	4.176*
2. Number of genera (S).	9.337*	2.359**	0.904	6.201*	7.935*	2.692*
3. Species diversity index (H').	8.667*	2.17**	0.486	6.32*	8.142*	2.273**
4. Species evenness Index (J').	2.978*	0.162	1.421	3.253*	2.032**	1.595
5. Species Richness Index (R).	4.824*	1.307	0.252	3.697*	4.287*	0.962
6. Species dominance Index (λ).	7.247*	2.071**	0.109	5.815*	7.036*	1.915**

pm-pre monsoon; mon-monsoon; psm-post monsoon; win-winter. \*1%level significant, \*\*5%level significant.

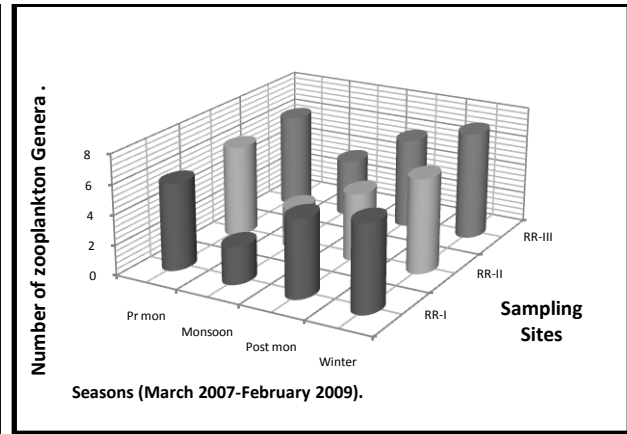
**Table 4.6-6 Mean Values (± standard deviation) of Density and Diversity Indices of zooplankton along the Altitudinal Gradient (n=24) of Relli and Comparisons of Mean (± standard deviation) Annual Values (n=36) During the two years of Study Period.**

Period of study	March 2007 – February 2009.			Annual variations	
Sampling sites	RR-I (704 m asl).	RR-II (566 m asl).	RR-III (340 m asl).	2007-08	2008-09
1. Density (Unit L <sup>-1</sup> ).	6.5±2.4	6.5±2.4	8.4±2.8	7.08±2.8	7.1±2.7
2. Number of Genera (S).	4.8±1.7	4.9±1.8	5.8±1.6	5.3±1.9	5.1±1.6
3. Shannon-Wiener diversity index (H').	2.081±0.59	2.113±0.61	2.357±0.43	2.205±0.60	2.163±0.52
4. Evenness Index (J').	0.957±0.02	0.957±0.02	0.952±0.02	0.957±0.02*	0.954±0.02*
5. Margalef's Richness Index (R).	1.50±0.7	2.07±0.7	2.32±0.5	1.84±0.8	2.09±0.5
6. Dominance Index (λ).	0.274±0.13	0.270±0.13	0.222±0.07	0.254±0.124	0.257±0.10

\*5%level significant.

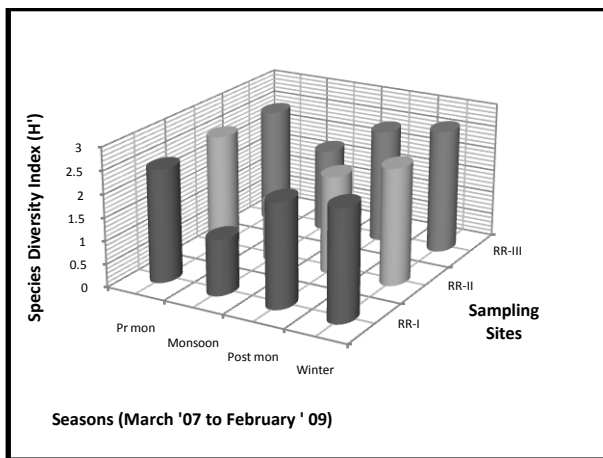


(a)

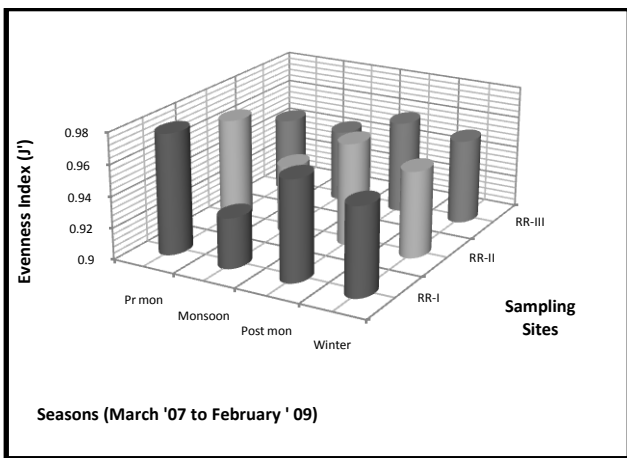


(b)

**Figure 4.6-5** Seasonal variations of zooplankton density (a) and number of genera (b) in the three sampling sites of the hill stream water during the study period.

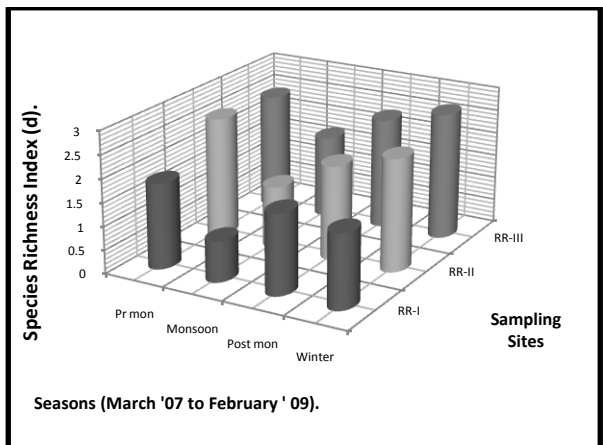


(a)

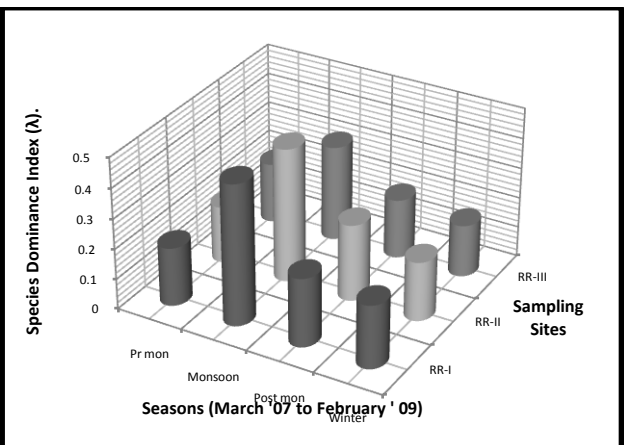


(b)

**Figure 4.6-6** Seasonal variations of Shannon-Wiener diversity Index (a) and Evenness Index (b) of zooplankton in the three sampling sites of the hill stream water during the study period.



(a)



(b)

**Figure 4.6-7** Seasonal variations of Margalef's Richness Index (a) and Index of Dominance (b) of zooplankton in the three sampling sites of the hill stream water during the study period.

The regression analysis showed causal relationship between physico-chemical variables (Independent or explanatory variables) and variables of zooplankton density and diversity indices (Dependant or regressand variables). Three Principal Components obtained for physico-chemical parameters in the hill stream were used as independent variables to understand the trend of control over zooplankton density and diversity (**Table 4.6-7**). Causal relationship as obtained in the regression analysis has been summarized below.

#### 4.6.7.1. Density of zooplankton

$$\begin{aligned}
 \text{Dens}_i &= 7.097 + -1.181 \text{ PC1}_i + 1.942 \text{ PC2}_i + -0.317 \text{ PC3}_i \\
 \text{SE} &= (0.17) \quad (0.17) \quad (0.17) \quad (0.17) \\
 \text{t-value} &= 42.214^* \quad -6.973^* \quad 11.472^* \quad -1.874 \\
 R^2 &= 0.730; \bar{R}^2 = 0.718; F_{3,68} = 61.246^*
 \end{aligned}$$

The  $\bar{R}^2$  value of 0.718 indicates that about 71.8% variation in the density of zooplankton in the hill stream Relli is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component I (PC1) has significant negative influence on the zooplankton density. Hence, density of zooplankton will increase in the augmented values of dissolved oxygen, total alkalinity, total hardness, chloride ion, pH, specific conductance and the decreased values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen and nitrite nitrogen in the stream water. The principal component II (PC2) has significant positive impact on the density of zooplankton. Hence, zooplankton density will increase if the value of nitrate nitrogen increases and the values of water velocity and water temperature decrease. The principal component III (PC3) has significant negative (6% level) influence on the density of zooplankton. Hence, zooplankton density will increase in the decreased values of Total alkalinity, chloride and total hardness related to increased density of zooplankton in the stream.

#### 4.6.7.2. Number of zooplankton genera

$$\begin{aligned}
 \text{NOG}_i &= 5.181 + -0.795 \text{ PC1}_i + 1.133 \text{ PC2}_i + -0.190 \text{ PC3}_i \\
 \text{SE} &= (0.13) \quad (0.13) \quad (0.13) \quad (0.13) \\
 \text{t-value} &= 40.516^* \quad -6.176^* \quad 8.799^* \quad -1.473 \\
 R^2 &= 0.634; \bar{R}^2 = 0.618; F_{3,68} = 39.245^*
 \end{aligned}$$

The  $\bar{R}^2$  value of 0.618 indicates that about 61.8% variation in the number of zooplankton genera in the stream is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component II (PC2) has significant positive impact on the number of zooplankton genera.

Hence, number of zooplankton genera will increase if the value of nitrate nitrogen increases and the values of water velocity and water temperature decrease. The principal component I (PC1) has significant negative influence on the number of zooplankton genera. Hence, number of zooplankton genera will increase in the augmented values of dissolved oxygen, total alkalinity, total hardness, chloride ion, pH, specific conductance and the decreased values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen and nitrite nitrogen in the stream water.

#### 4.6.7.3. Shannon-Weiner Diversity Index

$$SDI_i = 2.184 + -0.257 PC1_i + 0.372 PC2_i + -0.030 PC3_i$$

SE	= (0.039)	(0.040)	(0.040)	(0.040)
t-value	= 55.331*	-6.450*	9.351*	-0.746

$$R^2 = 0.656; \bar{R}^2 = 0.641; F_{3, 68} = 43.222^*$$

The  $\bar{R}^2$  value of 0.641 indicates that about 64.1% variation in the diversity index of zooplankton in the stream is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component II (PC2) has significant positive impact on the diversity index of zooplankton. Hence, diversity index of zooplankton will increase if the value of nitrate nitrogen increases and the values of water velocity and water temperature decrease. The principal component I (PC1) has significant negative influence on the diversity index of zooplankton. Hence, diversity index of zooplankton will increase in the augmented values of dissolved oxygen, total alkalinity, total hardness, chloride ion, pH, specific conductance and the decreased values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen and nitrite nitrogen in the stream water.

#### 4.6.7.4. Evenness Index of zooplankton

$$Even_i = 0.955 + -0.005 PC1_i + 0.004 PC2_i + 0.002 PC3_i$$

SE	= (0.002)	(0.002)	(0.002)	(0.002)
t-value	= 399.773*	-1.592	1.568	0.789

$$R^2 = 0.088; \bar{R}^2 = 0.048; F_{3, 68} = 2.196$$

The  $\bar{R}^2$  value of 0.048 indicates that about 4.8% variation of the evenness index of zooplankton in the stream is explained by the principal components. Since the F-statistic is significant at 10% level of significance and therefore, the estimated regression model fits the data. The principal component I (PC1) has significant (6% level) negative impact on the evenness index of zooplankton. Hence, evenness index of zooplankton will increase in the augmented values of

dissolved oxygen, total alkalinity, total hardness, chloride ion, pH, specific conductance and the decreased values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen and nitrite nitrogen in the stream water.

#### 4.6.7.5. Margalef's Richness Index

$$\begin{array}{l}
 Rich_i = 1.962 + -0.071 PC1_i + 0.449 PC2_i + -0.088 PC3_i \\
 SE = (0.063) \quad (0.064) \quad (0.064) \quad (0.064) \\
 t\text{-value} = 31.025^* \quad -1.110 \quad 7.047^* \quad -1.377 \\
 R^2 = 0.437; \bar{R}^2 = 0.412; F_{3, 68} = 17.597^*
 \end{array}$$

The  $\bar{R}^2$  value of 0.412 indicates that about 41.2% variation in the species richness index of zooplankton in the stream is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component II (PC2) has significant positive impact on the species richness index of zooplankton. Hence, richness will increase if the value of nitrate nitrogen increases and the values of water velocity and water temperature decrease.

#### 4.6.7.6. Zooplankton Dominance Index

$$\begin{array}{l}
 Domi_i = 0.255 + 0.049 PC1_i + -0.074 PC2_i + 0.001 PC3_i \\
 SE = (0.009) \quad (0.009) \quad (0.009) \quad (0.009) \\
 t\text{-value} = 30.022^* \quad 5.756^* \quad -8.649^* \quad -0.143 \\
 R^2 = 0.614; \bar{R}^2 = 0.596; F_{3, 68} = 35.955^*
 \end{array}$$

The  $\bar{R}^2$  value of 0.596 indicates that about 59.6% variation in the species dominance index of zooplankton in the stream is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component I (PC1) has significant positive influence on the species dominance index. Hence, the dominance index for zooplankton will increase in the augmented values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen, and nitrite nitrogen and in the decreased values of dissolved oxygen, total alkalinity, total hardness, chloride ion, pH, specific conductance in the stream water. The principal component II (PC2) has significant negative impact on the species dominance index. Hence, dominance index for zooplankton will increase if the value of nitrate nitrogen decreases and the values of water velocity and water temperature increase in the stream water.

**Table 4.6-7 Physico-Chemical Determinants of Zooplankton Diversity: OLS Estimation.**

Independent Variables	Density		Number of genera		SDI		Evenness		Richness		Dominance	
	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value
<b>Intercept</b>	<b>7.097</b>	<b>42.214*</b>	<b>5.181</b>	<b>40.516*</b>	<b>2.184</b>	<b>55.331*</b>	<b>0.955</b>	<b>399.773*</b>	<b>1.962</b>	<b>31.025*</b>	<b>0.255</b>	<b>30.022*</b>
<b>PCI: More physical &amp; nutrient and less chemical</b>	<b>-1.181</b>	<b>-6.973*</b>	<b>-0.795</b>	<b>-6.176*</b>	<b>-0.257</b>	<b>-6.454*</b>	<b>-0.005</b>	<b>-1.892**</b>	<b>-0.071</b>	<b>-1.110</b>	<b>0.049</b>	<b>5.756*</b>
<b>PCII: More nutrients, less physical.</b>	<b>1.942</b>	<b>11.472*</b>	<b>1.133</b>	<b>8.799*</b>	<b>0.372</b>	<b>9.351*</b>	<b>0.004</b>	<b>1.568</b>	<b>0.449</b>	<b>7.047*</b>	<b>-0.074</b>	<b>-8.649*</b>
<b>PCIII: More chemicals</b>	<b>-0.317</b>	<b>-1.874**</b>	<b>-0.190</b>	<b>-1.473</b>	<b>-0.030</b>	<b>-0.746</b>	<b>0.002</b>	<b>0.739*</b>	<b>0.088</b>	<b>1.377</b>	<b>-0.001</b>	<b>-0.143</b>
<b>R square</b>	<b>0.730</b>		<b>0.634</b>		<b>0.656</b>		<b>0.088</b>		<b>0.437</b>		<b>0.614</b>	
<b>Adjusted R square</b>	<b>0.718*</b>		<b>0.618</b>		<b>0.641</b>		<b>0.048</b>		<b>0.412</b>		<b>0.596</b>	
<b>F<sub>3, 68</sub> -value (ANOVA)</b>	<b>61.246*</b>		<b>39.245*</b>		<b>43.222*</b>		<b>2.196***</b>		<b>17.597*</b>		<b>35.955*</b>	

\*=> Significant at 1% level of Significance; \*\*=> Significant at 6% level of Significance; \*\*\*=> Significant at 10% level of Significance.

**Table 4.6-8 Pearson's Correlation Coefficients Matrix for Zooplankton Density and Diversity Indices and Water Quality of the the hill-stream Relli**

	AT	WT	WV	PH	COND	DO	FCO	TA	CL	HARD	PO4	NO3	NO2	NH4
DENSZ	-0.625**	-0.726**	-0.772**	0.498**	0.601**	0.621**	-0.666**	0.747**	0.759**	0.719**	-0.406**	0.060	-0.420**	-0.565**
NOGZ	-0.560**	-0.666**	-0.749**	0.473**	0.644**	0.590**	-0.663**	0.679**	0.690**	0.654**	-0.423**	0.098	-0.428**	-0.522**
SDIZ	-0.542**	-0.645**	-0.789**	0.435**	0.647**	0.608**	-0.675**	0.691**	0.691**	0.663**	-0.404**	0.158	-0.391**	-0.495**
EVENZ	-0.203	0.198	-0.287*	0.032	0.229	0.242*	-0.262*	0.230	0.185	0.172	-0.144	0.154	0.095	-0.099
RICHZ	-0.272*	-0.364**	-0.603**	0.369**	0.480**	0.269*	-0.401**	0.555**	0.569**	0.544**	-0.080	0.042	-0.295*	-0.354**
DOMIZ	0.495**	0.596**	0.778**	-0.383**	-0.621**	-0.592**	0.642**	-0.673**	-0.661**	-0.637**	0.363**	-0.190	0.335*	0.453**

AT= Air temperature; WT= Water temperature; WV=Water velocity; pH= Power of hydrogen ion concentration; COND= conductivity; DO= Dissolved oxygen; FC= Free carbon dioxide;TA= Total alkalinity; CL= Chloride; Hard= Total hardness; PO<sub>4</sub> = Phosphate-phosphorous; NO<sub>3</sub>= Nitrate- nitrogen; NO<sub>2</sub>= Nitrite-nitrogen; NH<sub>4</sub>=Ammonium-nitrogen; DENSZ= Zooplankton density;

NOGZ= Number of zooplankton genera; SDIZ= Diversity index of zooplankton; EVENZ= Evenness index of zooplankton; RICHZ= Richness index of zooplankton; DOMIZ=Dominance index.

\*\* Correlation is significant at the 0.01 level (2-tailed); \* Correlation is significant at the 0.05 level (2-tailed).

## 4.7. Ichthyodiversity in the Teesta River

---

### 4.7.1. Taxonomic Diversity and Relative Abundance

A total of 3585 fish were examined in two years of study (*i.e.* from March, 2007 to February, 2009) from all the sampling sites of the Teesta and these belong to 65 species, three orders, 10 families and 39 genera. Maximum number of species (30) recorded were of family Cyprinidae followed by families Sisoridae (12 species), family Balitoridae (9 species), Cobitidae (4 species), Psilorhynchidae and Shilbeidae (3 species each) and Bagridae, Olyridae, Amblyciptidae and Mastacembilidae (one species each) (**Table 4.7-1, 4.7-2 and Figure 4.7-1**).

A total of 11 species were found at all four sites. Species (10) like *Barilius barila*, *Devario devario*, *Puntius conchoniis*, *Puntius ticto*, *Lepidocephalichthyes guntea*, *Pangio pangia*, *Botia lohachata*, *Glyptothorax pectinopterus*, *Olyra longicauda* and *Amblyceps mangois* were found only at TR-IV. Distribution of species in all four sampling sites showed a trend of increment from upstream to downstream that is TR-I (28 sp.) < TR-II (41 sp.) < TR-III (45 sp.) < TR-IV (49sp). Five species of fishes were abundantly (62.9%) found in the river Teesta which were *Barilius bendelisis* (14.8%), *Schizothorax richardsonii* (12.8%), *Nemacheilus devdevi* (12.5%), *Barilius barna* (11.9%), *Neolissocheilus hexagonolepis* (10.9%). Almost all the species in the collection are represented mostly by young specimens. Fast flowing river Teesta calls for a special modification of the fish fauna. The individual modification is chiefly manifested in being small sized and development of structure of adhesion. Fish species found in the present study may be categorised into six major groups on the basis of morphological characteristics in relation to distributional pattern which enable them to inhabit the torrential streams. These are, i) fish dwelling in shallow, clear cold waters in the foothills without any striking modifications to current: *Barilius* spp; ii) fish inhabiting the bottom water layers in deep fast current, with powerful muscular cylindrical bodies: *Schizothorax* spp, *Tor* spp, *Neolissocheilus* spp; etc. iii) fish sheltering among pebbles and stones to ward off the strong current: *Crossocheilus latius*; iv) fish sheltering among pebbles and shingles in shallows, with special attachment devices: the loaches, *Nemacheilus* spp, *Schistura* spp, *Canthophrys gongota*, *Aborichthys elongatus*, *Acanthocobitis botia*; v) fish which cling to exposed surface of bare rocks in slower current, with adhesive organs on their ventral surface for attachment to rocks: *Garra* spp, *Glyptothorax* spp, *Pseudecheneis sulcata*; and vi) fish which cling to the exposed surfaces

of bare rocks in fast current, with limpet shaped bodies and mouth, gills and fins highly modified to suit the habitat: *Parachiloglanis hodgarti*.

#### **4.7.2. Monthly Variations of Density and Diversity Indices**

Variations of density and diversity indices of ichthyofauna in all four sampling sites of the river Teesta are summarized in the **Table 4.7-3**.

##### **4.7.2.1. Catch Per Unit Effort**

Recorded catch per unit effort (CPUE) in the in the river ranged from 21 individual/100m<sup>2</sup> to 64 individual/100m<sup>2</sup> with a mean value 36.9 individual/100m<sup>2</sup> ( $\pm 10.3$ ). Lowest CPUE was recorded in May 2007 (TR-II) and highest value recorded at TR-III during September 2007. Monthly variations of fish CPUE revealed a trend of gradual descend from the month of May to July then rose to touch peak in September. Then, values of CPUE again descended to attain lowest value in the month of December. Though, other small peaks and sinks were evident in both the years of study (**Figure 4.7-2**).

##### **4.7.2.2. Estimated Population Size**

Estimated population size in the in the river Teesta ranged from 74 individual/1000m<sup>2</sup> to 789 individual/1000m<sup>2</sup> with a mean value 265.6 individual/1000m<sup>2</sup> ( $\pm 155.3$ ). Lowest population size was recorded in December 2007 (TR-IV) and highest value recorded at TR-III during November 2007. Monthly variations of fish population size revealed a trend of gradual descend from the month of May to July then ascended to touch peak in October then again descended and attained lowest value in the month of December. Though, other small peaks and sinks were evident in both the years of study (**Figure 4.7-2**).

##### **4.7.2.3. Number of Fish Species**

A total of 65 species of fishes were recorded from River Teesta. Observed number of fish species at different sampling sites during the study period ranged from 05 to 26 with a mean value 13.6 ( $\pm 3.9$ ). Lowest number of species was recorded in July 2007 (TR-II). Highest number of species recorded at TR-III during September 2007. Monthly variations of number of fish species revealed a trend of gradual descend from the month of May and attained lowest value in the month of July then again ascended to touch peak in September. Though, other small peaks and sinks were evident in both the years of study (**Figure 4.7-3**).

##### **4.7.2.4. Shannon-Wiener Species Diversity Index**

Estimated values of Shannon-Wiener species diversity index for ichthyofauna in the river ranged from 2.170 bits per individual to 4.435 bits per individual with an average 3.435 bits

per individual ( $\pm 0.431$ ). Lowest value of Shannon-Wiener species diversity index of fish was recorded in July 2007 at TR-II and highest value recorded at TR-III during September 2007. Monthly variations of species diversity index revealed a trend of gradual descend from the month of May and attained lowest value in the month of July then again ascended to touch peak in September. Though, other small peaks and sinks were evident in both the years of study (**Figure 4.7-3**).

#### **4.7.2.5. Ichthyofaunal Evenness Index**

Projected values of ichthyofaunal evenness index in the river ranged from 0.793 to 0.980 with an average 0.924 ( $\pm 0.03$ ). Lowest evenness index was found in April 2008 at TR-I and highest species evenness index was found in February 2009 at TR-IV. Monthly variations of evenness index revealed an erratic trend (**Figure 4.7-4**).

#### **4.7.2.6. Ichthyofaunal Species Richness Index**

Estimated values of ichthyofaunal richness index in the river ranged from 1.214 to 6.269 with an average 3.508 ( $\pm 0.96$ ). Lowest richness index was found in July 2007 (TR-II) and highest species richness index was found in September 2008 (TR-IV). Monthly variations of ichthyofaunal species richness revealed a trend of gradual descend from the month of May and attained lowest value in the month of July then ascended again to touch peak in September. Though, other small peaks and sinks were evident in both the years of study (**Figure 4.7-4**).

#### **4.7.2.7. Index of Dominance**

Documented values ichthyofaunal index of dominance in the river ranged from 0.055 to 0.240 with an average 0.113 ( $\pm 0.04$ ). Lowest value of index of dominance was found in September 2008 (TR-IV) and highest value of index of dominance was found in July 2007 (TR-II). Monthly variations of ichthyofaunal index of dominance revealed a trend of gradual ascend from the month of May and attained highest peak in the month of July then again descended to touch lowest value in September. Though, other small peaks and sinks were evident in both the years of study (**Figure 4.7-5**).

### **4.7.3. Similarity Index (Sorensen's Coefficient of Community)**

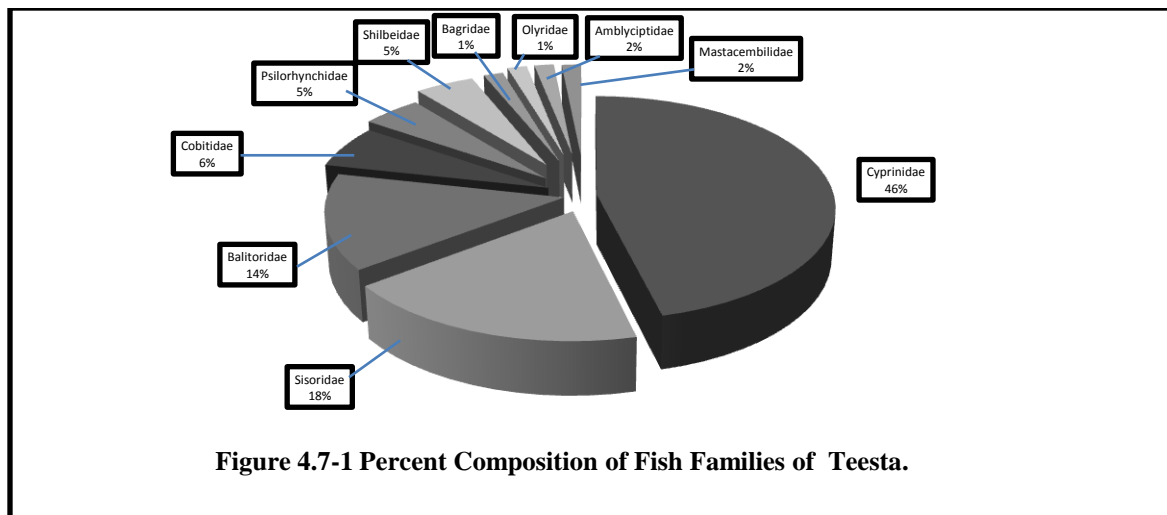
**Table 4.7-4** shows the similarity index of ichthyofauna at all sampling sites in the Teesta river. Highest similarity index 0.885 was recorded in between TR-I (07-08) and TR-I (08-09). The lowest value of similarity index (0.361) was found in between TR-I (07-08) and TR-IV (07-08).

#### 4.7.4. Seasonal Variations of Density and Diversity indices

When data on monthly variations of ichthyofaunal Catch Per Unit Effort was pooled into seasonal values, highest value observed in post monsoon months at all the sites. Lowest value recorded in winter months (TR-I, III and IV) and in pre monsoon months at TR-II of the river Teesta.

**Table 4.7-2 Percent Composition of Fish Groups in Four Sampling Sites of River Teesta During the Study Period.**

TAXON	2007-2008				2008-2009			
	TR-I	TR-II	TR-III	TR-IV	TR-I	TR-II	TR-III	TR-IV
<b>ORDER-CYPRINIFORMES</b>	<b>96.2</b>	<b>96.4</b>	<b>88.5</b>	<b>87.7</b>	<b>96.8</b>	<b>92.5</b>	<b>94.6</b>	<b>84.0</b>
FAMILY- CYPRINIDAE	74.1	71.5	60.9	58.6	75.6	69.0	65.6	63.2
Sub-family- Rasborinae	33.3	33.9	29.3	33.6	31.0	30.5	31.6	29.6
Sub-family- Cyprininae	13.7	10.8	13.5	12.9	15.6	12.9	15.6	17.4
Sub-family- Cultrinae	-	-	-	3.9	-	0.9	0.9	2.5
Sub-family- Schizothoracinae	12.4	16.3	10.2	2.2	19.0	12.7	6.9	4.7
Sub-family- Garrinae	14.7	10.5	7.9	5.9	10.0	12.0	10.5	9.0
FAMILY-PSILORHYNCHIDAE	<b>0.3</b>	<b>1.8</b>	<b>1.2</b>	-	-	<b>0.9</b>	<b>1.7</b>	<b>1.7</b>
FAMILY- BALITORIIDAE	<b>21.8</b>	<b>21.6</b>	<b>25.8</b>	<b>21.3</b>	<b>21.2</b>	<b>22.6</b>	<b>27.3</b>	<b>15.2</b>
Sub-family- Balitorinae	-	-	-	1.1	-	0.7	0.9	-
Sub-family- Nemacheilinae	21.8	21.6	25.8	20.2	21.2	21.9	26.3	15.2
FAMILY-COBITIDAE	-	<b>1.5</b>	<b>0.6</b>	<b>3.9</b>	-	-	-	<b>3.9</b>
Sub-family- Cobitinae	-	1.5	0.6	3.9	-	-	-	3.2
Sub-family- Botinae	-	-	-	-	-	-	-	0.7
<b>ORDER-SILURIFORMES</b>	<b>3.7</b>	<b>2.9</b>	<b>10.42</b>	<b>15.2</b>	<b>3.1</b>	<b>7.2</b>	<b>4.8</b>	<b>15.1</b>
FAMILY- BAGRIDAE	-	-	<b>0.8</b>	<b>1.8</b>	-	-	-	<b>2.0</b>
FAMILY- SCHELBEIDAE	<b>0.9</b>	-	<b>19.2</b>	<b>2.4</b>	<b>0.5</b>	-	<b>0.7</b>	-
Sub-family- Ailiinae	-	-	0.9	2.4	-	-	-	-
Sub-family- Schelbeinae	0.9	-	0.9	-	0.5	-	0.7	-
FAMILY- SISORIDAE	<b>2.8</b>	<b>2.9</b>	<b>7.7</b>	<b>9.7</b>	<b>2.6</b>	<b>7.2</b>	<b>4.1</b>	<b>10.7</b>
FAMILY- OLYRIDAE	-	-	-	-	-	-	-	<b>0.7</b>
FAMILY- AMBLYCRIPTIDAE	-	-	-	<b>1.3</b>	-	-	-	<b>1.7</b>
<b>ORDER-SYNBRANCHIFORMES</b>	-	<b>0.5</b>	<b>1.2</b>	<b>0.9</b>	-	-	<b>0.5</b>	<b>0.7</b>
FAMILY- MASTACEMBELIDAE	-	0.5	1.2	0.9	-	-	0.5	0.7

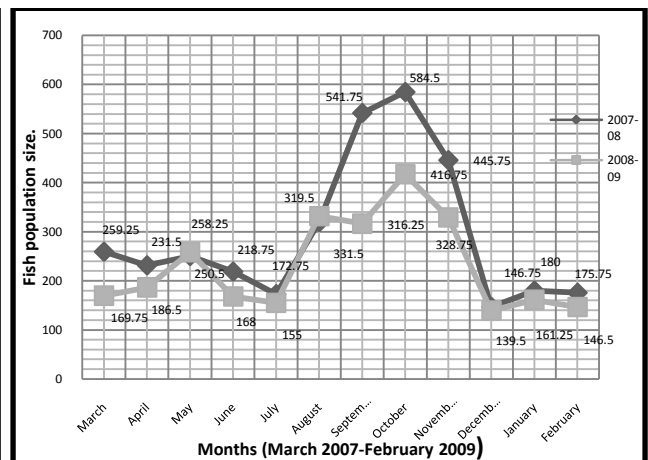
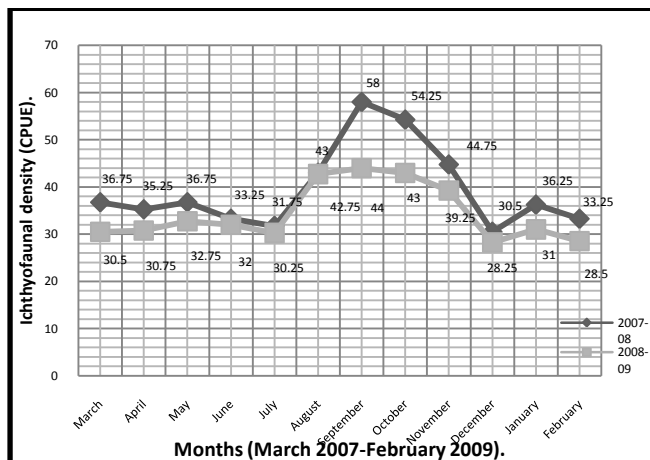


**Table 4.7-3 Summary of Ichthyofaunal Density and Diversity Indices of (showing the Range and Mean  $\pm$  Standard Deviation) of the River Teesta (n=96) During the Study Period.**

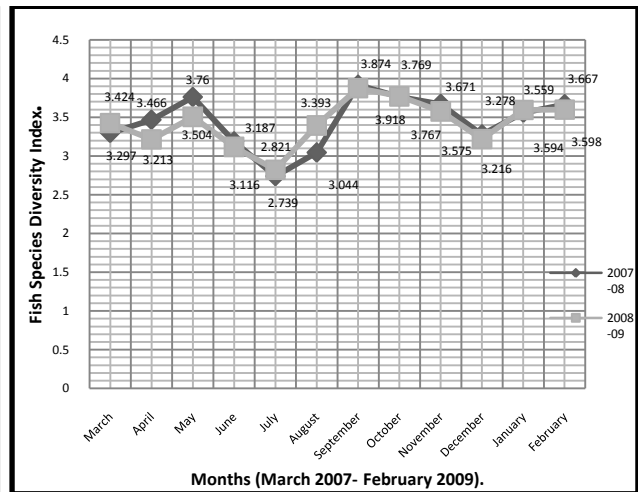
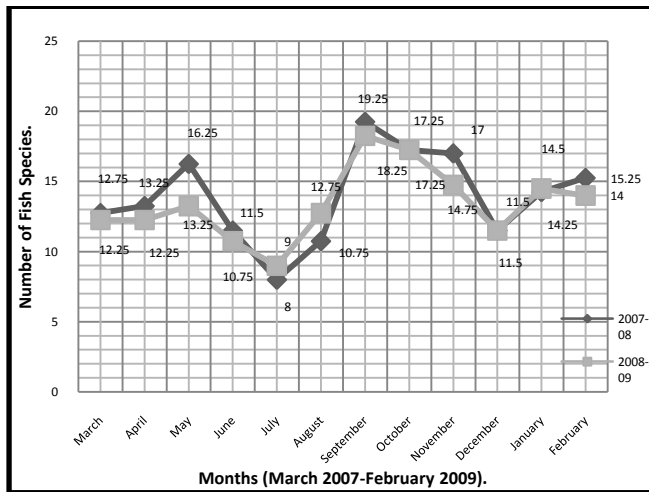
Period of study	March 2007 – February 2009		
	Range	Mean	S.D. ( $\pm$ ).
<b>Diversity indices</b>			
1. Catch Per Unit Effort.	21-64	36.9	10.3
2. Population size of Ichthyofauna (N).	74-789	265.6	155.2
3. Number of Species (S).	5-26	13.6	3.9
4. Species diversity index (H').	2.170-4.435	3.435	0.431
5. Species evenness Index (J').	0.793-0.980	0.924	0.03
6. Species Richness Index (R).	1.214-6.269	3.508	0.96
7. Species dominance Index ( $\lambda$ ).	0.055-0.240	0.113	0.04

**Table 4.7-4 Similarity Index Variations at Different Sampling Sites in Teesta river during the Study Period.**

	2007-2008				2008-2009			
	TR-I	TR-II	TR-III	TR-IV	TR-I	TR-II	TR-III	TR-IV
TR-I (07-08)	1	0.640	0.645	<b>0.361</b>	<b>0.885</b>	0.586	0.582	0.431
TR-II(07-08)		1	0.586	0.421	0.625	0.556	0.588	0.459
TR-III (07-08)			1	0.551	0.600	0.576	0.476	0.603
TR-IV(07-08)				1	0.373	0.523	0.548	0.750
TR-I (08-09)					1	0.571	0.528	0.445
TR-II(08-09)						1	0.610	0.579
TR-III(08-09)							1	0.606
TR-IV(08-09)								1



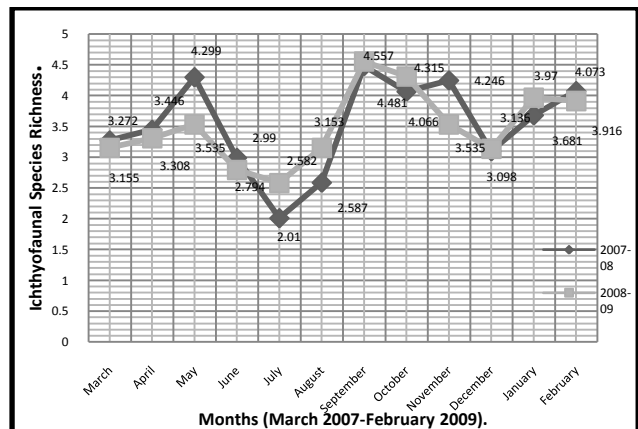
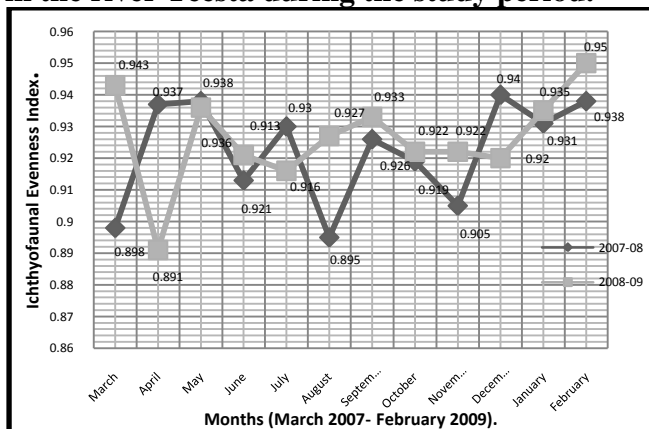
**Figure 4.7-2 Monthly variations of Ichthyofaunal CPUE (a) and Population Size (b) in the river Teesta during the study period.**



(a)

(b)

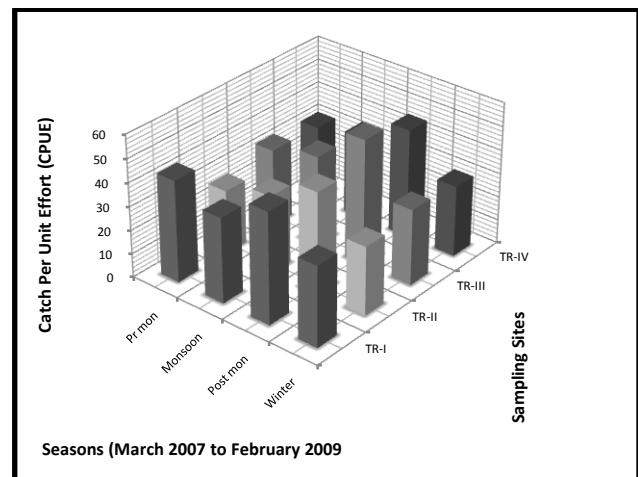
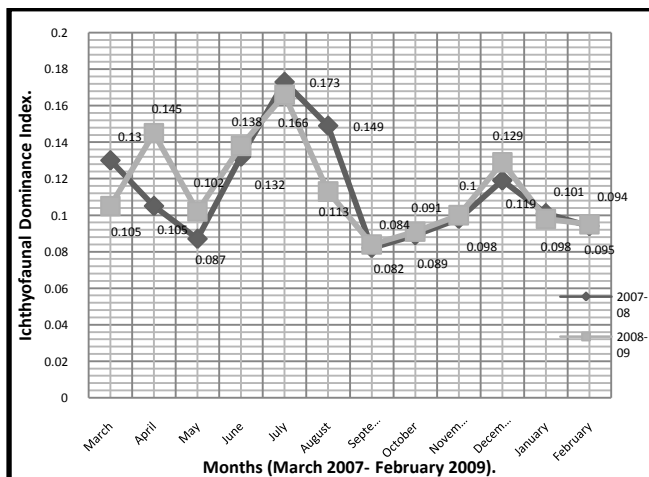
**Figure 4.7-3** Monthly variations of Number of Fish Species (a) and Species Diversity Index (b) in the river Teesta during the study period.



(a)

(b)

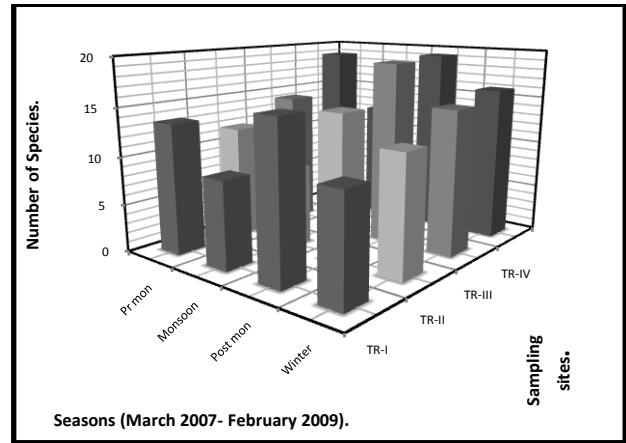
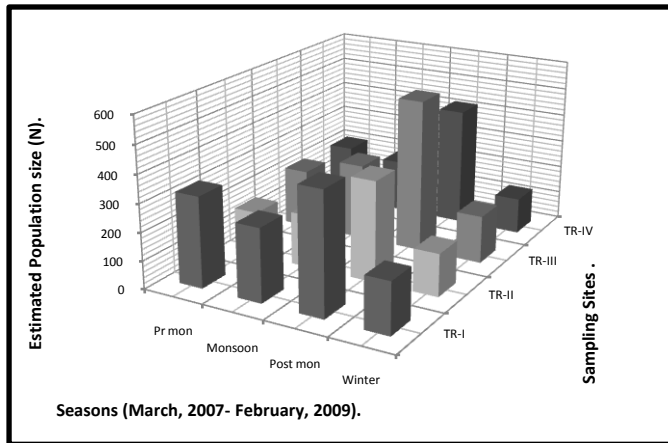
**Figure 4.7-4** Monthly Variations of Ichthyofaunal Evenness Index (a) and Species Richness Index (b) in the river Teesta during the study period.



(a)

(b)

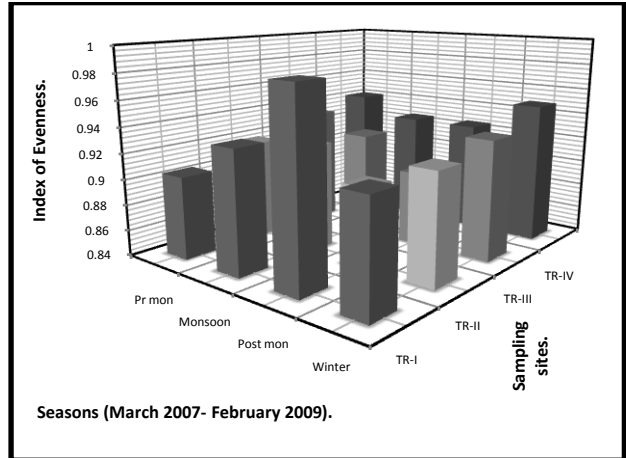
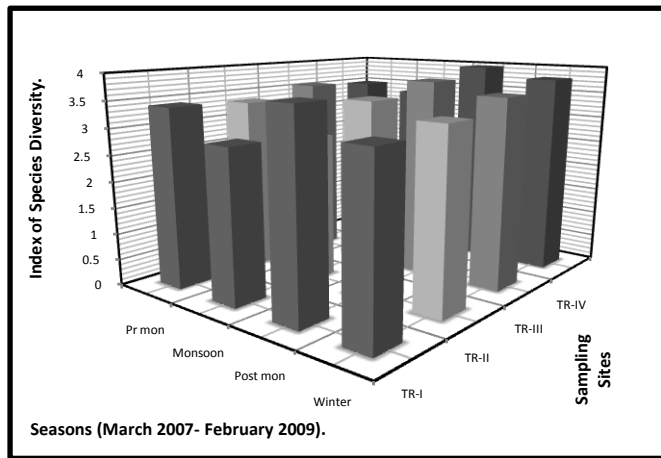
**Figure 4.7-5** Monthly variations of Ichthyofaunal Dominance Index (a) and Seasonal Variations of CPUE (b) in the river Teesta during the study period.



(a)

(b)

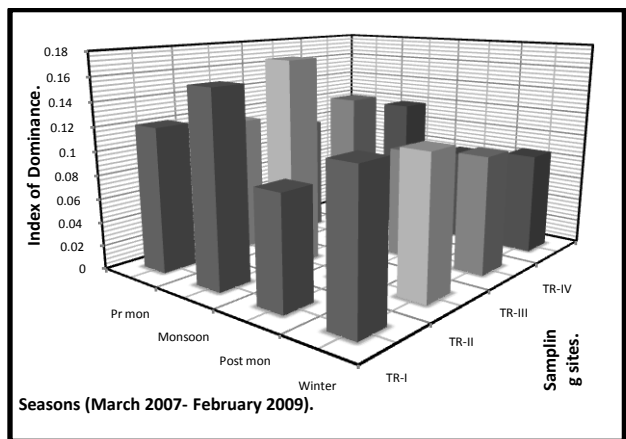
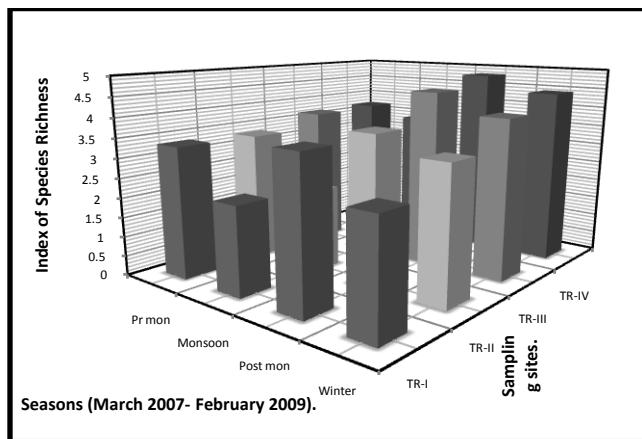
**Figure 4.7-6** Seasonal variations of Ichthyofaunal Population Size (a) and Number of Species (b) in the three sampling sites of the river water during the study period.



(a)

(b)

**Figure 4.7-7** Seasonal variations of Ichthyofaunal Species Diversity Index (a) and Evenness Index (b) in the three sampling sites of the river water during the study period.



(a)

(b)

**Figure 4.7-8** Seasonal variations of Ichthyofaunal Species Richness Index (a) and Species Dominance Index (b) in the three sampling sites of the river water during the study period.

Seasonal variation of number of fish species, Shannon-Wiener Species Diversity Index and Margalef's Richness Index showed highest value in post monsoon months and lowest value recorded in monsoon months at all sites. On the contrary, seasonal variations of index of dominance of ichthyofauna exhibited highest value in monsoon months and lowest value in post monsoon months at all sites. Highest seasonal value of Fish Population Size observed in post monsoon months and lowest value found in winter months at all the sampling sites. Interestingly, seasonal variations of evenness index of fish show the highest value in winter months (TR-I & IV) and in pre monsoon months (TR-II & TR-III) but, lowest value found in pre monsoon months (TR-I & IV) and in post monsoon months (TR-II & III). **Figure 4.7-5, 4.7-6, 4.7-7 and 4.5-8** explains seasonal variations of density and diversity indices of ichthyofauna in four sampling sites during the study period.

Test of significance for difference in means (Fisher's t) was performed to understand whether the observed seasonal differences of density and diversity indices of ichthyofauna connote any real difference among groups. The null hypothesis for testing of differences between means is  $H_0: \mu_1 = \mu_2$ , where  $\mu_1$  is a mean of a variable in one season and  $\mu_2$  is a mean of same variable in other season. As  $H_a$  is two sided, a two tailed test for determining the rejection region at 1% level which comes to as under, using table of t-distribution for 34 degrees of freedom: Critical Region:  $|t| \geq 2.46$  and at 5% level it is: Critical Region:  $|t| \geq 1.70$ . The observed values of t for ichthyofaunal density and diversity in different seasons is presented in the **Table 4.7-5**, most of which fall in the rejection region and thus,  $H_0$  is rejected and concluded that seasonality affect density and diversity of ichthyofauna of the river water.

#### **4.7.5. Annual Variations of Density and Diversity indices**

When data on monthly variations of density and diversity indices of ichthyofauna were pooled into annual values, the average values of fish catch per unit effort, estimated fish population size, number of fish genera, Shannon-Wiener Species Diversity Index and Margalef's richness index were found to be slightly higher in the first year of study (March 2007-February 2008) than the second year (March 2008-February 2009). On the contrary, average value of ichthyofaunal evenness index and dominance index was found to be slightly higher in the second year of study (March 2008-February 2009) than the first year (March 2007-February 2008). Fisher's t significant for CPUE ( $|t|=2.44$ ,  $p < 0.05$ ) and population size ( $|t|=1.99$ ,  $p < 0.05$ ). **Table 4.7-6** showed the comparisons of annual mean values of density and diversity indices of zooplankton in the river Teesta during two years of study period.

#### **4.7.6. Altitudinal Variations of Density and Diversity indices**

Along the elevational gradient that is in four sampling sites such as TR-I (224m), TR-II (216m), TR-III (168m) and TR-IV (147m) of the river Teesta average number of fish species and

Shannon-Wiener Species Diversity Index exhibited a trend of gradual increment from upstream to downstream except in site TR-II. On the contrary, average values of index of dominance along the altitudinal gradient of the river demonstrated a trend of decrease from upstream to the downstream except in site TR-II. Margalef's Richness Index exhibited gradual increase from upstream to downstream. But the average values of fish catch per unit effort, ichthyofaunal population size and evenness index showed complex variations along the altitudinal gradients of the river Teesta. Values of fisher's t were significant for CPUE (I and II, II and III,  $|t|=2.19, 1.89$ ,  $p < 0.05$ ), population size (I and II, II and III,  $|t|=2.13, 1.83$ ,  $p < 0.05$ ), number of species (I and III, I and IV, II and III, II and IV,  $|t|=2.54, 3.01, 2.99, 3.49$ ,  $p < 0.01$ ), species diversity index (I and III, II and III,  $|t|=1.99, 2.42$ ,  $p < 0.05$ ; I and IV, II and IV,  $|t|=2.81, 3.23$ ,  $p < 0.01$ ), evenness index (III and IV,  $|t|=1.54$ ,  $p < 0.05$ ), richness index (I and III, I and IV, II and IV,  $|t|=3.21, 4.34, 3.74$ ,  $p < 0.01$ ) and dominance index (I and IV, II and III, II and IV,  $|t|=2.12, 1.90, 2.45$ ,  $p < 0.05$ ). **Table 4.7-6** showed the comparisons of altitudinal mean values of density and diversity indices of ichthyofauna in the river Teesta during two years of study period.

#### 4.7.7. Density and Diversity Indices of Ichthyofauna and Water Quality

To examine individual relationship between Density and Diversity Indices of ichthyofauna and Physico-Chemical parameters of water quality, a Pearson Correlation matrix was calculated. The numerical values of correlation coefficient are depicted in **Table 4.7-8** for all the variables. Most of the calculated values depict some strong correlations. Pair having very high positive correlation between them shows the dependency of one parameter on the other while pair having very negative correlation between them shows inverse relation between them.

The regression analysis showed causal relationship between physico-chemical variables (Independent or explanatory variables) and variables of ichthyofaunal density and diversity indices (Dependant or regressand variables). Three Principal Components obtained for physico-chemical parameters in the river were used as independent variables to understand the trend of control over ichthyofaunal density and diversity (**Table 4.7-7**). Causal relationship as obtained in the regression analysis has been summarized below.

##### 4.7.7.1. Catch Per Unit Effort

$$Dens_i = 36.948 + 4.537 PC1_i + 1.435 PC2_i$$

$$SE = (0.94) \quad (0.95) \quad (0.95)$$

$$t\text{-value} = 39.117^* \quad 4.779^* \quad 1.512^*$$

$$R^2 = 0.213; \bar{R}^2 = 0.196; F_{2, 93} = 12.560^*$$

**Table 4.7-1 Occurrence, Distribution and Relative Abundance of Fish Species at all the Sampling Sites of the River Teesta During the Study Period.**

TAXON	2007-2008				2008-2009			
	TR-I	TR-II	TR-III	TR-IV	TR-I	TR-II	TR-III	TR-IV
1. <i>Barilius barna</i>	++	++	++	+++	++	+++	+++	++
2. <i>Barilius barila</i>	-	-	-	+	-	-	-	+
3. <i>Barilius bendelisis</i>	+++	+++	+++	+++	+++	+++	+++	++
4. <i>Barilius shacra</i>	+	+	+	-	+	-	-	-
5. <i>Barilius tileo</i>	-	-	+	+	-	+	+	+
6. <i>Barilius vagra</i>	+	+	+	-	+	+	-	+
7. <i>Aspidoparia morar</i>	-	-	+	+	-	-	+	+
8. <i>Raiamas bola</i>	-	-	+	+	-	+	-	-
9. <i>Devario devario</i>	-	-	-	+	-	-	-	+
10. <i>Devario aequipinnatus</i>	++	+	-	+	+	+	-	+
11. <i>Chagunius chagunio</i>	-	-	-	+	-	+	+	+
12. <i>Cyprinion semiplotum</i>	+	-	+	-	+	-	-	+
13. <i>Labeo boga</i>	+	+	+	-	+	+	+	-
14. <i>Labeo dero</i>	+	+	+	-	+	+	+	+
15. <i>Labeo dyocheilus</i>	-	-	+	-	-	+	-	+
16. <i>Labeo pungusia</i>	-	-	-	+	-	+	-	+
17. <i>Neolissocheilus hexagonolepis</i>	++	++	++	++	+++	++	++	++
18. <i>Neolissocheilus hexastichus</i>	+	-	+	-	+	-	-	-
19. <i>Tor putitora</i>	+	-	-	+	+	-	+	+
20. <i>Tor tor</i>	-	-	+	-	+	-	-	-
21. <i>Puntius conchonius</i>	-	-	-	+	-	-	-	+
22. <i>Puntius gelius</i>	-	-	-	+	-	-	+	-
23. <i>Puntius ticto</i>	-	-	-	-	-	-	-	+
24. <i>Salmophasia bacaila</i>	-	-	-	+	-	+	+	+
25. <i>Schizothorax progastus</i>	+	+	-	-	+	+	-	-
26. <i>Schizothorax richardsonii</i>	+++	+++	+++	+	+++	+++	++	+
27. <i>Garra annandalei</i>	+	+	+	-	-	+	-	-
28. <i>Garra gotyla gotyla</i>	++	++	++	+	++	++	++	++
29. <i>Garra lamta</i>	-	+	-	-	-	-	-	-
30. <i>Crossocheilus latius</i>	+	-	-	+	+	+	+	+
31. <i>Psilorhynchus balitora</i>	-	+	-	-	-	+	+	-
32. <i>Psilorhynchus sucatio</i>	-	+	+	-	-	-	-	+
33. <i>Psilorhynchus homaloptera</i>	+	-	-	-	-	-	+	-
34. <i>Balitora brucei</i>	-	-	-	+	-	+	+	-
35. <i>Aborichthyes elongatus</i>	-	-	-	-	+	+	-	-
36. <i>Acanthocobitis botia</i>	-	-	+	+	-	-	-	-
37. <i>Schistura beavani</i>	+	-	+	-	-	-	-	-
38. <i>Schistura rupicola</i>	+	-	+	-	+	-	-	-
39. <i>Schistura scaturigina</i>	+	+	++	++	+	++	++	+
40. <i>Nemacheilus devdevi</i>	+++	+++	++	++	++	++	+++	++
41. <i>Nemacheilus multifasciatus</i>	+	+	+	+	+	+	++	+
42. <i>Nemacheilus pavonaceus</i>	-	+	-	-	-	-	+	+
43. <i>Lepidocephalichthyes guntea</i>	-	-	-	+	-	-	-	+
44. <i>Pangio pangia</i>	-	-	-	+	-	-	-	-
45. <i>Somileptes gongota</i>	-	+	+	+	-	-	-	+
46. <i>Botia lohachata</i>	-	-	-	-	-	-	-	+
47. <i>Batasio batasio</i>	-	-	+	+	-	-	-	+
48. <i>Ailia colia</i>	-	-	+	+	-	-	-	-
49. <i>Clupisoma garua</i>	+	-	+	-	+	-	-	-

50. <i>Clupisoma Montana</i>	+	-	-	-	-	-	+	-
51. <i>Bagarius bagarius</i>	+	-	-	-	+	+	-	-
52. <i>Parachiloganis hodgarti</i>	-	-	-	-	-	+	-	-
53. <i>Gagata cenia</i>	-	-	+	-	-	+	-	+
54. <i>Glyptothorax telchitta</i>	-	-	+	-	-	+	+	+
55. <i>Glyptothorax cavia</i>	+	-	-	-	+	+	+	-
56. <i>Glyptothorax conirostris</i>	-	-	+	+	-	-	-	-
57. <i>Glyptothorax pectinopterus</i>	-	-	-	+	-	-	-	+
58. <i>Gogangra viridescens</i>	-	-	+	-	-	-	+	+
59. <i>Nangra nangra</i>	-	-	+	+	-	+	-	+
60. <i>Pseudecheneis sulcata</i>	+	+	-	-	+	-	+	-
61. <i>Pseudolaguvia shawi</i>	-	+	+	+	-	-	-	-
62. <i>Sisor rhabdophorus</i>	-	-	-	-	-	+	+	+
63. <i>Olyra longicauda</i>	-	-	-	-	-	-	-	+
64. <i>Amblyceps mangois</i>	-	-	-	+	-	-	-	+
65. <i>Mastacembelus armatus</i>	-	+	+	+	-	-	+	+

\*Absent (-), < 5% (+), <10% (++) , above 10% (+++).

**Table 4.7-5 Results of Test of Significance for Difference in Means (Fisher's t) of Seasonal Values of Density and Diversity Indices of Ichthyofauna in the river Teesta During the Study Period (March 2007 to February 2009).**

	pm/mon	pm/psm	pm/win	mon/psm	mon/win	psm/win
1. Catch Per Unit Effort.	0.734	4.53*	1.144	4.253*	2.224**	6.04*
2. Fish Population Size (N).	0.054	5.264*	3.069*	5.073*	2.866*	7.68*
3. Number of Species(S).	3.528*	4.338*	0.202	7.05*	3.438*	3.888*
4. Species Diversity Index (H').	3.505*	3.465*	0.431	6.369*	3.778*	2.904*
5. Evenness Index (J').	0.631	0.244	1.281	0.451	2.249**	1.881**
6. Richness Index (R).	3.604*	3.102*	0.628	6.122*	3.838*	2.231**
7. Dominance Index ( $\lambda$ ).	2.848*	2.596*	0.743	5.389*	3.771*	2.258**

pm-pre monsoon; mon-monsoon; psm-post monsoon; win-winter.\*1%level significant, \*\*5%level significant.

**Table 4.7-6 Mean Values ( $\pm$  standard deviation) of Density and Diversity Indices of Ichthyofauna along the Altitudinal Gradient (n=24) of Teesta river and Comparisons of Mean ( $\pm$  standard deviation) Annual Values (n=48) During the two years of Study Period.**

Period of study	March 2007 – February 2009.				Annual variations	
Sampling sites	TR-I	TR-II	TR-III	TR-IV	2007-08	2008-09
1. Catch Per Unit Effort.	39.9 $\pm$ 10.6	33.2 $\pm$ 10.2	39.0 $\pm$ 10.9	35.7 $\pm$ 8.8	39.5 $\pm$ 11.5*	34.4 $\pm$ 8.3*
2. Fish Population Size (N).	312.3 $\pm$ 145.7	214.3 $\pm$ 128.2	298.8 $\pm$ 180.5	237.1 $\pm$ 146.2	293.9 $\pm$ 176.7*	237.4 $\pm$ 125.9*
3. Number of Genera (S).	12.3 $\pm$ 3.4	11.9 $\pm$ 3.1	15.9 $\pm$ 3.9	15.5 $\pm$ 3.8	13.9 $\pm$ 4.1	13.4 $\pm$ 3.6
4. Species Diversity Index (H').	3.298 $\pm$ 0.4	3.259 $\pm$ 0.4	3.532 $\pm$ 0.4	3.652 $\pm$ 0.4	3.446 $\pm$ 0.4	3.425 $\pm$ 0.4
5. Evenness Index (J').	0.924 $\pm$ 0.04	0.926 $\pm$ 0.03	0.915 $\pm$ 0.03	0.932 $\pm$ 0.03	0.922 $\pm$ 0.03	0.926 $\pm$ 0.03
6. Margalef's Richness Index (R).	3.002 $\pm$ 0.8	3.131 $\pm$ 0.8	3.802 $\pm$ 0.9	4.097 $\pm$ 0.9	3.521 $\pm$ 0.98	3.496 $\pm$ 0.97
7. Dominance Index ( $\lambda$ ).	0.123 $\pm$ 0.04	0.126 $\pm$ 0.04	0.107 $\pm$ 0.03	0.099 $\pm$ 0.03	0.113 $\pm$ 0.04	<b>0.114<math>\pm</math>0.04</b>

\*5%level significant.

The  $\bar{R}^2$  value of 0.196 indicates that about 19.6% variation of ichthyofaunal catch per unit effort in the river Teesta is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component I (PC1) has significant (1% level) positive influence on the ichthyofaunal CPUE. Hence, the fish CPUE will soar in the augmented values of free carbon dioxide, water temperature, Phosphate phosphorous, ammonium nitrogen, nitrite nitrogen and nitrate nitrogen in the river water when there is less dissolved oxygen and specific conductance. On the other hand, principal component II (PC2) also has significant (1% level) positive impact on the fish CPUE. Hence, ichthyofaunal CPUE will increase if the value of pH, total alkalinity, chloride and hardness of the river water increases and the value of water velocity decreases.

#### 4.7.7.2. Estimated Fish Population Size

$$\begin{aligned}
 POP_i &= 262.698 + 72.645 PC1_i + 29.280 PC2_i \\
 SE &= (13.6) \quad (13.7) \quad (13.7) \\
 t\text{-value} &= 19.256^* \quad 5.297^* \quad 2.135^{**} \\
 R^2 &= 0.260; \bar{R}^2 = 0.244; F_{2, 93} = 16.310^*
 \end{aligned}$$

The  $\bar{R}^2$  value of 0.244 indicates that about 24.4% variation of ichthyofaunal population size in the river Teesta is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component I (PC1) has significant (1% level) positive influence on the ichthyofaunal population size. Hence, the population size will soar in the augmented values of free carbon dioxide, water temperature, Phosphate phosphorous, ammonium nitrogen, nitrite nitrogen and nitrate nitrogen in the river water when there is less dissolved oxygen and specific conductance. On the other hand, principal component II (PC2) also has significant (5% level) positive impact on the fish population size. Hence, population size will increase if the value of pH, total alkalinity, chloride and hardness of the river water increases and the value of water velocity decreases.

#### 4.7.7.3. Number of fish species

$$\begin{aligned}
 NOS_i &= 13.646 + 0.935 PC1_i + 1.879 PC2_i \\
 SE &= (0.33) \quad (0.34) \quad (0.34) \\
 t\text{-value} &= 40.743^* \quad 2.776^* \quad 5.582^* \\
 R^2 &= 0.295; \bar{R}^2 = 0.280; F_{2, 93} = 19.431^*
 \end{aligned}$$

The  $\bar{R}^2$  value of 0.280 indicates that about 28.0% variation of number of fish species in the river Teesta is explained by the principal components. Since the F-statistic is significant at

1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component I (PC1) has significant (1% level) positive influence on the number of fish species. Hence, the number of species will soar in the augmented values of free carbon dioxide, water temperature, Phosphate phosphorous, ammonium nitrogen, nitrite nitrogen and nitrate nitrogen in the river water when there is less dissolved oxygen and specific conductance. On the other hand, principal component II (PC2) also has significant (1% level) positive impact on the number of fish species. Hence, number of fish species will increase if the value of pH, total alkalinity, chloride and hardness of the river water increases and the value of water velocity decreases.

#### 4.7.7.4. Shannon-Weiner Species Diversity Index

$$SDI_i = 3.435 + 0.057 PC1_i + 0.219 PC2_i$$

SE	= (0.038)	(0.038)	(0.038)
t-value	= 90.623*	1.501	5.739*

$$R^2 = 0.275; \bar{R}^2 = 0.259; F_{2, 93} = 17.595^*$$

The  $\bar{R}^2$  value of 0.259 indicates that about 25.9% variation of ichthyofaunal species diversity index in the river Teesta is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component II (PC2) has significant (1% level) positive impact on the species diversity index. Hence, species diversity index for fish fauna will increase if the value of pH, total alkalinity, chloride and hardness of the river water increases and the value of water velocity decreases.

#### 4.7.7.5. Ichthyofaunal Evenness Index

$$Even_i = 0.924 + -0.002 PC1_i + 0.004 PC2_i$$

SE	= (0.003)	(0.003)	(0.003)
t-value	= 277.109*	-0.557	1.261

$$R^2 = 0.020; \bar{R}^2 = -0.001; F_{2, 93} = 0.950$$

The  $\bar{R}^2$  value of -0.001 indicates that variation of the ichthyofaunal evenness index in the river cannot be explained by the principal components. Since the F-statistic is not significant therefore, the estimated regression model does not fit the data well.

#### 4.7.7.6. Ichthyofaunal Species Richness Index

$$Rich_i = 3.508 + 0.140 PC1_i + 0.467 PC2_i$$

SE	= (0.086)	(0.086)	(0.086)
t-value	= 40.985*	1.629	5.424*

$$R^2 = 0.506; \bar{R}^2 = 0.240; F_{2, 93} = 16.039^*$$

The  $\bar{R}^2$  value of 0.240 indicates that about 24.0% variation in the ichthyofaunal species richness index in the river is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component II (PC2) has significant (1% level) positive impact on the ichthyofaunal species richness index. Hence, species richness index for fish fauna will increase if the value of pH, total alkalinity, chloride and hardness of the river water increases and the value of water velocity decreases.

#### 4.7.7.7. Ichthyofaunal Species Dominance Index

$$\begin{aligned}
 \text{Domi}_i &= 0.113 + -0.002 \text{ PC1}_i + -0.018 \text{ PC2}_i \\
 \text{SE} &= (0.003) \quad (0.003) \quad (0.003) \\
 \text{t-value} &= 33.763^* \quad -0.654 \quad -5.274^* \\
 R^2 &= 0.233; \bar{R}^2 = 0.216; F_{2,93} = 14.121^*
 \end{aligned}$$

The  $\bar{R}^2$  value of 0.216 indicates that about 21.6% variation in the ichthyofaunal species dominance index in the river is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component II (PC2) has significant (1% level) negative impact on the ichthyofaunal species dominance index. Hence, species dominance index for fish fauna will increase if the value of pH, total alkalinity, chloride and hardness of the river water decrease and the value of water velocity increase.

**Table 4.7-7 Physico-Chemical Determinants of Ichthyodiversity in Teesta: OLS Estimation.**

Independent Variables	CPUE of fish		population size		Number of species		SDI		Evenness		Richness		Dominance	
	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value
Intercept	36.948	39.117*	262.698	19.256*	13.64	40.743*	3.435	90.625*	0.924	277.1*	3.508	40.985*	0.113	33.763*
PCI: More physical & nutrient and less chemical	0.439	4.779*	0.473	5.297*	0.242	2.776*	0.133	1.501	-0.057	-0.557	0.146	1.629	-0.059	-0.654
PCII: More Chemical and less physical.	0.139	1.512	0.790	2.135**	0.486	5.582*	0.506	5.739*	0.0129	1.261	0.485	5.424*	-0.479	-5.274*
R square	0.213		0.259		0.295		0.275		0.020		0.256		0.233	
Adjusted R square	0.196		0.244		0.279		0.259		-0.001		0.240		0.216	
F <sub>2, 93</sub> -value (ANOVA)	12.56*		16.31*		19.43*		17.59*		0.949		16.039*		14.121*	

\*=> Significant at 1% level of Significance; \*\*=> Significant at 5% of Significance.

**Table 4.7-8 Pearson's Correlation Coefficients Matrix for Ichthyofaunal Density and Diversity Indices and Water Quality of the river Teesta.**

	AT	WT	WV	PH	COND	DO	FCO	TA	CL	HARD	PO <sub>4</sub>	NO <sub>3</sub>	NO <sub>2</sub>	NH <sub>4</sub>
DENSF	0.168	0.168	0.015	-0.141	-0.102	-0.25*	0.17	-0.01	0.052	-0.059	0.47**	0.266**	0.425**	0.475**
POPF	0.211*	0.178	-0.024	-0.149	-0.152	-0.25*	0.148	0.055	0.157	-0.044	0.389**	0.305**	0.508**	0.455**
NOGF	0.101	-0.14	-0.398**	0.246*	0.085	0.013	-0.132	0.464**	0.171	0.35**	0.231*	0.31	0.167	0.161
SDIF	0.013	-0.232*	-0.468**	0.337**	0.148	0.083	-0.192	0.508**	0.189	0.389**	0.141	0.255*	0.049	0.048
EVENF	-0.072	-0.084	-0.142	0.289**	0.009	0.011	-0.049	0.155	0.086	0.133	-0.045	-0.03	-0.103	-0.163
RICHF	0.096	-0.188	-0.442**	0.309**	0.122	0.084	-0.186	0.518**	0.134	0.401**	0.129	0.248*	0.075	0.054
DOMIF	0.061	0.265**	0.465**	-0.367**	-0.166	-0.127	0.207*	-0.48**	-0.187	-0.377**	-0.073	-0.216*	0.014	0.023

AT= Air temperature; WT= Water temperature; WV=Water velocity; pH= Power of hydrogen ion concentration; COND= conductivity; DO= Dissolved oxygen; FC= Free carbon dioxide;TA= Total alkalinity; CL= Chloride; Hard= Total hardness; PO<sub>4</sub> = Phosphate-phosphorous; NO<sub>3</sub>= Nitrate- nitrogen; NO<sub>2</sub>= Nitrite-nitrogen; NH<sub>4</sub>=Ammonium-nitrogen; DENSF= Ichthyofaunal CPUE;

POPF= Ichthyofaunal Population Size; NOGF= Number of Fish Species; SDIF= Species Diversity Index of Fish; EVENF= Evenness Index of Ichthyofauna; RICHF= Richness index of Ichthyofauna; DOMIF=Dominance Index Ichthyofauna.

\*\* Correlation is significant at the 0.01 level (2-tailed); \* Correlation is significant at the 0.05 level (2-tailed).

## 4.8. Ichthyodiversity in the Hill Stream Relli

---

### 4.8.1. Taxonomic Diversity and Relative Abundance

In the present investigation, a total of 25 species of fishes were recorded from the hill-stream Relli and these belong to 5 families and 15 genera (Table 4.8-1, 4.8-2 and Figure 4.8-1). Maximum number of species (14) recorded were of family Cyprinidae followed by families Balitoridae (6 species), family Sisoridae (3 species), Psilorhynchidae and Cobitidae (one species each). 14 species were found at all sites (Table-). Species like *Danio aequipinnatus*, *Crossocheilus latius latius*, *Cyprinion semiplotum*, *Psilorhynchus sucatio*, *Nemacheilus botia*, *Somileptes gongota*, *Euchiloglanis hodgarti* and *Glyptothorax cavia* were found only in site RR-III. *Barilius shacra* and *Garra lamta* were found in site RR-II and III whereas *Schizothoraichthyes progastus* was found in site RR-I and II. 22 species belongs to order Cypriniformes and only three belongs to Siluriformes. Seven species of fishes are abundantly (78.6%) found in the river Relli amongst which *Neolissocheilus hexagonolepis* (15.8%), *Garra gotyla gotyla* (14.5%), *Barilius bendelisis* (14.3%), *Schizothorax richardsonii* (10.1%), *Nemacheilus devdevi* (9.8%), *Barilius barna* (8.3%), and *Nemacheilus scaturigina* (5.8%). Almost all the species in the collection were represented by very young specimens, adult brood fishes were found mostly during monsoon and post-monsoon months.

Of the 25 species, almost all the species were considered as food fish, 23 species were ornamental fish, 4 species namely *Schizothoraichthyes progastus*, *Schizothorax richardsonii*, *Neolissocheilus hexagonolepis*, *N. hexastichus* are considered sport fish and the last two are commercially important.

### 4.8.2. Monthly Variations of Density and Diversity Indices

Variations of density and diversity indices of ichthyofauna in all three sampling sites of the hill stream Relli are summarized in the Table 4.8-3.

#### 4.8.2.1. Catch Per Unit Effort (CPUE)

Recorded density or Catch Per Unit Effort (CPUE) in the hill-stream ranged from 11 individual/100m<sup>2</sup> to 53 individual/100m<sup>2</sup> with a mean value 27.8 individual/100m<sup>2</sup> ( $\pm 9.7$ ). Lowest density was recorded in June 2008 (RR-II) and in January 2008 (RR-II). Highest value recorded at RR-III during October 2008. Monthly variations of fish density revealed a trend of gradual ascend from the month of April and touched peak in October then again descended to attain lowest value in the month of January. Though, other small peaks and sinks were evident in both the years of study (Figure 4.8-2).

**Table 4.8-1 Occurrence, Distribution and Relative Abundance of Fish Species at the Sampling Sites of the hill-stream Relli during the Study Period.**

	2007-08			2008-09		
	RR-I	RR-II	RR-III	RR-I	RR-II	RR-III
1. <i>Barilius barna</i>	++	++	++	++	++	++
2. <i>Barilius bendelisis</i>	+++	+++	+++	+++	+++	+++
3. <i>Barilius shacra</i>	+	-	-	-	+	+
4. <i>Barilius vagra</i>	-	-	-	-	+	+
5. <i>Danio aequipinnatus</i>	-	-	+	-	-	+
6. <i>Crossocheilus latius latius</i>	-	-	+	-	-	-
7. <i>Garra annandalei</i>	+	-	+	+	+	-
8. <i>Garra gotyla gotyla</i>	+++	+++	+++	+++	+++	+++
9. <i>Garra lamta</i>	-	-	-	-	+	+
10. <i>Schizothorachthys progastus</i>	-	-	-	+	-	+
11. <i>Schizothorax richardsonii</i>	++	+++	+++	++	++	++
12. <i>Cyprinion semiplotum</i>	-	-	+	-	-	-
13. <i>Neolissocheilus hexagonolepis</i>	+++	+++	+++	+++	+++	+++
14. <i>Neolissocheilus hexastichus</i>	+	++	+	++	+	+
15. <i>Psilorhynchus sucatio</i>	-	-	-	-	-	+
16. <i>Aborichthyes elongatus</i>	+	+	+	++	+	+
17. <i>Nemacheilus rupecola</i>	+	-	+	+	+	+
18. <i>Nemacheilus botia</i>	-	-	-	-	-	+
19. <i>Nemacheilus devdevi</i>	++	++	+++	++	++	+++
20. <i>Nemacheilus multifasciatus</i>	+	+	+	++	++	+
21. <i>Nemacheilus scaturigina</i>	+	++	++	++	++	++
22. <i>Somileptes gongota</i>	-	-	+	-	-	+
23. <i>Parachiloganis hodgarti</i>	-	-	+	-	-	+
24. <i>Glyptothorax cavia</i>	-	-	+	-	-	-
25. <i>Pseudecheiss sulcata</i>	+	+	-	-	+	+

\*Absent (-), < 5% (+), <10% (++) , above 10% (+++).

**Table 4.8-2 Percent Composition of Fish Groups in Three Sampling Sites of the hill-stream Relli During the Study Period.**

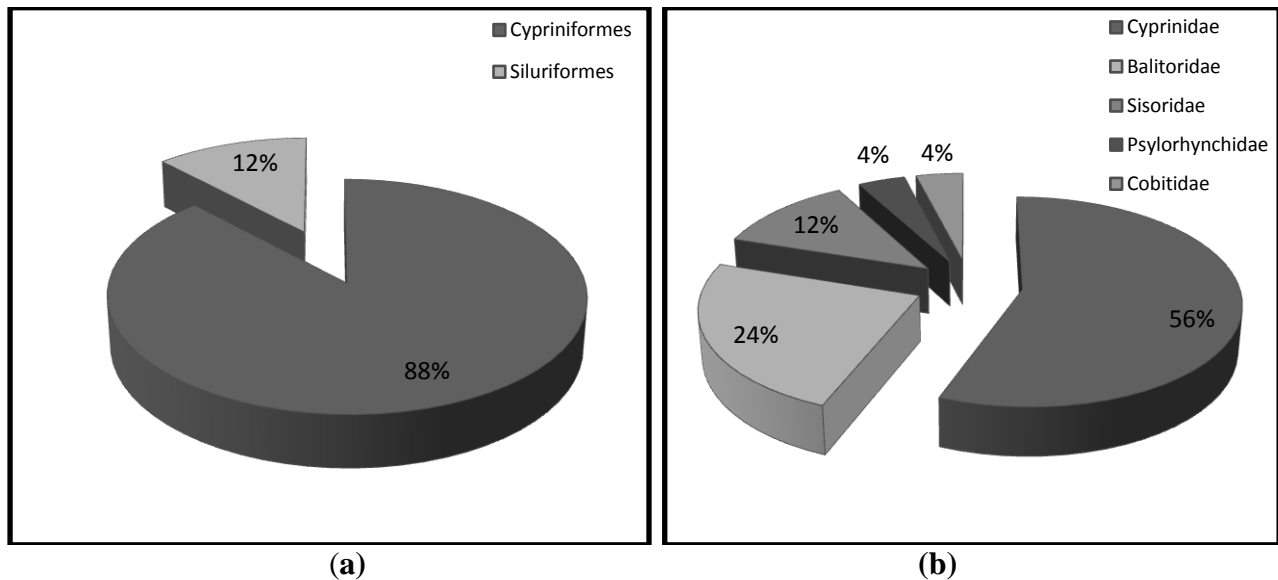
TAXON	2007- 2008			2008-2009		
	RR-I	RR-II	RR-III	RR-I	RR-II	RR-III
Order- Cypriniformes.	98.2%	97.4%	98.5%	100%	98.0%	97.4%
Family- Cyprininae	77.8%	74.8%	71.3%	70.0%	70.5%	71.5%
Sub family- Rasborinae	24.14%	24.6%	24.5%	25.8%	23.8%	30.9%
Sub family- Garrinae	23.8%	12.4%	16.5%	13.8%	18.1%	15.9%
Sub family- Schizothoracinae	9.5%	11.4%	11.9%	9.8%	11.3%	9.3%
Sub family- Cyprininae	20.4%	26.4%	18.4%	20.6%	17.3%	15.2%
Family- Psilorhynchidae	-	-	-	-	-	0.2%
Family- Balitoridae						
Sub family- Nemachelinae	20.1%	22.7%	26.2%	29.8%	27.4%	25.9%
Family- Cobitidae						
Sub family- Cobitinae	-	-	0.97%	-	-	-
Order- Siluriformes						
Family- Sisoridae	1.8%	2.6%	1.5%	-	2.0%	2.6%

**Table 4.8-3 Summary of Ichthyofaunal Density and Diversity Indices of (showing the Range and Mean  $\pm$  Standard Deviation) of the Hill Stream Relli (n=72) During the Study Period.**

Period of study	March 2007 – February 2009		
	Range	Mean	S.D. ( $\pm$ ).
<b>Diversity indices</b>			
1. Catch Per Unit Effort.	11-53	27.8	9.7
2. Population size of Ichthyofauna (N).	55-312	147.2	0.04
3. Number of Species (S).	04-13	7.9	2.2
4. Species diversity index (H').	1.905-3.496	2.753	0.4
5. Species evenness Index (J').	0.876-0.990	0.941	0.03
6. Species Richness Index (d).	0.985-3.396	2.093	0.5
7. Species dominance Index ( $\lambda$ ).	0.098-0.281	0.168	0.04

**Table 4.8-4 Similarity Index Variations at Different Sampling Sites in the Hill-Stream Relli during the Study Period.**

	2007-2008			2008-2009		
	RR-I	RR-II	RR-III	RR-I	RR-II	RR-III
RR-I (07-08)	1	0.800	0.750	0.889	0.903	0.788
RR-II(07-08)		1	0.689	<b>0.917</b>	0.786	0.734
RR-III(07-08)			1	0.774	<b>0.686</b>	0.703
RR-I(08-09)				1	0.867	0.688
RR-II(08-09)					1	0.834
RR-III(08-09)						1



**Figure 4.8-1 Percent Composition of Ichthyofaunal Orders (a) and Families (b) in the hill-stream Relli.**

#### **4.8.2.2. Estimated Population Size of Ichthyofauna**

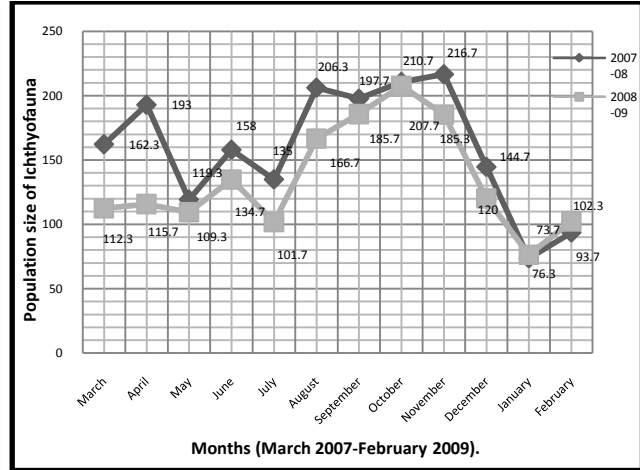
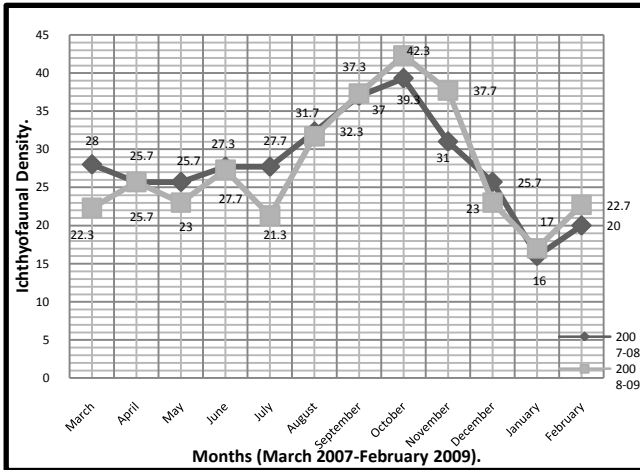
Estimated population size of the ichthyofauna in the hill-stream ranged from 55 individual/1000 m<sup>2</sup> to 312 individual/1000 m<sup>2</sup> with a mean value 147.2 individual/1000 m<sup>2</sup> ( $\pm 59.9$ ). Lowest population size was recorded in January and March 2008 at RR-II. Highest population size recorded at RR-III during August 2007. Monthly variations of fish population size revealed a trend of gradual ascend from the month of May and touched peak in October (2008-09) and November (2007-08) then descended to attain lowest value in the month of January. Though, other small peaks and sinks were evident in both the years of study (**Figure 4.8-2**).

#### **4.8.2.3. Number of Fish Species**

Observed number of fish species in the stream ranged from 04 to 13 with a mean value 7.9 ( $\pm 2.2$ ). Lowest number of species was recorded in July 2007 (RR-II), January 2008 (RR-II), and February 2008 (RR-II). Highest number of species recorded at RR-II during November 2008 and at RR-III during September 2008 and October 2008. Monthly variations of number of fish species revealed a trend of gradual ascend from the month of March and touched a small peak in June (2008-09) and May (2007-08) then descended to attain lowest value in the month of July (2007-08) again ascended to touch highest peak in October. In the second year of study (2008-09) lowest point was touched in December and January (**Figure 4.8-3**).

#### **4.8.2.4. Shannon Weiner Species Diversity Index**

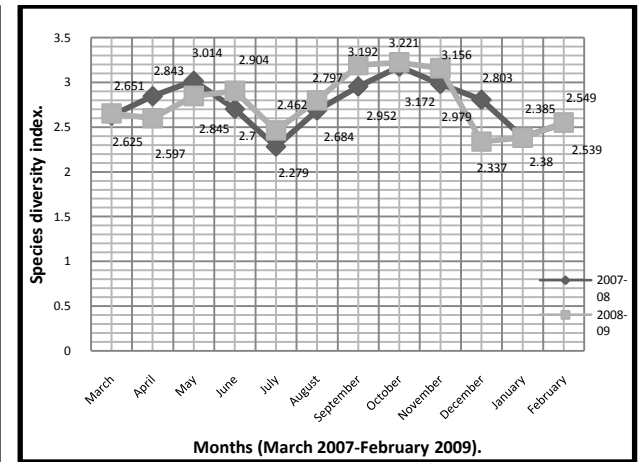
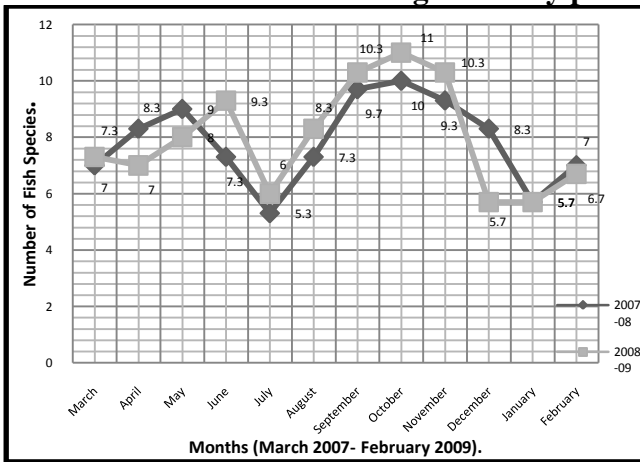
Estimated value of Shannon-Wiener species diversity index ranged from 1.905 bits individual<sup>-1</sup> to 3.496 bits individual<sup>-1</sup> with an average 2.735 bits individual<sup>-1</sup> ( $\pm 0.4$ ). Lowest value of Shannon-Wiener species diversity index of fish was recorded in February 2008 (RR-II) and highest value recorded at RR-III during September 2008. Monthly variations of species diversity index revealed a trend of gradual ascend from the month of March and touched a small peak in June (2008-09) and May (2007-08) then descended to attain lowest value in the month of July (2007-08) again ascended to touch highest peak in October. In the second year of study (2008-09) lowest point was touched in December (**Figure 4.8-3**).



(a)

(b)

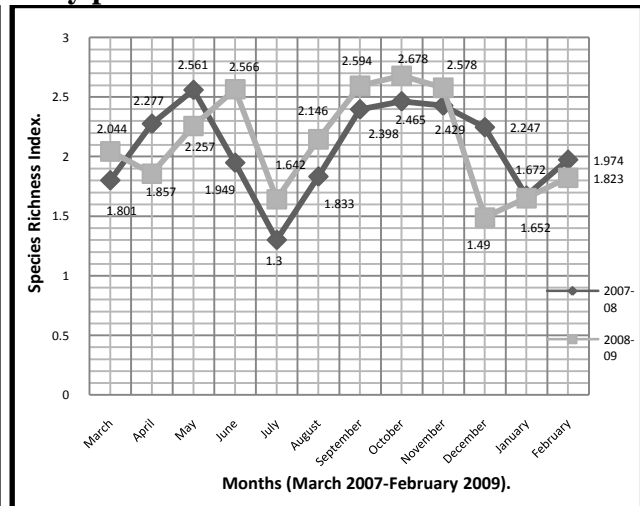
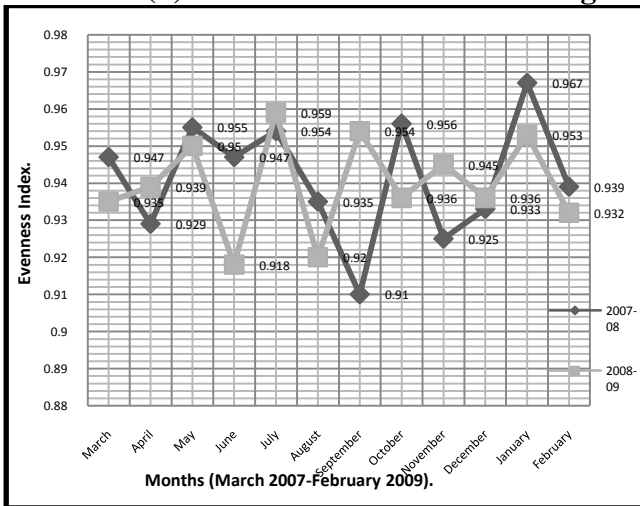
**Figure 4.8-2** Monthly variations of Ichthyofaunal CPUE (a) and Population Size (b) in the hill stream Relli during the study period.



(a)

(b)

**Figure 4.8-3** Monthly variations of Number of Fish Species (a) and Species Diversity Index (b) in the hill stream Relli during the study period.



(a)

(b)

**Figure 4.8-4** Monthly Variations of Ichthyofaunal Evenness Index (a) and Species Richness Index (b) in the hill stream Relli during the study period.

#### **4.8.2.5. Ichthyofaunal Evenness Index**

Evaluated ichthyofaunal evenness index in the stream ranged from 0.876 to 0.990 with an average 0.941 ( $\pm$  0.03). Lowest evenness index was found in December 2008 (RR-III) and highest species evenness index was found in January 2008 (RR-I). Monthly variations of evenness index revealed an erratic trend. In 2007-08 lowest sink observed in the month of September and highest peak in January. Similarly, in 2008-09 lowest point found in the month of June and highest point in July. Though, other small peaks and sinks were also observed in both the years of study (**Figure 4.8-4**).

#### **4.8.2.6. Ichthyofaunal Species Richness Index**

Assessed fish species richness index of the stream ranged from 0.985 to 3.396 with an average 2.093 ( $\pm$  0.5). Lowest richness index was found in July 2007 (RR-II) and highest species richness index was found in May 2007 (RR-I). Monthly variations of species richness index revealed bimodal peak and two sink in both the years of study (**Figure 4.8-4**).

#### **4.8.2.7. Index of Dominance**

Projected values of fish dominance index in the hill-stream Relli ranged from 0.098 to 0.281 with an average 0.168 ( $\pm$  0.043). Lowest value of index of dominance was found in December 2007 (RR-I) and highest value of index of dominance was found in February 2008 (RR-II). Monthly variations of species dominance index revealed two peaks and two sinks in both the years of study (**Figure 4.8-5**).

#### **4.8.3. Similarity Index (Sorensen's Coefficient of Community)**

**Table 4.8-4** shows the similarity index of ichthyofauna at all sampling sites in the hill-stream Relli. Highest similarity index 0.917 was recorded in between RR-II (07-08) and RR-I (08-09). The lowest value of similarity index (0.686) was found in between RR-III (07-08) and RR-II (08-09).

#### **4.8.4. Seasonal Variations**

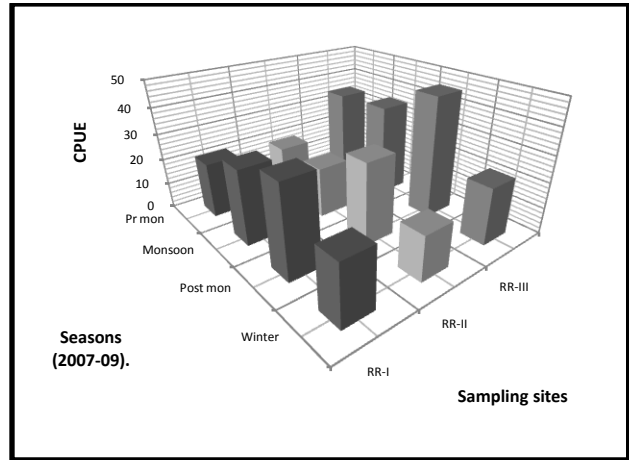
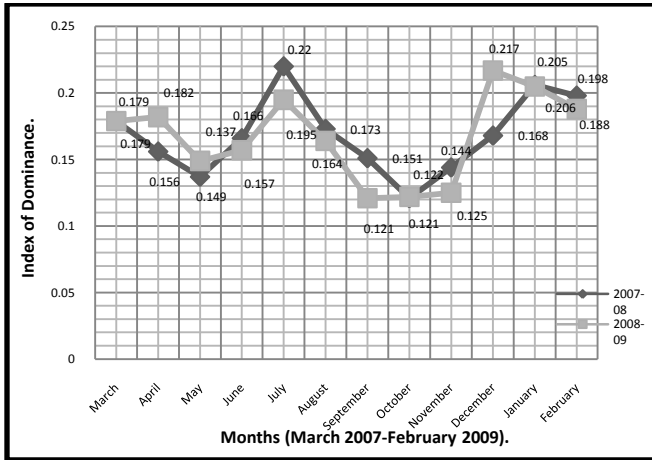
When data on monthly variations of ichthyofaunal Catch Per Unit Effort, Population Size, Number of Fish Species, Shannon-Wiener Species Diversity Index and Margalef's Species Richness Index were pooled into seasonal values highest values observed in the post monsoon months at all the sampling sites but evenness index (J') showed highest value in winter at RR-I and in monsoon at RR-II and III. Highest value of Species Dominance Index of ichthyofauna was found in monsoon months at RR-I and in winter months at RR-II and III. Lowest value of

Catch Per Unit Effort, Fish Population Size, Number of Fish Species found in pre monsoon months at RR-I and in winter months at RR-II and III. Species Dominance Index found to be lowest in post monsoon months at all sampling sites. Lowest value of Shannon-Wiener Species Diversity Index and Margalef's Species Richness Index were found in monsoon months at RR-I and winter months at RR-II and III. Evenness index of ichthyofauna showed lowest seasonal value in monsoon months (RR-I), pre monsoon months (RR-II) and in winter months (RR-III). **Figure 4.8-5, 4.8-6, 4.8-7 and 4.8-8** explains seasonal variations of density and diversity indices of ichthyofauna in three sampling sites during the study period.

Test of significance for difference in means (Fisher's t) was performed to understand whether the observed seasonal differences of density and diversity indices of ichthyofauna connote any real difference among groups. The null hypothesis for testing of differences between means is  $H_0: \mu_1 = \mu_2$ , where  $\mu_1$  is a mean of a variable in one season and  $\mu_2$  is a mean of same variable in other season. As  $H_a$  is two sided, a two tailed test for determining the rejection region at 1% level which comes to as under, using table of t-distribution for 34 degrees of freedom: Critical Region:  $|t| \geq 2.46$  and at 5% level it is: Critical Region:  $|t| \geq 1.70$ . The observed values of t for zooplankton density and diversity indices in different seasons is presented in the **Table 4.8-5**, most of which fall in the rejection region and thus,  $H_0$  is rejected and concluded that seasonality affect density and diversity of ichthyofauna of the stream water.

#### **4.8.5. Annual Variations of Density and Diversity indices**

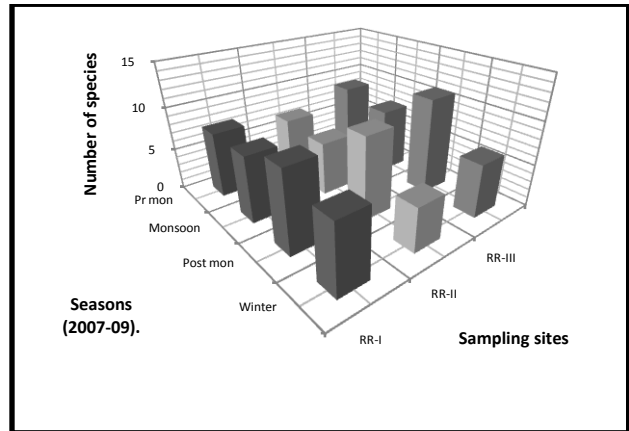
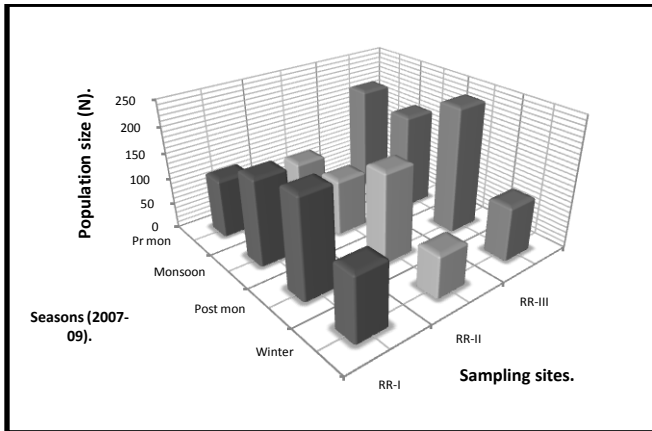
When data on monthly variations of density and diversity indices of ichthyofauna were pooled into annual values, the average values of ichthyofaunal Catch Per Unit Effort, Population Size, Shannon-Wiener Diversity Index, Evenness Index and Species dominance index were found to be slightly higher in the first year of study (March 2007-February 2008) than the second year (March 2008-February 2009). On the contrary, average value of Number of Fish Species and Margalef's Species Richness Index were found to be slightly higher in the second year of study (March 2008-February 2009) than the first year (March 2007-February 2008). Values of Fisher's t were not significant for annual variations. **Table 4.8-6** showed the comparisons of annual mean values of density and diversity indices of ichthyofauna in the hill-stream Relli during two years of study period.



(a)

(b)

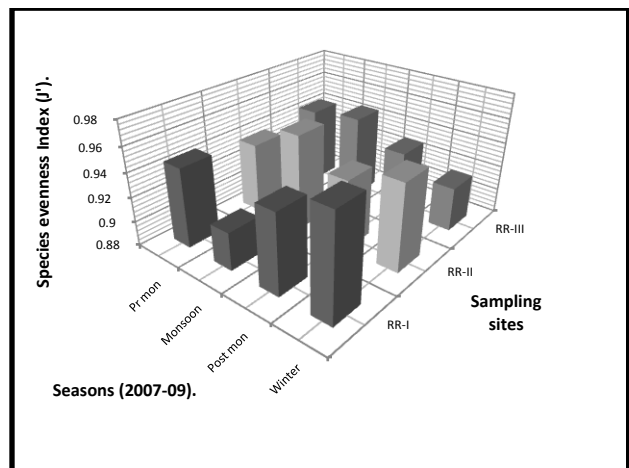
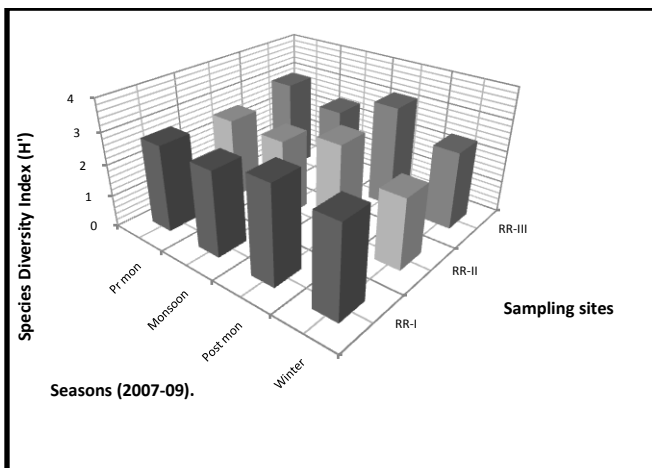
**Figure 4.8-5** Monthly variations of Ichthyofaunal Dominance Index (a) and Seasonal Variations of CPUE (b) in the hill stream Relli during the study period.



(a)

(b)

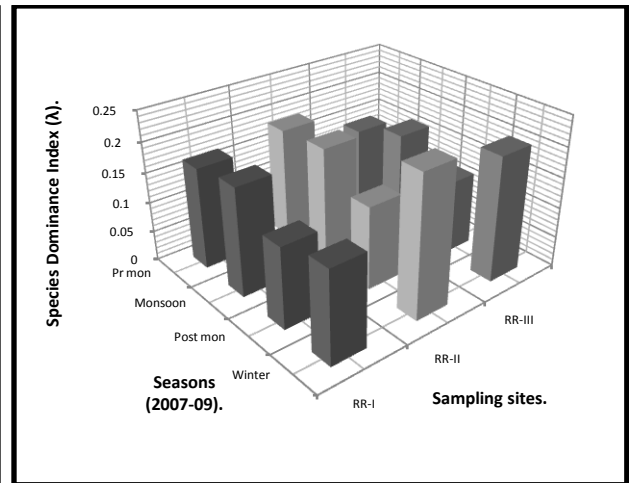
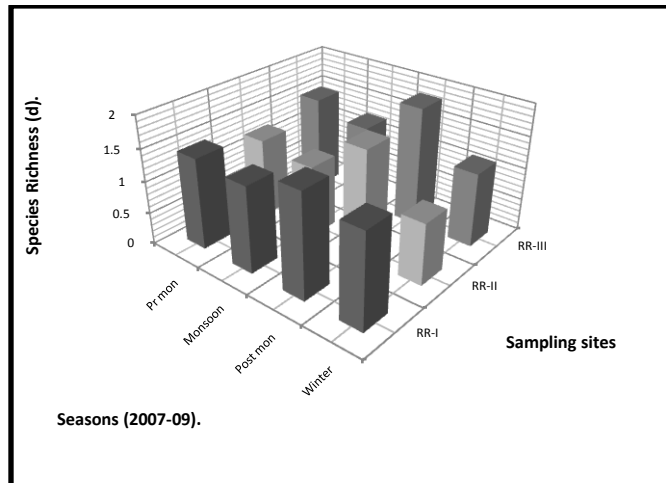
**Figure 4.8-6** Seasonal variations of Ichthyofaunal Population Size (a) and Number of Species (b) in the three sampling sites of the hill stream water during the study period.



(a)

(b)

**Figure 4.8-7** Seasonal variations of Ichthyofaunal Species Diversity Index (a) and Evenness Index (b) in the three sampling sites of the hill stream water during the study period.



**Figure 4.8-8** Seasonal variations of Ichthyofaunal Species Richness Index (a) and Species Dominance Index (b) in the three sampling sites of the hill stream water during the study period.

**Table 4.8-5** Results of Test of Significance for Difference in Means (Fisher's t) of Seasonal Values of Density and Diversity Indices of Ichthyofauna in the hill stream Relli During the Study Period (March 2007 to February 2009).

	pm/mon	pm/psm	pm/win	mon/psm	mon/win	psm/win
1. Catch Per Unit Effort.	1.05	4.38*	1.97**	3.18*	3.07*	6.95*
2. Population size (N).	0.37	3.78*	2.01**	3.42*	2.52*	8.00*
3. Number of Species (S).	0.82	4.12*	2.11**	4.52*	1.18	5.79*
4. Species Diversity Index (H').	1.18	3.69*	2.23*	5.02*	1.18	5.68*
5. Species evenness Index (J').	0.42	0.67	0.08	0.11	0.42	0.60
6. Species Richness Index (R).	1.34	2.64*	1.87**	3.97*	0.54	4.49*
7. Species dominance Index (λ).	1.25	3.16*	2.29*	4.79*	1.25	5.20*

pm-pre monsoon; mon-monsoon; psm-post monsoon; win-winter.\*1%level significant, \*\*5%level significant.

**Table 4.8-6** Mean Values ( $\pm$  standard deviation) of Density and Diversity Indices of Ichthyofauna along the Altitudinal Gradient (n=24) of Relli and Comparisons of Mean ( $\pm$  standard deviation) Annual Values (n=36) During the two years of Study Period.

Period of study	March 2007 – February 2009.			Annual variations	
	RR-I (704 m asl).	RR-II (566 m asl).	RR-III (340 m asl).	2007-08	2008-09
1. Catch Per Unit Effort.	27 $\pm$ 6.6	21.7 $\pm$ 7.4	34.7 $\pm$ 10.1	28 $\pm$ 8.6	27.6 $\pm$ 10.7
2. Population size (N).	146.1 $\pm$ 43.9	113.2 $\pm$ 46.1	182.2 $\pm$ 66.9	163.9 $\pm$ 68.4	134.8 $\pm$ 51.7
3. Number of Genera (S).	8.3 $\pm$ 2.0	7 $\pm$ 2.0	8.5 $\pm$ 2.3	7.9 $\pm$ 2.1	8.0 $\pm$ 2.4
4. Shannon-Wiener diversity index (H').	2.83 $\pm$ 0.33	2.59 $\pm$ 0.41	2.84 $\pm$ 0.37	2.75 $\pm$ 0.39	2.76 $\pm$ 0.38
5. Evenness Index (J').	0.941 $\pm$ 0.03	0.946 $\pm$ 0.02	0.935 $\pm$ 0.03	0.941 $\pm$ 0.03	0.940 $\pm$ 0.03
6. Margalef's Richness Index (R).	2.21 $\pm$ 0.57	1.95 $\pm$ 0.55	2.11 $\pm$ 0.51	2.08 $\pm$ 0.58	2.11 $\pm$ 0.52
7. Dominance Index (λ).	0.158 $\pm$ 0.035	0.186 $\pm$ 0.050	0.159 $\pm$ 0.040	0.168 $\pm$ 0.046	0.167 $\pm$ 0.041

#### 4.8.6. Altitudinal Variations of Density and Diversity indices

Along the elevational gradient that is in three sampling sites, RR-I (704m), RR-II (566m) and RR-III (340m), average values of Catch Per Unit Effort, Population Size, Shannon-Wiener Diversity Index and Margalef's Species Richness Index exhibited a trend of gradual increment from up to downwards except at RR-II. On the contrary, ichthyofaunal evenness index showed a trend of gradual decrease from upstream to downstream except at RR-II. Interestingly, Species Dominance Index was found to be highest at RR-II followed by equal values at RR-I and RR-III. Values of Fisher's t were significant for CPUE (I and II, I and III, II and III,  $|t|=2.56, 3.06, 4.99$ ,  $p < 0.01$ ), population size (I and II,  $|t|=2.02$ ,  $p < 0.05$ ; I and III, II and III,  $|t|=2.53, 4.07$ ,  $p < 0.01$ ), number of species (I and II, II and III,  $|t|=2.05, 2.28$ ,  $p < 0.05$ ), diversity index (I and II, II and III,  $|t|=2.16, 2.14$ ,  $p < 0.05$ ) and dominance index (I and II, II and III,  $|t|=2.19, 2.06$ ,  $p < 0.05$ ). **Table 4.8-6** showed the comparisons of altitudinal mean values of density and diversity indices of ichthyofauna in the hill-stream Relli during two years of study period.

#### 4.8.7. Density and Diversity Indices of Ichthyofauna and Water Quality

To examine individual relationship between Density and Diversity Indices of ichthyofauna and Physico-Chemical parameters of water quality, a Pearson Correlation matrix was calculated. The numerical values of correlation coefficient are depicted in **Table 4.8-8** for all the variables. Most of the calculated values depict some strong correlations. Pair having very high positive correlation between them shows the dependency of one parameter on the other while pair having very negative correlation between them shows inverse relation between them.

The regression analysis showed causal relationship between physico-chemical variables (Independent or explanatory variables) and variables of ichthyofaunal density and diversity indices (Dependant or regressand variables). Three Principal Components obtained for physico-chemical parameters in the hill stream were used as independent variables to understand the trend of control over ichthyofaunal density and diversity (**Table 4.8-7**). Causal relationship as obtained in the regression analysis has been summarized below.

##### 4.8.7.1. Ichthyofaunal Catch Per Unit Effort

$$\begin{aligned}
 \text{Dens}_i &= 27.806 + 3.897 \text{ PC1}_i + 0.632 \text{ PC2}_i + 4.545 \text{ PC3}_i \\
 \text{SE} &= (0.91) \quad (0.92) \quad (0.92) \quad (0.92) \\
 \text{t-value} &= 30.460^* \quad 4.239^* \quad 0.687 \quad 4.945^* \\
 R^2 &= 0.387; \bar{R}^2 = 0.360; F_{3, 68} = 14.298^*
 \end{aligned}$$

The  $\bar{R}^2$  value of 0.360 indicates that about 36.0% variation in the density of fish population in the hill stream Relli is explained by the principal components. Since the F-statistic

is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component I (PC1) has significant positive influence on the fish density. Hence, density of fish will increase in the augmented values of free carbon dioxide, water temperature, water velocity, Phosphate phosphorous, ammonium nitrogen and nitrite nitrogen and the decreased values of dissolved oxygen, total alkalinity, total hardness, chloride ion, pH, specific conductance in the stream water. The principal component III (PC3) has significant positive influence on the density of fish population. Hence, fish density will increase in the raised values of Total alkalinity, chloride ion and total hardness in the stream water.

#### 4.8.7.2. Estimated Fish Population Size

$$POP_i = 147.514 + 10.752 PC1_i + -9.018 PC2_i + 32.747 PC3_i$$

SE = (5.7)	(5.8)	(5.8)	(5.8)
t-value = 25.663*	1.858	-1.558	5.657*

$$R^2 = 0.358; \bar{R}^2 = 0.329; F_{3, 68} = 12.628^*$$

The  $\bar{R}^2$  value of 0.329 indicates that about 32.9% variation in the fish population size in the hill stream Relli is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component III (PC3) has significant positive influence on the fish population size. Hence, population size will increase in the raised values of Total alkalinity, chloride ion and total hardness in the stream water.

#### 4.8.7.3. Number of Fish Species

$$NOS_i = 7.917 + 0.241 PC1_i + 0.033 PC2_i + 0.959 PC3_i$$

SE = (0.24)	(0.24)	(0.24)	(0.24)
t-value = 33.106*	0.999	0.136	3.984*

$$R^2 = 0.199; \bar{R}^2 = 0.164; F_{3, 68} = 5.984^*$$

The  $\bar{R}^2$  value of 0.164 indicates that about 16.4% variation in the number of fish species in the hill stream Relli is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component III (PC3) has significant positive influence on the number of fish species. Hence, number of species will increase in the raised values of Total alkalinity, chloride ion and total hardness in the stream water.

#### 4.8.7.4. Shannon-Wiener Species Diversity Index

$$SDI_i = 2.753 + 0.029 PC1_i + -0.007 PC2_i + 0.153 PC3_i$$

SE = (0.042)	(0.042)	(0.042)	(0.042)
t-value = 65.615*	0.683	-0.159	3.619*

$$R^2 = 0.167; \bar{R}^2 = 0.130; F_{3, 68} = 4.531^*$$

The  $\bar{R}^2$  value of 0.130 indicates that about 13% variation in the species diversity index for fish fauna in the hill stream Relli is explained by the principal components. Since the F-statistic is significant at 1% level of significance and therefore, the estimated regression model fits the data quite well. The principal component III (PC3) has significant positive influence on the species diversity index for fish fauna. Hence, species diversity index will increase in the raised values of Total alkalinity, chloride ion and total hardness in the stream water.

#### 4.8.7.5. Evenness Index of Ichthyofauna

$$Even_i = 0.941 + -0.003 PC1_i + -0.00 PC2_i + -0.004 PC3_i$$

SE = (0.003)	(0.003)	(0.003)	(0.003)
t-value = 310.3*	-1.071	-0.008	-1.237

$$R^2 = 0.048; \bar{R}^2 = 0.006; F_{3, 68} = 1.132$$

The  $\bar{R}^2$  value of 0.006 indicates that only about 0.6% variation of the evenness index of ichthyofauna in the stream is explained by the principal components. Since the F-statistic is not significant, therefore, the estimated regression model does not fit the data.

#### 4.8.7.6. Margalef's Species Richness Index of Ichthyofauna

$$Rich_i = 2.093 + -0.008 PC1_i + 0.008 PC2_i + -0.177 PC3_i$$

SE = (0.06)	(0.06)	(0.06)	(0.06)
t-value = 33.759*	-1.129	-0.132	2.834*

$$R^2 = 0.106; \bar{R}^2 = 0.067; F_{3, 68} = 2.688^{***}$$

The  $\bar{R}^2$  value of 0.067 indicates that about 6.7% variation in the species richness index of ichthyofauna in the stream is explained by the principal components. Since the F-statistic is significant at 5% level of significance and therefore, the estimated regression model fits the data. The principal component III (PC3) has significant positive influence on the species richness index for fish fauna. Hence, species richness index will increase in the raised values of Total alkalinity, chloride ion and total hardness in the stream water.

#### 4.8.7.7. Species Dominance Index of Ichthyofauna

$$\begin{aligned} \text{Dom}_i &= 0.168 + -0.003 \text{ PC1}_i + 0.002 \text{ PC2}_i + -0.015 \text{ PC3}_i \\ \text{SE} &= (0.005) \quad (0.005) \quad (0.005) \quad (0.005) \\ \text{t-value} &= 34.411^* \quad -0.571 \quad 0.342 \quad -3.132^* \\ R^2 &= 0.131; \bar{R}^2 = 0.093; F_{3,68} = 3.417^{**} \end{aligned}$$

The  $\bar{R}^2$  value of 0.093 indicates that about 9.3% variation in the species dominance index of ichthyofauna in the stream is explained by the principal components. Since the F-statistic is significant at 2% level of significance and therefore, the estimated regression model fits the data quite well. The principal component III (PC3) has significant negative influence on the species dominance index for fish fauna. Hence, species dominance index will increase in the reduced values of Total alkalinity, chloride ion and total hardness in the stream water.

**Table 4.8-7 Physico-Chemical Determinants of Ichthyodiversity: OLS Estimation.**

Independent Variables	CPUE of fish		population size		Number of species		SDI		Evenness		Richness		Dominance	
	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value	$\beta$	t-value
Intercept	27.806	30.460*	147.514	25.663*	7.917	33.106*	2.753	65.615*	0.941	310.3*	2.093	33.759*	0.168	34.411*
PCI: More physical & nutrient and less chemical	3.897	4.239*	10.752	1.858	0.241	0.999	0.029	0.683	-0.003	-1.071	-0.008	-0.129	-0.003	-0.571
PCII: More nutrients, less physical.	0.632	0.687	-9.018	-1.558	0.033	0.136	-0.007	-0.159	-0.003	-0.848	-0.008	-0.132	0.002	0.342
PCIII: More chemicals	4.545	4.945*	32.747	5.657*	0.959	3.984*	0.153	3.619*	-0.004	-1.237	0.177	2.834*	-0.015	3.142*
R square	0.387		0.358		0.199		0.167		0.048		0.106		0.131	
Adjusted R square	0.359		0.329		0.164		0.130		0.006		0.067		0.093	
F <sub>3, 68</sub> -value (ANOVA)	14.298*		12.628*		5.984*		4.531*		1.132		2.688***		3.417**	

\*=> Significant at 1% level of Significance; \*\*=> Significant at 2% level of Significance; \*\*\*=> Significant at 5% of Significance.

**Table 4.6-8 Pearson's Correlation Coefficients Matrix for Ichthyofaunal Density and Diversity Indices and Water Quality of the hill-stream Relli**

	AT	WT	WV	PH	COND	DO	FCO	TA	CL	HARD	PO <sub>4</sub>	NO <sub>3</sub>	NO <sub>2</sub>	NH <sub>4</sub>
DENSF	0.452**	0.369**	0.152	-0.488**	-0.341**	-0.355**	0.410**	-0.271*	-0.028	-0.146	0.436**	0.477**	0.470**	0.569**
POPF	0.407**	0.310**	0.162	-0.460**	-0.298*	-0.256*	0.353**	-0.307	-0.042	-0.165	0.374**	0.502**	0.427**	0.498**
NOGF	0.308**	0.181	-0.060	-0.367**	-0.093	-0.135	0.162	-0.181	-0.022	-0.131	0.154	0.462**	0.362**	0.413**
SDIF	0.304**	0.175	-0.049	-0.333**	-0.060	-0.107	0.121	-0.194	-0.034	-0.143	0.125	0.434**	0.333**	0.387**
EVENF	-0.126	-0.069	-0.003	0.125	0.015	0.100	-0.180	0.010	-0.108	0.040	-0.123	-0.245*	-0.113	-0.093
RICHF	0.215	0.090	-0.122	-0.241*	0.031	-0.034	0.042	-0.119	-0.016	-0.116	0.017	0.365**	0.251*	0.283*
DOMIF	-0.302**	-0.176	0.026	0.300*	0.042	0.088	-0.097	0.195	0.043	0.142	-0.108	-0.382**	0.300*	-0.355**

AT= Air temperature; WT= Water temperature; WV=Water velocity; pH= Power of hydrogen ion concentration; COND= conductivity; DO= Dissolved oxygen; FCO= Free carbon dioxide;TA= Total alkalinity; CL= Chloride; Hard= Total hardness; PO<sub>4</sub> = Phosphate-phosphorous; NO<sub>3</sub>= Nitrate- nitrogen; NO<sub>2</sub>= Nitrite-nitrogen; NH<sub>4</sub>=Ammonium-nitrogen; DENSF= Ichthyofaunal CPUE;

POPF= Ichthyofaunal Population Size; NOGF= Number of Fish Species; SDIF= Species Diversity Index of Fish; EVENF= Evenness Index of Ichthyofauna; RICHF= Richness index of Ichthyofauna; DOMIF=Dominance Index Ichthyofauna.

\*\* Correlation is significant at the 0.01 level (2-tailed); \* Correlation is significant at the 0.05 level (2-tailed).



# *Chapter 5*



## *Discussion*

## 5.1. Water Quality

---

### 5.1.1. Water Colour

Colour in water results from the presence of natural metallic ions (iron and manganese), humus, plankton, weeds and industrial wastes. True colour of water can be observed after the removal of turbidity whereas apparent colour results from substances in solution along with suspended matter. The observed colour of natural water is the result of light being scattered upward from the water after it has passed through the water to various depths and undergone selective absorption en route. Because molecular scattering of light in the water is a function of the fourth power of the frequency, observed light and therefore colour is greater for shorter than longer wavelengths, and blue dominates in the visible portion of the spectrum (**Wetzel, 2001**). This can explain the bluish apparent water colour of the river Relli throughout the year except the monsoon months. Apparent water colour of the river Teesta was sea-green or blue-green in winter and in March. **Malley (1907)** and **Dash (1947)** also reported that the water colour of Teesta is sea-green in dry season. **Wetzel (2001)** explained that colloidal  $\text{CaCO}_3$  in certain glacially-fed streams scatters light in the greens and blues and gives these waters a very characteristic blue-green colour. Apparent colour of water during monsoon was muddy brown or giving a milky hue. This is due to the fact that river water acquires detritus suspension after rain washing received from different sources. Similar water colour was observed by **Malley (1907)** and **Dash (1947)** during the rainy season. Intermediate colour has been also observed during the transitional period.

### 5.1.2. Water Flavour

Flavour refers to a complex of gustatory, olfactory, and trigeminal sensations resulting from stimulation of sensory nerve endings located in the tongue, nasal cavity and oral cavity. Water in pure form is odour free. Most organic and some inorganic chemicals contribute taste or odour. These chemicals may originate from municipal and industrial waste discharges, from natural sources such as decomposition of vegetable matter, or from microbial activity and from disinfectants or their products. Some substances, such as certain inorganic salts, produce taste without odour. Flavour Rating Assessment (FRA) indicated that untreated and unfiltered water of both Teesta and Relli could not be accepted as everyday drinking water because the muddy brown water during monsoon smells strong earthy. This might be due to the reason that during rainy season heavy loading of silt and organic

materials enter into the river from the river basin. In winter months siltation was less, but density of phytoplankton was comparatively higher with suspended sand particle.

### 5.1.3. Air Temperature

The air temperature is the resultant effect of several meteorological factors such as solar radiation, humidity, wind, etc. and also the latitudinal and altitudinal position of the place under study (**Wetzel, 2001**). Moreover it was found that during day time sand, rock, boulders in the river-bed get quickly heated and radiating more heat. The lowest average air temperature in the month of January was 17.1<sup>0</sup>C at the hill stream Relli and 18.6<sup>0</sup>C at the river Teesta. The highest average temperature in the month of August was 32.3<sup>0</sup>C at Relli and in the month of July was 32.4<sup>0</sup>C at Teesta. Monthly and seasonal variations of average air temperature at both the water courses show the almost similar pattern. Monsoon months showed the highest value and winter exhibits lowest. Similarity in the air temperature variations may be result from being in the almost same latitude, longitude and altitude and where similar solar radiation, humidity and wind flow pattern is regulated by the tropical seasonality. Decrease of air temperature was evident in both cases as the altitude of the water course increases. **Mc Gregor and Neuwolt (1998)** calculated that the mean normal lapse rate (rate of decrease in temperature with elevation) within the tropics is approximately 0.65<sup>0</sup>C per 100 m of elevation. Positive and significant correlation between air and water temperature as found in the present study ( $r = 0.892$  and  $0.865$   $P < 0.01$  in Relli and Teesta respectively) was also reported by **Chakraborty et al., (1959)**, **Kant and Anand (1978)**, **Rawat et al., (1995)** and **Wetzel (2001)**.

### 5.1.4. Water Temperature

In the present study the range (12.2<sup>0</sup>C – 24.9<sup>0</sup>C), amplitude (12.7<sup>0</sup>C), mean value (18.2<sup>0</sup>C $\pm$ 3.2) of water temperature of glacier-fed deep river Teesta were found lower than the range (13.3<sup>0</sup>C – 27.8<sup>0</sup>C), amplitude (14.5<sup>0</sup>C), mean value (21.4<sup>0</sup>C  $\pm$ 3.4) of water temperature of shallow spring fed hill stream Relli. Fisher's t was highly significant ( $|t|=6.14$ ,  $p < 0.01$ ) for difference in two means. **Lewis (2008)** opined that annual range of water temperature follows patterns related to latitude, humidity, size of water body, and proximity to coastal waters. The water temperature of both the streams falling within the tolerance limits of the snow trouts and may be termed as cold (**Jhingran and Sehgal, 1978**). Low water temperature is the most characteristic feature of high altitude streams. Streams at the lower end of altitude gradient tend to be slightly cooler than the air (**Jacobsen, 2008**), as found in the present investigation. **Sehgal (1974)**, **Joshi et al., (1978)** and **Sehgal (1988)** have summarized average water temperature in Siwalik zone (below 1000 m asl) in Himalaya as 22.9<sup>0</sup>C. In rivers of Bhutan

Himalaya water temperature ranged from 8.5<sup>0</sup>C to 26<sup>0</sup>C (**Dubey, 1978**). **Thapa et al., (2010)** reported highest temperature 29.6<sup>0</sup>C in glacier-fed Trishuli River in Nepal. **Badola (1979)**, **Nautiyal (1991)** and **Sharma and Mishra (2002)** reported that glacier fed river water were cooler than the spring-fed river. Water temperature showed seasonal variation, minimum water temperature observed in winter and maximum in monsoon months. Similar observation has been made by **Singh et al., (1999)**. Monthly variations of average water temperature of both the streams showed almost similar pattern. In the present study water temperature of both streams increased downstream, similar increment of water temperature in Himalayan Rivers has been recorded (**Singh, 1988; Mathur, 1991; Nautiyal, 2001 and 2010**). Streams in the Ruwenzori Mountains, Uganda, closely follow a vertical lapse rate of 0.5<sup>0</sup>C per 100 m altitude gain, giving a mean temperature of 5<sup>0</sup>C at 4000m asl (**Busulwa and Bailey, 2004**). The water temperature is not determined solely by altitude or air temperature, but some of it may be due to differences in site characteristics such as insolation, groundwater input, and heat loss to evaporation (**Ward, 1985; Walling and Webb, 1992; Caissie, 2006**). **Bose and Gorai (1993)** reported negative significant correlation between water temperature and dissolved oxygen as found in the present investigation ( $r = -0.787$  and  $-0.765$ ,  $P < 0.01$  in Relli and Teesta respectively). **Wetzel (2001); Pathani and Upadhyay (2003)** mentioned significant positive correlation between air and water temperature, which corroborates with the present study.

### 5.1.5. Water Velocity

Water velocity of Himalayan river ranged from 0.06 m sec<sup>-1</sup> to 3.9 m sec<sup>-1</sup>. Highest velocity was found in the glacier-fed river Alaknanda (**Nautiyal, 2010**). The range (1.93 – 4.31 m sec<sup>-1</sup>), mean value (2.75 m sec<sup>-1</sup> ±0.74) of water velocity of glacier fed deep river Teesta were found higher than the range (0.61 – 1.51 m sec<sup>-1</sup>), mean value (0.90 m sec<sup>-1</sup> ±0.24) of water velocity of shallow spring fed stream Relli. Mean difference was highly significant ( $|t|=20.2$ ,  $p < 0.01$ ). **Shrestha (1990)** reported water velocity in Karnali River in Nepal ranged from 0.3 to 4.5 m sec<sup>-1</sup>. Similar high water velocity was observed by **Nautiyal and Nautiyal (1993)** in Garhwal Himalaya. **Dash (1947)** reported that current in river Teesta was swift and dangerous, running in places at 14 miles an hour *ie.*, 6.3 m sec<sup>-1</sup> and was liable to sudden rises in level due to its flow being constricted in a gorge. **Wetzel (2001)** reported that if velocity range is 120 – 200 cm sec<sup>-1</sup>, the general bottom composition will be of large cobbles to boulders and their approximate diameter will be >128mm. **Lampert and Sommer (2007)** opined that stream velocity depends on the incline and smoothness of the substrate, but also on the cross sectional area of the stream which could explain higher water velocity in

river Teesta. Low water velocity during winter and high during monsoon in both the streams might be related to seasonality and with precipitation events, as well as with variations in runoff and ground water inputs (Wetzel, 2001). Sharma *et al.*, (2007) observed that water current remained high throughout the year but it attained the peak value during monsoon months (July-August) due to frequent flash floods. Monthly variation of average water velocity of both the streams exhibited almost similar pattern. Velocity of the water in both the streams increases slightly with the increase of altitude. Water velocity decreased downstream and maximum velocity observed in monsoon months and minimum in winter months in Himalayan rivers has been reported earlier (Singh, 1988; Mathur, 1991; Nautiyal, 2001 and 2010). Water velocity of glacier-fed river was found higher than spring-fed river (Sharma and Mishra, 2002). The water velocity had significant positive correlation with free CO<sub>2</sub> ( $r = 0.803$  and  $0.775$ ,  $P < 0.01$  in Relli and Teesta respectively) and significant negative correlation with DO ( $r = -0.736$  and  $-0.688$ ,  $P < 0.01$  in Relli and Teesta respectively) in both the streams. This might be due to the huge loading of organic materials during the monsoon when water velocity and temperature were high.

#### 5.1.6. pH of water

In the present investigation the range (7.3-8.1), mean value ( $7.6 \pm 0.19$ ) of pH of glacier-fed deep river Teesta were found slightly lower than the range (7.3 – 8.3), mean value ( $7.8 \pm 0.26$ ) of pH of shallow spring fed stream Relli. Mean difference was highly significant ( $|t|=5.93$ ,  $p < 0.01$ ). pH recorded during the present study are comparable with others (Chakraborty *et al.*, 1959; Dubey, 1978; Kumar and Bhagat, 1978; Shrestha, 1990; Juttner *et al.*, 2003; Thapa *et al.*, 2010; Bagra and Das, 2010). Stream water which is just on the alkaline side of neutrality between pH 7.0 and 8.0 is usually good for production of the largest fish crops (Roule, 1930). The maximum pH in winter season (Teesta) and in Pre monsoon (Relli) may be attributed to algal blooms as Hutchinson *et al.*, (1929) and Roy (1955) have shown that the higher pH is associated with the phytoplankton maxima. Several workers have reported low pH during the low photosynthesis due to formation of carbonic acid (Hannan and Yong, 1974; Bais *et al.*, 1995). Present studies have revealed that in both the streams pH slightly increases downstream which corroborates with the observations of other workers (Petr, 1983; Segnini and Chacón, 2005). In the present study the pH showed positive and significant correlation with Conductivity ( $r = 0.735$  and  $0.418$ ,  $P < 0.01$ ), total alkalinity ( $r = 0.622$  and  $0.656$ ,  $P < 0.01$ ), hardness ( $r = 0.395$  and  $0.776$ ,  $P < 0.01$ ) and negative significant correlation with free CO<sub>2</sub> ( $r = -0.559$  and  $-0.581$ ,  $P < 0.01$ ) in Relli and Teesta respectively. Similar relations have been observed by Thapa Chhetri and Pal (2010) and

**Mondal (2009)**, **Bharti and Kore (1975)** and **Prasad *et al.*, (1985)** have obtained close relation between pH and carbonates. A significant correlation between pH and alkalinity has also been reported by **Trivedy (1988)**. **Rawat *et al.* (1995)** reported positive correlation of pH of water of Deoria Tal of Garhwal Himalaya with total alkalinity and inverse correlation with water temperature.

### **5.1.7. Specific Conductance**

The range ( $46 \mu\text{S cm}^{-1}$  -  $98 \mu\text{S cm}^{-1}$ ), mean value ( $70.5 \pm 13.3$ ) of conductivity of glacier fed deep river Teesta were found slightly lower than the range ( $52 \mu\text{S cm}^{-1}$  -  $99 \mu\text{S cm}^{-1}$ ), mean value ( $77.5 \pm 13.5$ ) of conductivity of shallow spring fed stream Relli. Mean difference was highly significant ( $|t|=3.34$ ,  $p < 0.01$ ). The values of conductivity of both the streams as found in the present investigation agree with finding of others (**Singh, 1988; Mathur, 1991; Nautiyal, 2001; Thapa *et al.*, 2010; Dubey, 1978; Boruah and Biswas, 2000**) in different parts of Himalayan river. Lower water volume during Pre monsoon and winter could be associated with high conductivity and during monsoon months the conductivity values were lower due to dilution as a result of high runoff and precipitation. This view has been supported by the findings of **Mondal (2009)**, **Imevbore (1978)**, **Adebisi (1980)** and **Mishra (1999)**. Increase of specific conductance from upstream to downstream, as found in the present study has been reported by earlier workers (**Singh, 1988; Mathur, 1991; Nautiyal 1996, 2001; Segnini and Chacón, 2005**). The specific conductance of water had significant positive correlation with pH, DO ( $r = 0.623$  and  $0.706$ ,  $P < 0.01$ ), total alkalinity ( $r = 0.645$  and  $0.648$ ,  $P < 0.01$ ), total hardness ( $r = 0.432$  and  $0.507$ ,  $P < 0.01$ ) in the Relli and Teesta respectively. Similar observation was also recorded by **Mariappan and Vasudevan (2002)** and **Mondal (2009)**.

### **5.1.8. Dissolved Oxygen**

In the present study, the mean value ( $9.49 \text{ mg L}^{-1} \pm 1.06$ ) of dissolved oxygen of glacier fed deep river Teesta was found slightly lower than the mean value ( $9.71 \text{ mg L}^{-1} \pm 1.15$ ) of dissolved oxygen of shallow spring fed hill stream Relli. Mean difference was not significant. **Nautiyal and Nautiyal (1993)** also reported higher dissolved oxygen in spring-fed than the glacier-fed river in Garhwal Himalaya. **Dobriyal and Singh (1988)** stated that in hill streams the amount of dissolved oxygen is higher because of large surface exposed to air, constant motion, less depth and photosynthesis by green algae. Present result on amount of dissolved oxygen is comparable with the earlier workers in Himalayan rivers and streams (**Dubey, 1978; Singh, 1990; Jhingran, 1991; NWWFCC, 2001; Ranjit, 2002; Biswas and Boruah, 2002; Thapa *et al.*, 2010; Haque *et al.*, 2010; Sharma and Choudhury, 2011**).

The maximum DO found during winter in the present study, may be due to low temperature. Similar observations were made by **Moitra and Bhattacharya (1965)**. **Hancock (1973)** reported that DO was maximum in winter and minimum in summer. The decreased water temperature during winter season has a greater capacity to hold DO than warm water and probably led to a lower rate of respiration thereby allowing maximum DO in winter (**Welch, 1952**). Positive correlation between DO and pH as observed in the present investigation was also reported by **Shastri and Pandse (2001)** and **Mondal (2009)**. Negative correlation between DO, water temperature ( $r = -0.787$  and  $-0.765$ ,  $P < 0.01$ ) and free CO<sub>2</sub> ( $r = -0.835$  and  $-0.790$ ,  $P < 0.01$ ) found in the Teesta and Relli respectively.

### 5.1.9. Free Carbon dioxide

Present study revealed the range (1.2-4.2 mg L<sup>-1</sup>), mean value (2.48 mg L<sup>-1</sup> ±0.64) of free CO<sub>2</sub> of glacier fed deep river Teesta were found slightly lower than the range (0.6 – 5.8 mg L<sup>-1</sup>), mean value (3.11 mg L<sup>-1</sup> ±1.40) of free CO<sub>2</sub> of shallow spring fed hill stream Relli. Mean difference was highly significant ( $|t|=3.86$ ,  $p < 0.01$ ). **Badola (1979)** reported higher value of free CO<sub>2</sub> in spring-fed stream. Present result on amount of free CO<sub>2</sub> in both the streams is comparable with the earlier workers in Himalayan rivers and streams (**NWWFCC, 2001; Biswas and Boruah, 2002; Thapa-Chhetry and Pal, 2011**). As opposed to oxygen entry from air to water, surface agitation is very effective way of elimination of free CO<sub>2</sub> in water (**Welch, 1952**). Lowest Seasonal value in winter months as observed in the present study has also been reported by **Goutam (1990)** and **Sharma et al., (2007)**. Concentration of free CO<sub>2</sub> increased from upstream to downstream was also observed by **Pathani and Upadhyay (2003)**. In the present study free CO<sub>2</sub> showed negative significant correlation with conductivity, pH, DO, total alkalinity, and total hardness in both the river. **Ayyapan and Gupta (1981)** and **Dhanze et al. (1998)** have been observed inverse relationship of free CO<sub>2</sub> with pH and alkalinity ( $r = -0.682$  and  $-0.692$ ,  $P < 0.01$  in the Relli and Teesta respectively). **Rawat et al. (1993)** also found negative correlation between free CO<sub>2</sub> and DO in Deoria Tal Lake.

### 5.1.10. Total Alkalinity

The overall pH in the present study varied from 7.3 – 8.3, hence only bicarbonate alkalinity was obtained at all the sites (**Jhingran, 1991**). The range (23.3-45.6 mg L<sup>-1</sup>), mean value (34.2 mg L<sup>-1</sup> ±5.78) of total alkalinity of glacier fed deep river Teesta was found slightly higher than the range (24.1 – 42.1 mg L<sup>-1</sup>), mean value (33.5 mg L<sup>-1</sup> ±3.97) of total alkalinity of shallow spring fed hill stream Relli. Mean difference was not significant. Total alkalinities recorded during the present study are comparable with others (**Dobriyal and**

Singh, 1988; Goutam, 1990; Mukhopadhyay, 1996; Haque *et al.*, 2010) and both the streams can be categorized as moderately productive water. Because, total alkalinity ranged from 40 to 90 mg L<sup>-1</sup> is considered as medium productive (Jhingran, 1991). Seasonal variations of total alkalinity in the present study showed highest value in winter and lowest value in monsoon months. According to Bishop (1973) low alkalinity in the monsoon months were due to dilution effect. Similar observations were also reported by Dhanapakiam *et al.* (1999) and Shastri and Pandse (2001). Maximum total alkalinity during winter was also reported by Chakraborty *et al.* (1959), Singh (1990), Mishra *et al.* (1998), and Thapa-Chhetry and Pal, 2011, which may be associated with high winter pH. Present investigation revealed increase of total alkalinity downstream in both the streams, similar observation has been made by other investigators in the Himalayan streams (Singh, 1988; Mathur, 1991; Nautiyal 1996, 2001, 2010; Pathani and Upadhyay, 2003). Present investigation revealed increase of total alkalinity downstream in both the streams, similar observation has been made by other investigators in the Himalayan streams (Singh, 1988; Mathur, 1991; Nautiyal 1996, 2001, 2010; Pathani and Upadhyay, 2003) and also in other parts of world (Petr, 1983; Segnini and Chacón, 2005). In the present study, total alkalinity showed positive significant correlation with conductivity, pH, DO, chloride ion, and total hardness and negative significant correlation with free CO<sub>2</sub> and water temperature in both the streams. Barat and Jha (2002) reported positive significant correlation of total alkalinity with hardness. Thapa-Chhetry and Pal (2011) found positive and significant correlation of total alkalinity with total hardness and chloride. A positive correlation between pH and total alkalinity has been observed by Dobriyal and Singh (1988), Trivedi (1988) and Chopra *et al.* (1990). Dhanze *et al.* (1998) confirmed that there is a positive significant relationship between total alkalinity and pH and negative significant relationship between total alkalinity and free CO<sub>2</sub>.

#### 5.1.11. Chloride

In the present study the range (3.2-6.5 mg L<sup>-1</sup>), mean value (4.5 mg L<sup>-1</sup> ±0.53) of chloride of glacier fed deep river Teesta was found slightly lower than the range (3.4 – 7.9 mg L<sup>-1</sup>), mean value (5.9 mg L<sup>-1</sup> ±0.95) of chloride of shallow spring fed stream Relli. Mean difference was highly significant (|t|=12.31, p< 0.01). Goutam (1990) reported concentration of chloride in the river Bhagirathi varied from 2.8 to 4.3 mg L<sup>-1</sup>. Chloride concentration of Torsa river ranged from 5.8 to 11.1 mg L<sup>-1</sup> as observed by Bhadra *et al.* (2003). Sharma and Chowdhary (2011) found range of chloride concentration from 21.95 to 59.88 mg L<sup>-1</sup> with an average value of 36.81 mg L<sup>-1</sup> in the river Tawi of Central Himalaya. Thapa-Chhetry and

**Pal (2011)** reported values of ranged from 7.11 to 11.3 mg L<sup>-1</sup> in Nepal Himalaya. **Shrestha (1990)** observed 6 mg L<sup>-1</sup> in the Karnali River. **Biswas and Boruah (2002)** reported range of chloride concentration from 1.9 to 10.2 mg L<sup>-1</sup> with an average value of 5.6 mg L<sup>-1</sup> in the river Brahmaputra. **Barat and Jha (2002)** reported highest value of 39.4 mg L<sup>-1</sup> in the river Mahananda located in the foot-hill of Darjeeling Himalaya. Maximum amount of chloride in winter and post monsoon months may be due to loading of organic material, high rate of decomposition of organic matter, and low level volume of water. Lowest quantity of chloride recorded in the monsoon might be due to dilution by rain water. **Thapa-Chhetry and Pal (2011)** and **Mondal (2009)** observed almost similar seasonal variations. Present investigation revealed a trend of downstream increase of chloride in both the stream, which may be elevated as a result of human activities. In the present study chloride showed positive significant correlation with conductivity ( $r = 0.745$  and  $0.281$ ,  $P < 0.01$ ), pH ( $r = 0.393$  and  $0.281$ ,  $P < 0.01$ ), total alkalinity ( $r = 0.745$  and  $0.281$ ,  $P < 0.01$ ), and total hardness ( $r = 0.746$  and  $0.776$ ,  $P < 0.01$ ) and negative significant correlation with water temperature ( $r = -0.610$   $P < 0.01$  and  $-0.202$ ,  $P < 0.05$ ) in the Relli and Teesta respectively. **Thapa-Chhetry and Pal (2011)** found positive and significant correlation between chloride and total alkalinity.

#### **5.1.12. Total Hardness**

The range (20.3-30.9 mg L<sup>-1</sup>), mean value (24.7 mg L<sup>-1</sup>  $\pm 2.6$ ) of total hardness of glacier fed deep river Teesta was found slightly higher than the range (18.4 – 27.1 mg L<sup>-1</sup>), mean value (22.7 mg L<sup>-1</sup>  $\pm 1.9$ ) of total hardness of shallow spring fed stream Relli. Mean difference was significant ( $|t|=5.28$ ,  $p < 0.01$ ). The result indicated that water of both the streams may be regarded as soft (**Swingle, 1967; Kannan, 1991**). According to **Boyd (1982)**, normal fish culture needs at least 20 mg L<sup>-1</sup> hardness. Alkalinity and hardness are closely related, since calcium and magnesium which cause most of the hardness of waters, are generally associated with carbonate minerals which are the principal sources of alkalinity. In the present study total alkalinity of water exceeds its total hardness in both the streams, indicating the bicarbonate and carbonate are associated with K<sup>+</sup> and Na<sup>+</sup>. The values of total hardness as found in the present study agreed with the observations of other workers (**Goutam, 1990; Mukhopadhyay; 1996; Barat and Jha, 2002; Haque et al., 2010**). The maximum total hardness was observed in winter season might be due to low volume of water and slow current of water. Similar results were obtained by **Misra et al. (1999)**, **Thapa-Chhetry and Pal (2011)**. Minimum quantity in rainy season may be due to more dilution of water (**Patralekh, 1994**). Similar relationship has also been recorded by **Ruttner (1953)**, **Thapa-Chhetry and Pal (2011)**. Present investigation revealed a trend of downstream

increase of total hardness in both the stream, which may be elevated due to nature of rocks and soils of drainage basin. The total hardness of water had significant positive correlation with Specific conductance, pH, total alkalinity, chloride,  $\text{NO}_3$  ( $r = 0.279$ ,  $P < 0.01$ ) and significant negative correlation with water temperature, water velocity, free  $\text{CO}_2$ . **Thapa-Chhetry and Pal (2011)** found positive and significant correlation between total hardness and total alkalinity. **Mondal (2009)** reported positive correlation of total hardness with conductivity and negative correlation with water temperature in Mirik Lake of Darjeeling.

### 5.1.13. Ammonium-Nitrogen ( $\text{NH}_4\text{-N}$ )

In the present investigation the Ammonium-N concentrations were found out to be low in both the streams. The range (0.016-0.037  $\text{mg L}^{-1}$ ), mean value (0.024  $\text{mg L}^{-1} \pm 0.005$ ) of  $\text{NH}_4\text{-N}$  of glacier fed deep river Teesta was found slightly higher than the range (0.008 – 0.028  $\text{mg L}^{-1}$ ), mean value (0.016  $\text{mg L}^{-1} \pm 0.005$ ) of  $\text{NH}_4\text{-N}$  of shallow spring fed stream Relli. Mean difference was highly significant ( $|t|=9.62$ ,  $p < 0.01$ ). Huge drainage area of the river Teesta may be responsible for the variations. Distribution of  $\text{NH}_4\text{-N}$  as found in the present study corroborates with the distribution of  $\text{NH}_4\text{-N}$  in unpolluted rivers as mentioned by **Wetzel (2001)**. **Thapa et al. (2010)** observed concentration of  $\text{NH}_4\text{-N}$  ranged from nil to 0.013  $\text{mg L}^{-1}$  in the Trishuli River of Nepal. **Jha and Barat (2003)** recorded  $\text{NH}_4\text{-N}$  concentration varied from 0.006 to 0.072  $\text{mg L}^{-1}$  in Mirik lake and suggested that the low concentrations may be due to the fact, that aquatic autotrophs rapidly utilize ammonium ions preferring these to nitrates; accordingly,  $\text{NH}_4\text{-N}$  does not reach a harmful concentration. Present investigation revealed a trend of downstream increase of  $\text{NH}_4\text{-N}$  in both the streams. **Jacobsen (2008)** opined that nutrient (like  $\text{NH}_4\text{-N}$ ) levels in tropical high-altitude streams are not necessarily different from lowland streams, but they may be elevated as a result of human activities or the sometimes naturally-fertile highland soils. The  $\text{NH}_4\text{-N}$  of water had significant positive correlation with  $\text{NO}_3\text{-N}$  ( $r = 0.395$  and  $0.326$ ,  $P < 0.01$ ),  $\text{NO}_2\text{-N}$  ( $r = 0.574$ , and  $0.677$ ,  $P < 0.01$ ) and negative significant correlation with DO ( $r = -0.770$  and  $-0.769$ ,  $P < 0.01$ ) in the Relli and Teesta respectively. **Jana and Barat (1984)** observed similar relation between DO and  $\text{NH}_4\text{-N}$ .

### 5.1.14. Nitrite-nitrogen ( $\text{NO}_2\text{-N}$ )

The range (0.008-0.019  $\text{mg L}^{-1}$ ), mean value (0.013  $\text{mg L}^{-1} \pm 0.003$ ) of  $\text{NO}_2\text{-N}$  of glacier fed deep river Teesta was found slightly higher than the range (0.006 – 0.014  $\text{mg L}^{-1}$ ), mean value (0.009  $\text{mg L}^{-1} \pm 0.002$ ) of  $\text{NO}_2\text{-N}$  of shallow spring fed stream Relli. Mean difference was highly significant ( $|t|=7.18$ ,  $p < 0.01$ ). The Nitrite-N concentrations were found out to be quite low. **Jha and Barat (2003)** reported similar low values of  $\text{NO}_2\text{-N}$  ranged from

0.002 to 0.032 mg L<sup>-1</sup> in Mirik lake. Range of NO<sub>2</sub>-N in the two sub Himalayan Rivers of north Bengal (Torsha and Mahananda) were 0.001-0.008 mg L<sup>-1</sup> and 0.002- 0.030 mg L<sup>-1</sup> respectively (**Bhadra et al., 2003; Barat and Jha, 2002**). The post monsoon showed the highest value and lowest value recorded in the pre monsoon in both the streams and in winter (Teesta). Highest seasonal value in post monsoon may be related to huge organic loading during monsoon and subsequent decomposition in post monsoon. Highest value of NO<sub>2</sub>-N in winter and lowest value in pre monsoon has been reported by **Bhadra et al. (2003)**. The concentration of NO<sub>2</sub>-N showed no change along the elevational gradient of both the streams. **Jacobsen (2008)** opined that nutrient (like NH<sub>4</sub>-N) levels in tropical high-altitude streams are not necessarily different from lowland streams. The NO<sub>2</sub>-N of water had significant positive correlation with NO<sub>3</sub>-N ( $r = 0.574$  and  $0.344$ ,  $P < 0.01$ ), NH<sub>4</sub>-N in the Relli and Teesta respectively.

### 5.1.15. Nitrate-nitrogen (NO<sub>3</sub>-N)

In the present study the range (0.032-0.062 mg L<sup>-1</sup>), mean value (0.046 mg L<sup>-1</sup> ±0.007) of NO<sub>3</sub>-N of glacier fed deep river Teesta was found slightly higher than the range (0.021 – 0.057 mg L<sup>-1</sup>), mean value (0.038 mg L<sup>-1</sup> ±0.009) of NO<sub>3</sub>-N of shallow spring fed hill stream Relli. Mean difference was significant ( $|t|=6.68$ ,  $p < 0.01$ ). The quantities of NO<sub>3</sub>-N as found in the present investigation were slightly higher than the distribution of NO<sub>3</sub>-N as mentioned by **Wetzel (2001)** in unpolluted rivers. The level of nitrates in mountainous Bhagirathi was observed between 0.001 and 0.99 mg l<sup>-1</sup> (**Goutam, 1990**). Range of NO<sub>3</sub>-N in the two sub Himalayan Rivers of north Bengal (Torsha and Mahananda) were 0.090-2.200 mg L<sup>-1</sup> and 0.080- 0.042 mg L<sup>-1</sup> respectively (**Bhadra et al., 2003; Barat and Jha, 2002**). The nitrate-nitrogen values recorded during the present study agree with all these observations and other findings of other workers (**Kumar and Dobriyal, 1993; Chakraborty, 1998b**). The highest concentrations of nitrate were recorded in the post monsoon, probably by the transport of nitrate from the watershed areas with the runoff water. This view is supported by the findings of **Jha and Barat (2003)**. The concentration of nitrate-nitrogen was more during monsoon than during winter months in the river Brahmaputra and ranged from 0.030 to 0.300 mg L<sup>-1</sup> (**Jhingran, 1991**). Present investigation revealed a trend of slight downstream increase of NO<sub>3</sub>-N in the river Teesta but remained almost same in the Relli. **Jacobsen (2008)** opined that nutrient (like NO<sub>3</sub>-N) levels in tropical high-altitude streams are not necessarily different from lowland streams, but they may be elevated as a result of human activities or the sometimes naturally-fertile highland soils. The NO<sub>3</sub>-N of water had significant positive correlation with NO<sub>2</sub>-N, NH<sub>4</sub>-N in both the streams.

### 5.1.16. Phosphate-phosphorus (PO<sub>4</sub>-P)

In the present investigation the range (0.013-0.049 mg L<sup>-1</sup>), mean value (0.025mg L<sup>-1</sup> ±0.010) of PO<sub>4</sub>-P of glacier fed deep river Teesta was found slightly higher than the range (0.006 – 0.033 mg L<sup>-1</sup>), mean value (0.016 mg L<sup>-1</sup> ±0.006) of PO<sub>4</sub>-P of shallow spring fed stream Relli. Mean difference was significant (|t|=6.07, p< 0.01). Low value found in the stream Relli may be due to low receipt of phosphorus from allochthonous source. Similar opinion has been forwarded by **Dhanze *et al.* (1998)**. Throughout the investigation period, the Phosphate-P concentration was found out to be low. Low values of phosphate have been reported from various Himalayan rivers (**Thapa *et al.*, 2010; Barat and Jha, 2002; Chakraborty, 1998b; Kumar and Dobriyal, 1993**) also in lakes and reservoirs (**Raina and Petr, 1999; Jha and Barat, 2003**). Higher value of phosphate-phosphorus during the monsoon and post monsoon period may be due to rain washings received from catchment areas. Similar observation has been made by **Chakraborty *et al.* (1959)**. Present investigation revealed a trend of downstream increase of PO<sub>4</sub>-P in both the streams. **Jacobsen (2008)** opined that nutrient (like PO<sub>4</sub>-P) levels in tropical high-altitude streams are not necessarily different from lowland streams, but they may be elevated as a result of human activities or the sometimes naturally-fertile highland soils. The total PO<sub>4</sub>-P had significant positive correlation with NO<sub>3</sub>-N (r = 0.326, P<0.01 and 0.243, P<0.05), NO<sub>2</sub>-N (r = 0.680 and 0.626, P<0.01), NH<sub>4</sub>-N (r = 0.745 and= 0.863, P<0.01) and significant negative correlation with pH, conductivity, total alkalinity and Hardness in Relli and Teesta respectively.

### 5.1.17. Principal Component Analysis (PCA) of Physico-chemical Variables

The Principal Component Analysis (PCA) is a statistical technique of simply data reduction, and it does so by transforming the original data to describe the same amount of variability, the total variance, with the same number of axes. It seeks to reduce the complexity of the interrelationships among a potentially large number of variables to a new set of uncorrelated transformed variables which are expressed as a linear combinations of the original variables, and termed as principal components (PCs) (**Raykov and Marcoulides, 2008**). The PCs are used to discover and interpret the dependences that persist among the variables, and to investigate relationships that may exist among individuals (**Timm, 2002**). The PCA concentrates variances of the original data set and explains a large part of total variances of the variables (**Rencher, 2002**), though it does not ignore co-variances and correlation of the original data set (**Jolliffe, 2002**).

### **5.1.17.1. PCA of Water Quality of the hill-stream Relli**

#### **5.1.17.1.1. Principal Component I: More Physical/ Nutrients and Less Chemical**

The physico-chemical quality of water of the stream Relli is mostly influenced by the greater presence of physical/nutrient parameters and less presence of chemical parameters. Inorganic carbon, Nitrogen and phosphorus constitute what are called *nutrients*. They are essential to the composition of living matters. Inorganic carbon, Nitrogen and phosphorus are major nutrients of photosynthetic, protein and nucleic acid metabolism. Thus, high positive loadings of free carbon dioxide, ammonium nitrogen, phosphate phosphorous and nitrate nitrogen ions on the first principal component suggest that the first principal component is associated with a combination of various hydrogeochemical processes and augment more mineralized water (TDS) with nutrients essential for stream metabolism. Temperature and water velocity of the stream are two physical factors augmenting mineralization and metabolism as indicated by their high positive loading. At the same time high negative loadings of total alkalinity, dissolved oxygen, conductivity, total hardness, pH value, chloride ion in the first principal component indicated that the first principal component is associated with less presence of ions which make up TDS of stream water.

#### **5.1.17.1.2. Principal Component II: More Nutrients, Less Physical**

High positive loading of nutrient  $\text{NO}_3\text{-N}$  in the second principal component indicates that the second principal component is associated with a combination of various hydrogeochemical processes and augments more mineralized water (TDS) with nutrient ( $\text{NO}_3\text{-N}$ ) essential for stream metabolism. More nitrate nitrogen, an essential plant nutrient in the stream water, utilized by nitrifying bacteria, phytoplankton, periphyton and aquatic macrophytes. Whereas less negative loadings of water temperature and velocity suggests mineralization operates at comparatively low water temperature and velocity. Thus, densities of primary producers increase when water temperature and water velocity is less.

#### **5.1.17.1.3. Principal Component III: More Chemicals**

The high positive loadings of  $\text{HCO}_3^-$  (total alkalinity), calcium and magnesium salts with carbonate, bicarbonate, sulphates, chlorides, and other anions of mineral acids (total hardness) on the third principal component suggest that the third principal component is associated with a combination of various hydrogeochemical processes and augment more mineralized water (TDS) for stream metabolism.

## **5.1.17.2. PCA of Water Quality of the river Teesta**

### **5.1.17.2.1. Principal Component I: More Physical/ Nutrients and Less Chemicals**

First principal component is associated with a combination of various hydrogeochemical processes and augment more mineralized water (TDS) with nutrients (free CO<sub>2</sub>, PO<sub>4</sub>-P, NO<sub>3</sub>-N, NO<sub>2</sub>-N & NH<sub>4</sub>-N) essential for stream metabolism. Water temperature is the physical factor augmenting mineralization and metabolism as indicated by their high positive loading. High negative loadings of DO and conductivity in the PC I indicated that it is associated with less presence of ions and DO may be resulted from more utilization during metabolism.

### **5.1.17.2.2. Principal Component I: More Chemicals and less physical**

The high positive loadings of H<sup>+</sup> and OH<sup>-</sup> (pH), HCO<sub>3</sub><sup>-</sup> (total alkalinity), Ca and Mg salts with, CO<sub>3</sub><sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>-</sup>, Cl<sup>-</sup> and other anions of mineral acids (total hardness) on the PC II suggest that the component is associated with a combination of various hydrogeochemical processes and augment more mineralized water (TDS) for stream metabolism when water velocity is less.



## 5.2. *Phytoplankton Diversity*

---

### 5.2.1. Taxonomic diversity

In the present investigation, a total of 47 genera of phytoplankton found in the glacier-fed river Teesta was higher than 34 genera observed in spring fed hill stream Relli. Both the streams were dominated by Bacillariophyceae followed by Chlorophyceae, Cyanophyceae and Euglenophyceae. In the river Teesta another group Dinophyceae was found with least frequency. Higher number of phytoplankton genera in the river Teesta may be due to larger drainage area and variety of habitats. Almost similar number of genera in other Himalayan streams has been reported by **Negi *et al.*, (2007)** and **Negi and Rajput, (2011)**. **Nautiyal (1984)** reported that the diatoms account for more than 80% of the potamo-phytoplankton in Himalayan streams and rivers. **Jhingran (1991)** reported that the bacillariophyceae formed the most dominant group followed by Chlorophyceae, Myxophyceae and Desmidiaceae among phytoplankton in the Brahmaputra River near Tezpur. Almost similar pattern of dominance of phytoplankton groups was observed in the present investigation. **Biswas and Boruah (2000)** found Diatoms was dominant among phytoplankton of Brahmaputra River. Seasonal variations of occurrence of different phytoplankton group in both the streams showed an interesting pattern in the present study. Cyanophyceae give peak during pre monsoon, Chlorophyceae crested during post monsoon, and Bacillariophyceae presented peak during winter months. Diatoms grow on rocks and boulders as benthic or periphytic algae. **Lund (1965)** reported abundance of Bacillariophyceae population in colder months and opined that they grow under the condition of weak light and low temperature. **Zafar (1967)** also observed colder months to be more favourable for the multiplication of Bacillariophyceae in fresh water bodies. **Rao (1955), Sarwar and Jutsi (1988)** reported that the cold water was more suitable for the growth of the diatoms. Chlorophyceae were abundant during the post monsoon months in the backwater “dead zones” of reduced currents near and among the banks and flood plains. During the period there was bright sunshine and water was alkaline. **Philipose (1967)** reported development of Chlorococcales in bright sunshine and alkaline pH range of 7.7 to 8.5. In the present study Cyanophyceae grow well in back water, rock pools like Chlorophyceae, but during the pre monsoon months. This may be due to long photoperiod and abundance of organic matter in low water level. Similar observations have been made by **Rao (1955)**. The generation times of river phytoplankton must be more rapid than the time of displacement downstream (**Wetzel, 2001**). Survival in rivers is aided by a number of water retentive mechanisms, particularly backwater “dead

zones” of reduced currents near and among the banks and flood plains. These backwater areas retain water sufficiently to permit additional cell divisions of suspended phytoplankton (Allan, 1995; Wetzel, 2001). Thus, Perenniation of phytoplankton in rivers arises from surviving periphytic and benthic populations, often of backwater areas (Cummins, 1964; Reynolds and Descy, 1996) in various stages of growth or dormancy (Wetzel, 2001). A theoretical assumption that can account for this phytoplankton structure builds-up from the life history strategies for phytoplankton composition, which includes R-strategy (ruderal or opportunist) species, C-strategy (competing) species and S-strategy (stress tolerant) species, and addresses how species are associated with particular categories of water bodies (Reynolds 1988a)

Coexistence of many competitive phytoplankton species as found in the present investigation is extremely common in nature. However, experiments and mathematical theories show that interspecific competition often leads to the extinction of most inferior species (competitive exclusion principle). This is known as '*paradox of the plankton*' (Hutchinson, 1961). Hutchinson himself already suggested that the explanation could be that plankton communities are not in equilibrium at all due to weather-driven fluctuations. Subsequent research confirmed that such externally imposed variability can allow many species to coexist. Another important point is that in practice the homogeneous well-mixed conditions assumed in the competitive exclusion principle hardly exist. Various competition and predation models suggest that even in homogeneous and constant environments plankton will never settle to equilibrium. Instead, interactions between multiple species may give rise to oscillations and chaos, with a continuous wax and wane of species within the community. This chaotic behaviour implies among other things that plankton dynamics are intrinsically unpredictable in the long run when viewed in detail. Nonetheless, on a higher aggregation level, indicators such as total algal biomass may show quite regular patterns (Scheffer *et al.* 2003).

Highest value of Sorensen's similarity index in both the streams may be result of more or less uniform water temperature, water velocity, zooplankton density and number of zooplankton genera. According to Singh (2012) more or less uniform environmental conditions are revealed by higher value of similarity index, in contrast lower value indicates distinct heterogeneity. Value of similarity Index (Sorensen's Coefficient of Community) of phytoplankton between two streams was 0.84.

## 5.2.2. Density and Diversity Indices

In the present study range (16 - 137 unit L<sup>-1</sup>) and mean (67.9 unit L<sup>-1</sup>±28.9) of phytoplankton density in the glacier fed river Teesta is higher than the range (16 – 91 unit L<sup>-1</sup>) and mean (48.6 unit L<sup>-1</sup>±18.5) of the spring feed stream Relli. Mean difference was highly significant (|t|=4.88, p< 0.01). **Jhingran, (1991)** observed similar low phytoplankton density in the river Brahmaputra which varied from 13 – 81 unit L<sup>-1</sup>. Biomass and productivity of phytoplankton is very low in Himalayan streams, they are even low in low order streams. The view is supported by **Ryder and Presendorfer (1989)** and they said biomass and productivity of phytoplankton is often light-limited by advective flows and turbidity. The range (9 - 32), mean (21.1±5.5) of number of phytoplankton genera in the glacier-fed river Teesta is higher than the range (8 - 25), mean (17.8±4.2) of number of phytoplankton genera in the spring fed stream Relli. Mean difference was highly significant (|t|=4.17, p< 0.01). But contrary to the present study, **Dobriyal (1991)** have found glacial snow-fed Bhagirathi with high water velocity favours low growth of phytoplankton (0.1 to 4.6 units/ml) while spring-fed and moderately warm Nayar with low velocity favours good phytoplankton growth (0.4 – 9.06 units/ml). **Nautiyal (1984)** have also reported similar low (0.55 to 4.59 units/ml) diatom density in glacier-fed Alaknanda and high (0.40 to 9.06 units/ml) in spring-fed Nayar. High phytoplankton density in the glacier-fed Teesta with high velocity may be explained on the basis of large water shed, many tributary streams and various microhabitats. Backwater “dead zones” of reduced currents near and among the banks and flood plains, many deep pools and periphytic and benthic algal population may continuously supplying phytoplankton. Factors controlling phytoplankton growth includes light, temperature, water current, substrate, water chemistry and invertebrate grazing, all these factors have potential effects on periphytonic populations (**Whitton, 1975; Hynes, 1970; Biggs, 1996**). **Chankraborty et al., (1959)** reported low densities in fast flow areas and high densities in slow flow areas. Phytoplankton are sensitive to velocity and turbulence of flow in the streams. Phytoplankton density and number of phytoplankton genera in the present investigation have shown significant negative correlation with water velocity in both the streams (r = -0.858, P<0.01 in Teesta and r = -0.805, P<0.01 in Relli). According to **Hynes (1972)** water movement, turbidity, temperature and nutrients are the main environmental factors which control the abundance of plankton. High water velocity and turbidity has a negative impact on the growth of phytoplankton. Erosive silt in the rivers acts as an opaque screen to all wavelengths of light not allowing the phytoplankton to carry out photosynthesis. **Chandler (1937)** and **Cushing (1965)** reported that mechanical destruction of plankton occurs by the grinding action of water heavily laden with silt. All these factors may be responsible for low density and number of genera of

phytoplankton in both the streams in monsoon months at all the sites. In a period of high turbidity and temperature during monsoon months, especially in the outflow zone, the nutrient concentration increased, but the water transparency decreased. It was found that the phytoplankton density and number of genera was then low. Thus, light is an important factor for phytoplankton growth through photosynthesis, in which light energy is used to transform inorganic molecules into organic matter (**Graham and Wilcox, 2000**). Turbulence, sediment instability, high turbidity, reduced light availability, and other characteristics preclude extensive photosynthesis, despite high nutrient availability (**Wetzel, 2001**). Further, phytoplankton population density exhibited a negative correlation with the nutrients ( $\text{PO}_4\text{-P}$ ,  $\text{NO}_2\text{-N}$  and  $\text{NH}_4\text{-N}$ ). Occurrence of higher density during the winter season especially coincided with the lower nutrients concentration and this might be during the utilization by the phytoplankton, similar observations were also made by **Ananthan (1995)** from Pondicherry coastal environments. **Smith (1983)** had discussed the role of phosphate in the formation of bloom. Probably, higher amount of phosphate and nitrogen are pre-requisite for the luxuriant growth of phytoplankton. Phytoplanktons need a wide variety of chemical elements but the two critical ones are nitrogen and phosphorous (**Dawes, 1981**). **Wani and Subla (1990)** reported that the higher pH values in natural waters were produced by photosynthetic rate that demands more  $\text{CO}_2$  than quantities furnished by respiration and decomposition. Thus, phytoplankton population density and number of genera exhibited a significant negative correlation with free  $\text{CO}_2$  ( $r = -0.792, -0.616, P < 0.01$  in Teesta and  $r = -0.719, -0.690, P < 0.01$  in Relli) and significant positive correlation with pH ( $r = 0.646, 0.540, P < 0.01$  in Teesta and  $r = 0.525, 0.448, P < 0.01$  in Relli). The higher range of pH indicates higher productivity of water (**Khan and Khan, 1985**). The pH of a water body determines the solubility and biological availability of certain chemical nutrients (**Ghosh et al., 2012**). Several workers like **Hannan and Yong (1974)**; **Bais et al., (1995)** have reported low pH during the low photosynthesis due to formation of carbonic acid. Thus, higher pH is associated with the phytoplankton maxima (**Hutchinson et al., 1939**; **Roy, 1955**). Bicarbonate alkalinity of water exhibited significant positive correlation with density, number of phytoplankton genera in both the streams. Alkalinity plays an important role in aquatic production and is associated with free  $\text{CO}_2$  and pH. **Jhingran (1991)** suggested that the water bodies having total alkalinity from 40 to 90  $\text{mg L}^{-1}$  is considered as medium productive and above 90  $\text{mg L}^{-1}$  as highly productive. The specific conductance of the common bicarbonate type river water is closely proportional to concentration of the major ions ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{CO}_3^{2-}$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ ) (**Juday and Birge, 1933**; **Rodhe, 1949**). In this study density and number of phytoplankton genera and exhibited significant positive correlation with specific

conductance ( $r = 0.714, 0.601, P < 0.01$  in Teesta and  $r = 0.644, 0.658, P < 0.01$  in Relli). An increased conductivity due to essential ions present in the water from anthropogenic sources and the climatic monsoon effect may result in increased density, and number of phytoplankton genera. Maximum Chloride content has been correlated with high degree of organic pollution and eutrophication (**Goel *et al.*, 1980**). This might be reason for significant positive correlation of density, number of phytoplankton genera with Chloride ( $r = 0.278, P < 0.01; 0.196, P < 0.05$  in Teesta and  $r = 0.773, 0.784, P < 0.01$  in Relli). The total hardness of water is governed by the content of calcium and magnesium salts, largely combined with bicarbonate and carbonate, sulfates, chlorides, and other anions of mineral acids. All essential for the growth of phytoplankton, hence showed positive significant correlation with phytoplankton density and number of phytoplankton genera ( $r = 0.676, 0.663, P < 0.01$  in Teesta and  $r = 0.689, 0.728, P < 0.01$  in Relli). **Dobriyal and Singh (1988)** stated that in hill streams the amount of dissolved oxygen is higher because of large surface exposed to air, constant motion, less depth and photosynthesis by green algae. The dissolved oxygen concentration depends on the photosynthetic rate and subsequently on nutrient concentrations. The dissolved oxygen concentration increases with increasing of photosynthetic rate (**Wheeler *et al.*, 2002**). In the present study the dissolved oxygen exhibited significant positive correlation with density and number of phytoplankton genera ( $r = 0.785, 0.616, P < 0.01$  in Teesta and  $r = 0.727, 0.638, P < 0.01$  in Relli). This indicates higher photosynthetic rates and high productivity during winter months. In general, the requirement of dissolved oxygen for growth of many diatom species is well documented. In the present study, the river water showed higher population of diatoms coincided with the higher dissolved oxygen throughout the study period. The investigation of **Venkateshwarlu (1970)** who found that diatoms choose well aerated waters that are rich in dissolved oxygen, which support the present observation. Similar winter maxima and monsoon minima of phytoplankton has been reported by **Joshi *et al.* (1993)** and **Dobriyal and Singh (1988)**. **Joshi *et al.* (1996)** also reported that the plankton density was maximum during winter and it decreased due to increased turbidity during rainy season.

Range (2.92 – 4.65 bits per individual) and mean (3.96 bits per individual  $\pm 0.40$ ) of Shannon-Wiener diversity index for phytoplankton in the glacier-fed river Teesta is higher than the range (2.91 – 4.34 bits per individual) and mean (3.87 bits per individual  $\pm 0.40$ ) found in the spring-fed stream Relli. Mean difference was not significant. S-W diversity index  $> 4.0$  have been reported from other parts of Himalaya *e. g.*, Shillong stream (1.6 to 4.1; **Rout and Gour, 1994**). Lesser Himalayan spring-fed tributaries of Garhwal Himalaya had relatively higher diatom diversity levels (2.02 to 3.02) in the Saung and (2.37 to 3.58) in

the Nayar (**Nautiyal, 1997**). The value of Shannon-Wiener species diversity index (S-W Index) or  $H'$  vary from 0, where the community is composed of single species ( $\log_2 1=0$ ), to 4.5 or 5 bits/ individual for the most diversified community (**Faurie et al., 2001**). Lowest value of Shannon-Wiener diversity index (S-W index) was found in the monsoon months may be due to low density and less occurrences of number of phytoplankton genera. This may be related to high water velocity and increased turbidity of water. Highest value of S-W diversity index found in pre monsoon and winter months indicates that the ecosystem does not suffer any exogenous disturbance during the period, and the settlements diversify over time. Similar view expressed by **Faurie et al. (2001)** and they opined that the value of  $H'$  goes beyond 2.5 bits per individual. In Shannon-Wiener legislation, the studied aquatic environment may be classified as good quality (**Mishra et al., 2010**). According to the scale of pollution in terms of species diversity in the studied stretches of streams may be categorized as slightly polluted (**Staub et al., 1970**). Number of species and even distribution of individuals per species are the two important components of species diversity which increases with increased number of species and more even distribution of individuals among species. Therefore, diversity measures both species richness and species evenness (distribution of individuals among the species) in a community (**Poole, 1974**). Species diversity index in the present study had significant positive correlation with Phytoplankton density ( $r = 0.646$ ,  $P < 0.01$  in Teesta and  $r = 0.773$ ,  $P < 0.01$  in Relli), number of phytoplankton genera ( $r = 0.933$ ,  $P < 0.01$  in Teesta and  $r = 0.952$ ,  $P < 0.01$  in Relli), Margalef's Species richness index ( $r = 0.946$ ,  $P < 0.01$  in Teesta and  $r = 0.958$ ,  $P < 0.01$  in Relli) and evenness index ( $r = 0.180$ ,  $P < 0.07$  in Teesta and  $r = 0.326$ ,  $P < 0.01$  in Relli). **Hill (1973)** hypothesized that richness fundamentally regulates variation in evenness and diversity statistics.

Most of the phytoplankton communities, as in the present investigation, contain a few dominant species and many species that are relatively uncommon. In the present study, Range (0.86 – 0.96) and mean ( $0.91 \pm 0.02$ ) of evenness index for phytoplankton in the glacier-fed river Teesta is slightly lower than the range (0.91 – 0.98) and mean ( $0.94 \pm 0.02$ ) found in the spring-fed stream Relli. Mean difference was highly significant ( $|t|=8.64$ ,  $p < 0.01$ ). A greater evenness may be biologically equivalent to having more species, since a species that is present in small numbers is unlikely to contribute much to density and diversity. Assemblage of phytoplankton community with opportunist, competing and stress tolerant species in different proportion might have resulted in highest value of evenness index during post monsoon (In Relli) and monsoon months (in Teesta). Evenness index for phytoplankton had negative correlation with Phytoplankton density ( $r = - 0.427$ ,  $P < 0.01$ ) and number of Phytoplankton genera (In Teesta river). In the hill stream Relli evenness index for

phytoplankton had negative correlation with Phytoplankton density but positive correlation number of Phytoplankton genera. **Hill (1973)** hypothesized that richness fundamentally regulates variation in evenness and diversity statistics. But, the empirical review by **Stirling and Wilsey (2001)** also indicated that there can be important deviations from the expectation of a strong positive relationship between richness and evenness. For example, they found that richness and evenness were negatively correlated, and that evenness can account for more variation in diversity indices than richness in plant communities. Negative relationships between plant richness and evenness were also found by **Weiher and Keddy (1999)**, **Bell (2003)**, and **Wilsey *et al.*, (2005)**.

In the present investigation range (2.52 – 6.56) and mean (4.82 ±0.92) of richness index for phytoplankton in the glacier-fed river Teesta was slightly higher than the range (2.23 – 5.37) and mean (4.35 ±0.75) found in the spring-fed stream Relli. Mean difference was highly significant ( $|t|=3.48$ ,  $p < 0.01$ ). As the Species diversity index (H') and species richness index (R) depend upon the number of species as well as number of individuals in each species and contribute equally to the values of H' and d (**Ludwig and Reynolds, 1988**). Hence if any one of these two variables decreases or increases, it will affect the overall values of Species diversity index (H') and species richness index (d). Environmental stress such as flash floods, high water velocity and turbidity might have resulted in the dominance of a few phytoplankton species and which in turn responsible for lowest value of richness index in monsoon months. Similar opinion has been expressed by **Plafkin *et al.*, (1989)**. Margalef's Species richness index for phytoplankton in both the streams were positively correlated with density ( $r = 0.606$ ,  $P < 0.01$  in Teesta and  $r = 0.739$ ,  $P < 0.01$  in Relli), number of genera ( $r = 0.954$ ,  $P < 0.01$  in Teesta and  $r = 0.954$ ,  $P < 0.01$  in Relli), S-W diversity index ( $r = 0.946$ ,  $P < 0.01$  in Teesta and  $r = 0.958$ ,  $P < 0.01$  in Relli) and evenness index ( $r = 0.076$ , in Teesta and  $r = 0.238$ ,  $P < 0.05$  in Relli). Neutral diversity theories predict that species number and immigration rates are sufficient to predict animal and plant community abundance distributions (**Caswell 1976; Bell 2000; Hubbel 2001**), and Caswell's model makes explicit predictions that evenness and richness will be positively correlated in the absence of species interactions.

In the present study range (0.046 – 0.160) and mean (0.081 ±0.02) of dominance index for phytoplankton in the glacier-fed river Teesta is almost similar to the range (0.057 – 0.152) and mean (0.081 ±0.03) found in the spring-fed stream Relli. Mean difference was not significant. The present investigation also indicated that, evenness index and index of dominance have significant negative correlation in both the streams, as predicted by

**Whittaker (1963)** and **Walting *et al.*, (1979)**. In the present study index of dominance was negatively correlated with evenness index ( $r = -0.209$ ,  $P < 0.05$  in Teesta and  $r = -0.400$ ,  $P < 0.01$  in Relli) of phytoplankton in both the streams. Environmental stress such as flash floods, high water velocity and turbidity during monsoon months might have resulted in the dominance of a few phytoplankton species in both the streams. A community dominated by relatively few species indicates environmental stress (**Plafkin *et al.*, 1989**).

### **5.2.3. Altitudinal variation of Density and Diversity Indices**

Along the elevational gradient of the hill stream Relli (*i.e.*, along RR-I, RR-II and RR-III) average value of density and diversity indices like Number of genera (S), Species diversity index (H'), and Species richness index (R) of phytoplankton community showed decreasing tendency with the increase of altitude in the selected stretch of hill stream Relli, but on the contrary index of dominance ( $\lambda$ ) and Evenness index (J') increased with the increase of altitude. Interestingly, in the present study, highest average value of evenness index (J') and lowest average values of density, and S-W diversity index (H') of phytoplankton community were found at RR-II. This might be due to anthropogenic disturbances such as car and cloth washing, boulder and sand lifting, fishing etc. in the RR-II.

But, in the river Teesta average value of diversity indices like Number of genera (S), Species diversity index (H'), Evenness index (J') and Species richness index (R) of phytoplankton community showed decreasing tendency with the increase of altitude in the selected stretch. Density of phytoplankton was slightly higher in TR-I than TR-II and TR-III but lower than TR-IV. On the contrary, index of dominance ( $\lambda$ ) increased with the increase of altitude. Altitude is frequently correlated with changes in diversity (**Lomolino, 2001**). Generally, the observed pattern is marked by a decrease in species diversity and the substitution of species as altitude increases; however, the processes that determine those patterns remain poorly understood (**Lomolino, 2001**). Several hypotheses have been proposed to explain such changes in diversity associated with altitude; most of them are based on only a few ecological factors. These can be summarized as: (1) reduction in the available area and environmental complexity, (2) greater severity of climatic conditions, (3) reduction in the diversity of available resources and (4) decrease in primary productivity with increasing altitude (**Huston, 1994**). There is no consensus on how these ecological factors co-vary and interact with environmental variables to generate the patterns of diversity observed in mountains (**Nogués-Bravo *et al.*, 2008**). The density and diversity of phytoplankton assemblages along the gradient of both the streams was in agreement with the “river continuum concept” (**Vannote *et al.*, 1980**). Central to the RCC (**Vannote *et al.*, 1980**) are

the linked concepts that: (a) physical variables within a river network present a ‘continuous gradient’ of physical conditions from headwaters to a river’s mouth; and (b) this longitudinal gradient ‘ . . . should elicit a series of responses within the constituent populations resulting in a continuum of biotic adjustments and consistent patterns of loading, transport, utilization and storage of organic matter along the length of a river’. Such concept involving energy sources and allocation (**Vannote *et al.*, 1980**) *i.e.*, at lower altitudes, there are higher amounts of energy available because of more solar radiation, more resources (for example, minerals and water); as a result, even higher levels of species richness can be allowed at lower altitudes.

#### **5.2.4. Annual variation of Density and Diversity Indices**

In the present study, annual variation of density and diversity indices of phytoplankton community in the stream Relli showed slight fluctuation. During 2007-08, the average value of phytoplankton density ( $50.4 \text{ uL}^{-1}$ ), number of genera (18.0), S-W diversity index (3.88), and richness index (4.371) was found to be slightly higher than 2008-09 (*i.e.*, 46.9, 17.7, 3.86, and 4.332 respectively). But, the average value of phytoplankton evenness index (0.946) during 2008-09 was found to be slightly higher than 2007-08 (*i.e.*, 0.939). Interestingly, average value (0.081) of dominance index was found same in both the year of study. Similarly in the river Teesta, during 2008-09, the average value of number of phytoplankton genera (21.06), S-W diversity index (3.92), evenness index (0.904) and richness index (4.745) was found to be slightly higher than 2007-08 (*i.e.*, 21.13, 4.01, 0.924 and 4.887 respectively). But, the average value of phytoplankton density ( $70.8 \text{ uL}^{-1}$ ) and dominance index (0.084) during 2007-08 was found to be slightly higher than 2008-09 (*i.e.*,  $60.1 \text{ uL}^{-1}$  and 0.077 respectively). Indicating strong seasonal variation of phytoplankton density and diversity indices in a highly predictable manner year after year unless occurrence of huge natural disaster. Dynamics of phytoplankton diversity may be the result of adaptation to geomorphological and physico-chemical characteristics which form fundamental template along drainage basin of the streams. This could have evolved during the evolution of Himalayan mountain system.

#### **5.2.5. Phytoplankton diversity in relation to water quality**

The plankton production depends on various biotic and abiotic factors (**Welch, 1952; Wetzel, 2001**). The main tendencies of physico-chemical variables reflected in two principal components (PC-I and PC-II) for the river Teesta. Ordinary Least Square (OLS) or linear regression analysis shows causal relationship between the principal components of physico-chemical parameters and density and diversity of phytoplankton. The principal component I

(PC-I) has significant negative influence and principal component II (PC-II) has significant positive impact on the phytoplankton density, number of phytoplankton genera, Shannon-Wiener diversity Index, Margalef's richness Index of phytoplankton. PC-I might have exerted negative significant effect with raised ionic strength (specific conductance) in clear water and in comparatively low temperature. The condition resulted in enhanced growth of phytoplankton density, increased number of phytoplankton genera as well as raised values of Shannon-Wiener diversity Index and Margalef's richness Index. During which free CO<sub>2</sub> and other nutrients (PO<sub>4</sub>-P, NO<sub>3</sub>-N, NO<sub>2</sub>-N & NH<sub>4</sub>-N) were utilized and more oxygen was evolved due to augmented metabolism and photosynthetic activity. PC-II may possibly applied positive significant effect on the phytoplankton density, number of phytoplankton genera, Shannon-Wiener diversity Index, Margalef's richness Index by the way of increasing H<sup>+</sup> and OH<sup>-</sup> (pH), HCO<sub>3</sub><sup>-</sup> (total alkalinity), Ca and Mg salts with, CO<sub>3</sub><sup>=</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>=</sup>, Cl<sup>-</sup> and other anions of mineral acids (total hardness), when water velocity was less. Evenness Index and Index of dominance both increased when water velocity and nutrient (free CO<sub>2</sub>, PO<sub>4</sub>-P, NO<sub>3</sub>-N, NO<sub>2</sub>-N & NH<sub>4</sub>-N) loading is high, but with less production of oxygen, decreased values of ionic strengths (specific conductance), H<sup>+</sup> and OH<sup>-</sup> (pH), HCO<sub>3</sub><sup>-</sup> (total alkalinity), Ca and Mg salts with, CO<sub>3</sub><sup>=</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>=</sup>, Cl<sup>-</sup> and other anions of mineral acids (total hardness). Dominance of phytoplankton might have been inversely regulated by H<sup>+</sup> and OH<sup>-</sup> (pH) and Ca and Mg salts with, CO<sub>3</sub><sup>=</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>=</sup>, Cl<sup>-</sup> and other anions of mineral acids (total hardness) of the river water.

The main tendencies of physico-chemical variables reflected in three components (PC-1, PC-II and PC-III) in the hill stream Relli. Ordinary Least Square (OLS) or linear regression analysis shows causal relationship between the principal components of physico-chemical parameters and density and diversity of phytoplankton. Phytoplankton density regulated by the physico-chemical water quality of Relli in a slightly different fashion. The OLS estimation indicated that variations in phytoplankton density were regulated significantly in three ways. Firstly, Phytoplankton density increased when water temperature and velocity was low and NO<sub>3</sub>-N was more. According to **Hynes (1972)** water movement, turbidity, temperature and nutrients are the main environmental factors which control the abundance of plankton. High water velocity and turbidity has a negative impact on the growth of phytoplankton. Phytoplankton community of both the streams was dominated by diatoms which grow well in cold water and weak light (**Lund, 1965**) and nutrient like NO<sub>3</sub>-N is an important factor. Secondly, increased values of total alkalinity, Chloride and total hardness augmented the growth of phytoplankton density. Increased values of HCO<sub>3</sub><sup>-</sup> (total alkalinity), Ca and Mg salts with, CO<sub>3</sub><sup>=</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>=</sup>, Cl<sup>-</sup> and other anions of mineral acids

(total hardness) indicating more mineralization of stream water may be essential for phytoplankton growth. Thirdly, Phytoplankton density also increased when total alkalinity, dissolved Oxygen, Specific conductance, pH, Chloride and total hardness increases and Water temperature, velocity, free Carbon dioxide, PO<sub>4</sub>-P, NO<sub>2</sub>-N and NH<sub>4</sub>-N decreases. Increased values of H<sup>+</sup> and OH<sup>-</sup> (pH), HCO<sub>3</sub><sup>-</sup> (total alkalinity), Ca and Mg salts with, CO<sub>3</sub><sup>=</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>=</sup>, Cl<sup>-</sup> and other anions of mineral acids (total hardness), increment of major ions such as Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>, CO<sub>3</sub><sup>2-</sup>, SO<sub>4</sub><sup>2-</sup>, Cl<sup>-</sup> (specific conductivity) indicating more mineralized stream water that enhances phytoplankton growth with the evolution of more O<sub>2</sub> due to photosynthetic activity. During this enhanced growth period more nutrients like free CO<sub>2</sub> and PO<sub>4</sub>-P, NO<sub>2</sub>-N and NH<sub>4</sub>-N utilized and the process was aided by low water temperature and low water velocity. Number of phytoplankton genera, Shannon-Wiener diversity Index and Margalef's richness Index increased when water temperature and velocity was low and NO<sub>3</sub>-N was more. All the three diversity indices also increased when total alkalinity, dissolved Oxygen, Specific conductance, pH, Chloride and total hardness increases and water temperature, velocity, free Carbon dioxide, PO<sub>4</sub>-P, NO<sub>2</sub>-N and NH<sub>4</sub>-N decreases. On the contrary, evenness index of phytoplankton in Relli significantly regulated by NO<sub>3</sub>-N and NO<sub>2</sub>-N indicating nitrogen may be essential for evenness of phytoplankton community. Interestingly, Index of phytoplankton dominance increased when water temperature and velocity was high and NO<sub>3</sub>-N was less. Index of dominance was also increased when total alkalinity, dissolved Oxygen, Specific conductance, pH, Chloride and total hardness decreases and water temperature, velocity, free Carbon dioxide, PO<sub>4</sub>-P, NO<sub>2</sub>-N and NH<sub>4</sub>-N increases.



## 5.3. Zooplankton Diversity

---

### 5.3.1. Taxonomic Diversity

In the present investigation, a total of 22 genera of zooplankton found in the glacier-fed river Teesta was higher than 18 genera observed in spring fed hill stream Relli. The river Teesta was dominated by Rotifera followed by Cladocera, Protozoa, and Copepoda. But in Relli zooplankton community was dominated by Rotifera followed by Protozoa, Copepoda and Cladocera. The cladoceran zooplankton has low abundance in the Relli may be due to predation by juvenile fish. Similar observation has been made by **Zaret (1980) and Garcia et al., (2009)**. The dominant status of rotifer species in rivers comparative to the cladocerans and copepods is characteristic of tropical lakes and rivers and this has been reported in the studies of **Bidwell and Clarke (1977)**, **Neves et al., (2003)** and **Mwebaza-Nadwula et al., (2005)**, in particular **Edema et al., (2002)** had reported that numerically, the rotifers constituted 72.60% of plankton during a preliminary studies of the zooplankton and macrobenthos of the Okhuo River. As espoused in the present work, the dominance of smaller zooplankton species like rotifers in both the streams may possibly be due to predation pressure from planktivorous fishes that selectively prey on larger sized zooplankton (**Carpenter et al., 1985; Stemberger and Lazorchak, 1994**). The ability of rotifers to undergo vertical migration, which minimizes competition through niche exploitation and food utilization, could be probably the reason for their dominance in the river (**Arimoro and Oganah, 2010**). Also, rotifer richness in the stream probably could be due to high microhabitat diversity. The high population abundance of rotifer may also be attributed to their parthenogenetic reproductive pattern and short developmental rates under favourable conditions in most fresh water systems (**Akin-Oriola, 2003**). Similar low occurrence of zooplankton genera and pattern of dominance of zooplanktonic groups in Himalayan streams has been reported by several workers (**Rashid and Pandit, 2008; Ayoade et al., 2009; Negi and Negi, 2010**). **Jhingran (1991)** reported dominant zooplankton genera in the river Brahmaputra were *Filina*, *Lecane*, *Brachionus*, *Cyclops*, *Bosmina*, *Daphnia* and Copepod nauplii. At Tezpur, rotifers share (13.5%), Copepods (8.3%) and Protozoa (2.7%) of total plankton community. In the present investigation, *Brachionus sp*, *Keratella sp*, *Lecane sp* (Rotifera) and *Bosmina sp* (Cladocera) were also abundantly found zooplankton at all the sites of both the streams. In the zooplankton community of the hill stream, the main role is played only by these dominant genera. Similar report has been forwarded by **Anderson (1971, 1974)**, **Patalas (1990)** and **Yousuf et al. (1986)**. Dominance of rotifera in the hill

stream may be controlled by local factors and no generalization can be made. All the genera found in both the stream were either cosmopolitan, cosmotropical or pantropical genera of the world (Fernando, 1980; Dussart *et al.*, 1984; Michael and Sharma, 1988). The tropical rotifer fauna are characterised by the abundance of certain families and genera. Out of 25 families known from the country, five, viz Lecanidae, Brachionidae, Colurellidae, Notommatidae and Trichocercidae are reported to constitute nearly 58.5% of total recorded species (Sharma and Sharma, 1999 b). However, from West Bengal, only three families constituted the bulk of species composition (Sharma and Sharma, 1999 a). Among genera, the dominance of the species belonging to *Brachionus* and *Lecane* in tropical waters of the world is by now well established and they have been rightly designated as ‘tropic centre genera’ (Khan, 2003).

Highest value of Sorensen’s similarity index in both the streams may be result of more or less uniform water temperature, water velocity, zooplankton density and number of zooplankton genera. According to Singh (2012) more or less uniform environmental conditions are revealed by higher value of similarity index, in contrast lower value indicates distinct heterogeneity. Value of similarity Index (Sorensen’s Coefficient of Community) of zooplankton between two streams was 0.80.

### 5.3.2. Density and Diversity Indices

Zooplankton in rivers tend to be significantly fewer, which would result in less efficient herbivory of phytoplankton in river ecosystem (Wetzel, 2001). In the present study range (05 - 34 organisms L<sup>-1</sup>) and mean (17.5 organisms L<sup>-1</sup>± 6.6) of zooplankton density in the glacier fed river Teesta is higher than the range (03 – 14 organisms L<sup>-1</sup>) and mean (7.1 organisms L<sup>-1</sup>±2.7) of the spring feed stream Relli. Mean difference was highly significant ( $|t|=12.45$ ,  $p < 0.01$ ). Similar low density of zooplankton has been reported by Boruah and Biswas (2002) in the upper stretch of river Brahmaputra and in a hill stream (Manas) of Assam by Bhattacharjya (2005). The range (3 - 14), mean (9.6±2.5) of number of zooplankton genera in the glacier-fed river Teesta is higher than the range (2 - 9), mean (5.2±1.8) of number of zooplankton genera in the spring fed stream Relli. Mean difference was highly significant ( $|t|=12.59$ ,  $p < 0.01$ ). High zooplankton density and number of genera in the glacier-fed Teesta with high velocity may be explained on the basis of large water shed, many tributary streams and various microhabitats. Backwater “dead zones” of reduced currents near and among the banks and flood plains, many deep pools may continuously supplying phytoplankton. Seasonal variations of density and Number of zooplankton genera showed the lowest value in monsoon months in all the sites of both streams. This may be due

to high water velocity and less occurrence of phytoplankton during monsoon months. Zooplankton with limited power of locomotion, largely move by means of flagella or various mechanisms altering their distribution by changes in buoyancy and are more or less passively drifted by waves and water currents (**Westlake, 1980**). Many microcrustaceans are associated with substrata in benthic and littoral backwater habitats as a mean of alleviating downstream movement (**Quiros and Cuch, 1990; Richardson, 1991, 1992; Robertson et al., 1995**). Microcrustacea and rotifers tend to be moved from prevailing habitats of backwater areas and lower areas of pools during periods of flow exceeding  $2.5 \text{ cm s}^{-1}$  and exported downstream (**Wetzel, 2001**). **Steveninck et al., (1992)** have pointed out that water velocity plays an important role in the both composition and abundance of zooplankton in the lotic water ecosystems. The other factors such as short retention of nutrients in fast flowing water, washing out of eggs and food availability also contribute for occurrence and abundance of zooplankton (**Dizk and Zanlen, 1995**). Zooplankton biomass tends to be negatively correlated with water velocities and positively correlated with temperature and phytoplankton chlorophyll a biomass (**Wetzel, 2001**). In the present investigation zooplankton density and number of zooplankton genera had significant negative correlation with water velocity in both the streams ( $r = -0.794, -0.792, P < 0.01$  in Teesta and  $r = -0.772, -0.749, P < 0.01$  in Relli). In comparison to the fast flowing reaches, the slow flowing calm water reach of the river recorded a good density and diversity of zooplankton. When water velocity was high and more turbid in monsoon months, water temperature was also high. This may be the reason for negative correlation of zooplankton density and number of genera with water temperature. Zooplankton density and number of zooplankton genera had significant positive correlation with phytoplankton density and number of phytoplankton genera in both the streams. In the present study, highest overall value of zooplankton density and number of zooplankton genera found in winter months in both the streams. This pattern may be attributed to the abundance of phytoplankton. The present investigation is in agreement with the findings of others (**Goswami and Selvakumar, 1977; Suresh et al., 2009**). Increased nutrient loadings during monsoon flood may cause a change in the ratio of macronutrients that may alter zooplankton species composition, dominance and succession (**Breitburg et al., 1999; Park and Marshall, 2000**). In freshwater systems, the total zooplankton abundance may increase with increasing eutrophication, while large species may be replaced by small species (**Beaver and Crisman, 1982; Bays and Crisman, 1983; Pace, 1986**).

Range (1.37 – 3.68 bits per individual) and mean (3.07 bits per individual  $\pm 0.45$ ) of Shannon-Wiener diversity index for zooplankton in the glacier-fed river Teesta is higher than the range (0.92 – 3.04 bits per individual) and mean (2.18 bits per individual  $\pm 0.56$ ) found in

the spring-fed stream Relli. Mean difference was highly significant ( $|t|=11.23$ ,  $p < 0.01$ ). High zooplankton diversity index in the glacier-fed Teesta with high velocity may be explained on the basis of large water shed, many tributary streams and various microhabitats. Similar values of zooplankton diversity index in two flood plain wetlands of Teesta river in Jalpaiguri district has been recorded by **Datta (2011)**. Seasonal variation of zooplankton diversity index (H') showed the lowest value in monsoon months in all the sites of both streams. In the hill stream Relli lowest average seasonal value found to be 1.4 bits per individual. The lowest values, lower than 1.5 bit/individual, are associated with settlements dominated quantitatively by one or a few species. This type of situation is found during the phase of colonization of a biotope, when the community is essentially composed of pioneering species with *r*-strategies of development (**Faurie et al., 2001**). Zooplankton with *r*-selected traits has small body size, high fecundity, and short generation time and that persist under harsh discharge regimes. Similar *r*- strategies of development in benthic macro invertebrates has been reported by several investigators (**Petr, 1970; Bishop, 1973; Turcotte and Harper, 1982; Miller and Golladay, 1996; Townsend et al., 1997**). In the river Teesta lowest average seasonal value found to be 2.5 bits per individual and highest average seasonal value in Relli was found to be 2.53 bits per individual. The value of H' goes beyond 2.5 bits per individual, when the ecosystem does not suffer any exogenous disturbance, the settlements diversify over time. A majority of species of *K*-strategies of development progressively appear (**Faurie et al., 2001**). Zooplankton with *K*-selected traits has large body size, low fecundity, and long generation time and that cannot persist under harsh discharge regimes. As the maintenance of a complex structure is energy intensive, diversity diminishes slightly at the end of evolution. The values of H' stabilize at around 3.5 to 4 bits per individual (**Faurie et al., 2001**). Mean values of Shannon-Wiener diversity index (H') of zooplankton community was found to be 3.07 and 2.18 bits per individual in Teesta and Relli respectively. The result suggests that the stream suffer from disturbance in the month of June-July-August in the form of monsoonal flood. This could be the important factor and accordingly the lowest seasonal value of Shannon-Wiener diversity index (H') of zooplankton found in monsoon months and highest value recorded in winter months at all the sites of both the streams. During severe flood events, boulders several metres in diameter can move by saltation, subsequently creating the matrix around which smaller bed material accumulates once discharge declines (**Gupta, 1987**). Thus, year to year highly synchronized sub tropical monsoon is sufficiently pronounced to cause major restructuring in hill stream environments and microhabitat. High water velocity during monsoon months is the main force that may give rise to oscillations and chaos, with a continuous wax and wane of species within the zooplankton community. Various competition

and predation models suggest that even in homogeneous and constant environments plankton will never settle to equilibrium. Thus, zooplankton communities are not in equilibrium at all due to weather-driven fluctuations. Externally imposed variability may allow many species to coexist and leads to diversified community. In the present investigation Shannon-Wiener diversity index for zooplankton had significant negative correlation with water velocity in both the streams ( $r = -0.755$ ,  $P < 0.01$  in Teesta and  $r = -0.789$ ,  $P < 0.01$  in Relli).

In the present study, Range (0.865 – 0.983) and mean ( $0.960 \pm 0.02$ ) of evenness index of zooplankton in the glacier-fed river Teesta is slightly higher than the range (0.896 – 0.998) and mean ( $0.955 \pm 0.02$ ) found in the spring-fed stream Relli. Mean difference was significant ( $|t| = 1.71$ ,  $p < 0.05$ ). Evenness indices standardize abundance and range from near 0 when most individuals belong to a few species, to close to 1, when species are nearly equally abundant (**Smith and Wilson 1996**). **Hill (1973)** hypothesized that richness fundamentally regulates variation in evenness and diversity statistics. The mean value of the evenness index ranged from 0.54 to 0.94 in two flood plain wetlands of Teesta river in Jalpaiguri district (**Datta, 2011**). In the present study, evenness index of zooplankton were strongly and positively correlated with number of zooplankton genera ( $r = 0.202$ ,  $P < 0.05$  in Teesta and  $r = 0.411$ ,  $P < 0.01$  in Relli), Margalef's richness index ( $r = 0.324$ ,  $P < 0.01$  in Teesta and  $r = 0.339$ ,  $P < 0.01$  in Relli) and S-W diversity index ( $r = 0.346$ ,  $P < 0.01$  in Teesta and  $r = 0.543$ ,  $P < 0.01$  in Relli) in both the streams. In the river Teesta evenness index of zooplankton has significant positively correlated with  $\text{NO}_3\text{-N}$  ( $r = 0.206$ ,  $P < 0.05$ ). But in the hill stream Relli evenness index of zooplankton has significant positive correlation with DO ( $r = 0.242$ ,  $P < 0.01$ ) and significant negative correlation with water velocity ( $r = -0.287$ ,  $P < 0.01$ ) and free  $\text{CO}_2$  ( $r = -0.262$ ,  $P < 0.01$ ).

In the present investigation range (1.24 – 4.24) and mean ( $3.02 \pm 0.58$ ) of Margalef's richness index for zooplankton in the glacier-fed river Teesta was slightly higher than the range (0.32 – 3.19) and mean ( $1.96 \pm 0.70$ ) found in the spring-fed stream Relli. Mean difference was highly significant ( $|t| = 10.70$ ,  $p < 0.01$ ). **Datta (2011)** recorded range of zooplankton richness index varied from 2.08 to 4.52 in two flood plain wetlands of Teesta river in Jalpaiguri district. Environmental stress such as flash floods, high water velocity and turbidity might have resulted in the dominance of a few zooplankton species and which in turn responsible for lowest value of richness index in monsoon months. Similar opinion has been expressed by **Plafkin et al., (1989)**. Margalef's Species richness index for zooplankton in both the streams were positively correlated with density ( $r = 0.622$ ,  $P < 0.01$  in Teesta and  $r = 0.697$ ,  $P < 0.01$  in Relli), number of genera ( $r = 0.928$ ,  $P < 0.01$  in Teesta and  $r = 0.778$ ,

$P < 0.01$  in Relli), S-W diversity index ( $r = 0.926$ ,  $P < 0.01$  in Teesta and  $r = 0.763$ ,  $P < 0.01$  in Relli) and evenness index ( $r = 0.324$ , in Teesta and  $r = 0.339$ ,  $P < 0.05$  in Relli). Neutral diversity theories predict that species number and immigration rates are sufficient to predict animal and plant community abundance distributions (Caswell, 1976; Bell, 2000; Hubbel, 2001), and Caswell's model makes explicit predictions that evenness and richness will be positively correlated in the absence of species interactions. Stirling and Wilsey (2001) found that species richness and evenness were positively correlated in vertebrate communities, and that a neutral model largely predicted the strong positive relationships among invertebrate richness, evenness, and diversity.

In the present study range (0.075 – 0.440) and mean ( $0.136 \pm 0.06$ ) of dominance index of zooplankton in the glacier-fed river Teesta was lower to the range (0.133 – 0.556) and mean ( $0.255 \pm 0.11$ ) found in the spring-fed stream Relli. Mean difference was highly significant ( $|t|=8.91$ ,  $p < 0.01$ ). According to Whittaker (1963) the value of dominance index is always higher where the community is dominated by a fewer number of species and when the dominance is shared by a large number of species. The present investigation also indicated that, evenness index and index of dominance have significant negative correlation ( $r = -0.505$ ,  $P < 0.01$  in Teesta and  $r = 0.623$ ,  $P < 0.01$  in Relli) in both the streams.

### 5.3.3. Altitudinal variation of Density and Diversity Indices

Along the elevational gradient of the hill stream Relli (*i.e.*, along RR-I, RR-II and RR-III) average value of density and diversity indices (table-) like Number of genera (S), Species diversity index ( $H'$ ), and Species richness index (R) of zooplankton community showed decreasing tendency with the increase of altitude in the selected stretch of hill stream Relli, but on the contrary index of dominance ( $\lambda$ ) and Evenness index ( $J'$ ) increased with the increase of altitude. Interestingly, in the present study, average values of evenness index ( $J'$ ) and density of zooplankton community at the RR-II was equal to that of RR-I. This might be due to anthropogenic disturbances such as car and cloth washing, boulder and sand lifting, fishing etc. in the RR-II.

But, in the river Teesta average value of density, Number of zooplankton genera (S), Species diversity index ( $H'$ ), Evenness index ( $J'$ ) and Species richness index (R) of zooplankton community showed decreasing tendency with the increase of altitude in the selected stretch. Hart (1996) observed a downstream increase of cladoceran richness between the first and second reservoirs of the Mgeni River cascade in South Africa. The author considered that the changes were primarily related to rising water temperature. This explanation is also a possibility to be considered in the present results, as a longitudinal

(downstream) increase in temperature. On the contrary index of dominance ( $\lambda$ ) increased with the increase of altitude. Interestingly, in the present study, average values of density, Number of zooplankton genera (S), Species diversity index (H'), Evenness index (J') and Species richness index (d) of zooplankton community at the TR-II was low to that of TR-I but value of dominance index was higher. This might be due to anthropogenic disturbances such as car and cloth washing, boulder and sand lifting, fishing, waste disposal etc. at the TR-II. Generally, the observed pattern is marked by a decrease in species diversity and the substitution of species as altitude increases; however, the processes that determine those patterns remain poorly understood (**Lomolino, 2001**). Several hypotheses have been proposed to explain such changes in diversity associated with altitude; most of them are based on only a few ecological factors. These can be summarized as: (1) reduction in the available area and environmental complexity, (2) greater severity of climatic conditions, (3) reduction in the diversity of available resources and (4) decrease in primary productivity with increasing altitude (**Huston, 1994**). There is no consensus on how these ecological factors covary and interact with environmental variables to generate the patterns of diversity observed in mountains (**Nogués-Bravo et al., 2008**). The density and diversity of zooplankton assemblages along the gradient of both the streams was in agreement with the “river continuum concept” (**Vannote et al., 1980**). Central to the RCC (**Vannote et al., 1980**) are the linked concepts that: (a) physical variables within a river network present a ‘continuous gradient’ of physical conditions from headwaters to a river’s mouth; and (b) this longitudinal gradient ‘ . . . should elicit a series of responses within the constituent populations resulting in a continuum of biotic adjustments and consistent patterns of loading, transport, utilization and storage of organic matter along the length of a river’. Such concept involving energy sources and allocation (**Vannote et al., 1980**) *i.e.*, at lower altitudes, there are higher amounts of energy available because of more solar radiation, more resources (for example, minerals and water); as a result, even higher levels of species richness can be allowed at lower altitudes.

#### **5.3.4. Annual Variation of Density and Diversity Indices**

Slight annual variations of zooplankton density and diversity indices in both the streams indicated strong seasonal variation of zooplankton density and diversity indices occurs in a highly predictable manner year after year unless occurrence of huge natural disaster. Dynamics of zooplankton diversity may be the result of adaptation to geomorphological and physico-chemical characteristics which form fundamental template along drainage basin of the streams. This could have evolved during the evolution of Himalayan mountain system.

### 5.3.5. Zooplankton Diversity in Relation to Water Quality

Individual relationship between physico-chemical variables and values of zooplankton density and diversity index reflected in the Pearson correlation matrix. Zooplankton density, Number of zooplankton genera (S), Species diversity index (H'), and Species richness index (d) of zooplankton community in both the stream showed significant positive correlation with pH, specific conductance, dissolved Oxygen, total alkalinity, chloride and total hardness. **Arimoro and Oganah (2010)** have reported significant positive correlation between zooplankton density and dissolved oxygen ( $r = 0.96$ ,  $P < 0.01$ ) and total alkalinity ( $r = 0.48$ ,  $P < 0.05$ ) in a tropical stream of Niger Delta of Nigeria. **Byars (1960)** reported that zooplankton prefer alkaline waters. Both conductivity and total dissolved solids promoted high zooplankton growth and abundance in the river Haraz in Northeast Iran (**Zafari et al., 2011**). But all these indices had negative correlation with water temperature, velocity, free  $\text{CO}_2$ ,  $\text{PO}_4\text{-P}$ ,  $\text{NH}_4\text{-N}$  and  $\text{NO}_2\text{-N}$ . Zooplankton biomass tends to be negatively correlated with water velocities and positively correlated with temperature and phytoplankton chlorophyll a biomass (**Wetzel, 2001**). In comparison to the fast flowing reaches, the slow flowing calm water reach of the river recorded a good density and diversity of zooplankton. When water velocity was high and more turbid in monsoon months, water temperature was also high. This may be the reason for negative correlation of zooplankton density and number of genera with water temperature. Zooplankton evenness index (J') in the river Teesta showed positive correlation with  $\text{NO}_3\text{-N}$ , whereas in the hill stream Relli evenness index (J') had significant positive correlation with dissolved oxygen and negative correlation with water velocity and free  $\text{CO}_2$ . Dominance index of zooplankton exhibited significant positive correlation with water temperature, velocity, free  $\text{CO}_2$ ,  $\text{PO}_4\text{-P}$ ,  $\text{NH}_4\text{-N}$  and  $\text{NO}_2\text{-N}$  and negative correlation with pH, specific conductance, dissolved Oxygen, total alkalinity, chloride and total hardness of water. Consistent with the present findings, **Sarkar and Choudhury (1999)** reported significant multiple correlations between plankton abundance and several physical and chemical variables in their study. But it was failed to explain causal relationships.

The regression analysis showed causal relationship between physico-chemical variables (Independent or explanatory variables) and variables of zooplankton density and diversity indices (Dependant). Principal Components obtained for physico-chemical parameters in both the streams were used as independent variables to understand the trend of control over zooplankton density and diversity.

The main tendencies of physico-chemical variables reflected in two principal components (PC-I and PC-II) for the river Teesta. Ordinary Least Square (OLS) or linear

regression analysis shows causal relationship between the principal components of physico-chemical parameters and density and diversity of zooplankton. The principal component I (PC-I) has significant negative influence and principal component II (PC-II) has significant positive impact on the zooplankton density, number of zooplankton genera, Shannon-Wiener diversity Index, Margalef's richness Index of zooplankton. PC-I might have exerted negative significant effect with raised ionic strength (specific conductance) in clear water and in comparatively low temperature. The condition resulted in enhanced growth of phytoplankton density, increased number of phytoplankton genera as well as raised values of Shannon-Wiener diversity Index and Margalef's richness Index. During which free CO<sub>2</sub> and other nutrients (PO<sub>4</sub>-P, NO<sub>3</sub>-N, NO<sub>2</sub>-N and NH<sub>4</sub>-N) were utilized and more oxygen was evolved due to augmented metabolism and photosynthetic activity. In the present investigation zooplankton density, number of zooplankton genera, Shannon-Wiener diversity Index, Margalef's richness Index of zooplankton had significant positive correlation with phytoplankton density ( $r = 0.851, 0.777, 0.722$  and  $0.585, P < 0.01$ ), number of phytoplankton genera ( $r = 0.787, 0.804, 0.768$  and  $0.674, P < 0.01$ ), phytoplankton species diversity index ( $r = 0.707, 0.757, 0.751$  and  $0.662, P < 0.01$ ) and Margalef's richness Index of phytoplankton ( $r = 0.639, 0.699, 0.679$  and  $0.621, P < 0.01$ ). PC-II may possibly applied positive significant effect on the zooplankton density, number of zooplankton genera, Shannon-Wiener diversity Index, Margalef's richness Index by the way of increasing H<sup>+</sup> and OH<sup>-</sup> (pH), HCO<sub>3</sub><sup>-</sup> (total alkalinity), Ca and Mg salts with, CO<sub>3</sub><sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>-</sup>, Cl<sup>-</sup> and other anions of mineral acids (total hardness), when water velocity was less. Index of zooplankton dominance increased when water temperature, velocity and nutrient (free CO<sub>2</sub>, PO<sub>4</sub>-P, NO<sub>3</sub>-N, NO<sub>2</sub>-N & NH<sub>4</sub>-N) loading is high, but with less production of oxygen, decreased values of ionic strengths (specific conductance), H<sup>+</sup> and OH<sup>-</sup> (pH), HCO<sub>3</sub><sup>-</sup> (total alkalinity), Ca and Mg salts with, CO<sub>3</sub><sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>-</sup>, Cl<sup>-</sup> and other anions of mineral acids (total hardness).

The main tendencies of physico-chemical variables reflected in three components (PC-1, PC-II and PC-III) in the hill stream Relli. Ordinary Least Square (OLS) or linear regression analysis shows causal relationship between the principal components of physico-chemical parameters and density and diversity of zooplankton. Zooplankton density regulated by the physico-chemical water quality of Relli in a slightly different fashion. The OLS estimation indicated that variations in zooplankton density, number of zooplankton genera, Shannon-Wiener diversity Index of zooplankton in the hill stream were regulated significantly in two ways. Firstly, zooplankton density increased when water temperature and velocity was low and NO<sub>3</sub>-N was more. Secondly, zooplankton density, number of zooplankton genera, Shannon-Wiener diversity Index of zooplankton also increased when

total alkalinity, dissolved Oxygen, Specific conductance, pH, Chloride and total hardness increases and water temperature, velocity, free Carbon dioxide, PO<sub>4</sub>-P, NO<sub>2</sub>-N and NH<sub>4</sub>-N decreases. Increased values of H<sup>+</sup> and OH<sup>-</sup> (pH), HCO<sub>3</sub><sup>-</sup> (total alkalinity), Ca and Mg salts with, CO<sub>3</sub><sup>=</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>=</sup>, Cl<sup>-</sup> and other anions of mineral acids (total hardness), increment of major ions such as Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>, CO<sub>3</sub><sup>2-</sup>, SO<sub>4</sub><sup>2-</sup>, Cl<sup>-</sup> (specific conductivity) indicating more mineralized stream water that enhances phytoplankton growth with the evolution of more O<sub>2</sub> due to photosynthetic activity. During this enhanced growth period more nutrients like free CO<sub>2</sub> and PO<sub>4</sub>-P, NO<sub>2</sub>-N and NH<sub>4</sub>-N utilized and the process was aided by low water temperature and low water velocity. In the present investigation zooplankton density, number of zooplankton genera and Shannon-Wiener diversity Index had significant positive correlation with phytoplankton density (r = 0.914, 0.858, and 0.766, P<0.01), number of phytoplankton genera (r = 0.853, 0.857 and 0.819, P<0.01) and phytoplankton species diversity index (r = 0.812, 0.877 and 0.864, P<0.01). Margalef's richness Index increased when water temperature and velocity was low and NO<sub>3</sub>-N was more. Interestingly, Index of phytoplankton dominance increased when water temperature and velocity was high and NO<sub>3</sub>-N was less. Index of dominance was also increased when total alkalinity, dissolved Oxygen, Specific conductance, pH, Chloride and total hardness decreases and water temperature, velocity, free Carbon dioxide, PO<sub>4</sub>-P, NO<sub>2</sub>-N and NH<sub>4</sub>-N increases. Environmental stress such as flash floods, high water velocity, high water temperature and turbidity might have resulted in the dominance of a few zooplankton species in both the streams. A community dominated by relatively few species indicates environmental stress (**Plafkin *et al.*, 1989**). On the contrary, evenness index of zooplankton in both the streams showed no significant causal relationship between the principal components of physico-chemical parameters. Evenness index of zooplankton might have controlled by other factors such as selective predation by planktivorous fish.

## 5.4. Ichthyodiversity

---

### 5.4.1. Taxonomic Diversity

In the present investigation, a total of 65 species of fish belong to 3 orders, 10 families and 39 genera found in the glacier-fed river Teesta was higher than 25 species of fish belong to 5 families and 15 genera observed in spring fed hill stream Relli. Maximum number of species (30) recorded in the river Teesta were of family Cyprinidae followed by families Sisoridae (12 species), family Balitoridae (9 species), Cobitidae (4 species), Psilorhynchidae and Shilbeidae (3 species each) and Bagridae, Olyridae, Amblycypidae and Mastacembilidae (one species each). 11 species were found at all four sites of the river Teesta. Maximum number of species (14) recorded in the hill stream Relli were of family Cyprinidae followed by families Balitoridae (6 species), family Sisoridae (3 species), Psilorhynchidae and Cobitidae (one species each). 14 species were found at all sites. It is evident from the present investigation that the ichthyofaunal composition of both the streams in the studied stretches was represented mostly by rheophilic, cold water hill stream species belongs to order Cypriniformes and Siluriformes. **Nelson (1994)** reported the greatest diversity in Cypriniformes and Siluriformes in the freshwater habitats. Similar observations were made by **Johal and Rawal (2005)** in western Himalayan hill stream and by **Shrestha (1999)** in the Nepal region of the Himalayas. Dominance of rheophilic, cold water hill stream species may be probably due to the nature of the stream with high water current and gradient, low water temperature. From the fishery point of view, water temperature falling with the tolerance limit of the trouts (here snow trouts) may be termed as cold (**Jhingran and Sehgal, 1978**). Similar observation has been made by **Bagra and Das (2010)** in Siyom River of Arunachal Pradesh. Seven species of fishes are abundantly (78.6%) found in Relli such as *Neolissocheilus hexagonolepis* (15.8%), *Garra gotyla gotyla* (14.5%), *Barilius bendelisis* (14.3%), *Schizothorax richardsonii* (10.1%), *Nemacheilus devdevi* (9.8%), *Barilius barna* (8.3%), and *Nemacheilus scaturigina* (5.8%). In the river Teesta, five species of fishes were abundantly (62.9%) found which were *Barilius bendelisis* (14.8%), *Schizothorax richardsonii* (12.8%), *Nemacheilus devdevi* (12.5%), *Barilius barna* (11.9%), *Neolissocheilus hexagonolepis* (10.9%). Thus, the stretch of the river Teesta can be designated as 'Barilius-Mahseer-Snow trout Stream'. Similar zonation of stream on the basis of the dominant fish species has been identified by **Shrestha (1999)**. The analysis of the trophic structure of the fishes indicates dominancy of omnivorous (*Neolissocheilus hexagonolepis*, *Barilius bendelisis*, *Barilius barna*) fishes in all sites followed by carni-omnivorous (*Nemacheilus*

*devdevi*, *Nemacheilus scaturigina*) and herbivorous (*Garra gotyla gotyla*, *Schizothorax richardsonii*) fish. Similar findings were reported from Yangtze River basin of China (**Fu et al., 2003**) and two tropical river of India (**Das and Chakrabarty, 2007**). Based on the study of trophic level of fishes it appears that omnivores are often the most tolerant of degradation or ecosystem dysfunction because they are able to consume food from a wide variety of sources in a changing ecosystem (**Wichert and Rapport, 1998**) and this may be useful to assess quality of the fish habitat. Some authors attributed dominance of Himalayan fishes to complex physico-hydrological characteristics as well as in part to zoogeographical factors regarding the dispersal and dominance from the oriental realm, and Central Asia, after the early Tertiary upheavals that created these mountains and during interglacial periods of the Pleistocene respectively (**Menon, 1954; Edds, 1993**). It is evident from the present investigation that the ichthyofaunal composition of 29 km stretch (altitudinal variations 224 to 147 m asl) of the river Teesta and 14 km stretch (altitudinal variations 704 to 340 m asl) of hill-stream Relli was represented mostly by rheophilic, cold water hill stream species and has sufficient similarity with cold water species of Nepal, Sikkim, Bhutan, Assam and other parts of Indian Himalaya. Some species like *Crossocheilus latius*, *Psilorhynchus sucatio*, *Psilorhynchus homaloptera*, *Aborichthyes elongatus*, *Acanthocobitis botia*, *Schistura rupicola*, *Schistura scaturigina*, *Nemacheilus devdevi*, *Bagarius bagarius* and *Pseudolaguvia shawi* are endemic to India (**Molur and Walker, 1998**).

Highest value of Sorensen's similarity index in both the streams may be result of more or less uniform water temperature, water velocity, zooplankton density and number of zooplankton genera. According to **Singh (2012)** more or less uniform environmental conditions are revealed by higher value of similarity index, in contrast lower value indicates distinct heterogeneity. Value of similarity Index (Sorensen's Coefficient of Community) of ichthyofauna between two streams was 0.56.

Almost all the species in the collection are represented by very young specimens, adult brood fishes were found mostly during monsoon and post-monsoon months especially in Relli. The array of juveniles and sub adults in this work suggests this stream used as a breeding ground and nursery ground for fish species particularly of *Schizothorax richardsonii*, *Schizothorax progastus*, *Neolissocheilus hexagonolepis*, *Neolissocheilus hexastichus*. **Hora and Gupta (1940)** found very young fish specimen in Kalimpong duars and Siliguri Terai and opined that the fish species of this region breed during and after the monsoon months. **Hora and Nair (1944)** reported mature fish with developed gonads in Riyang stream a small tributary of the river Teesta in Darjeeling Himalaya and also found small fry of some species in the same stream and they opined that Teesta provides a highway

for the migration of fishes. However, the absence of adults among other factors may be due to pressure exerted from overfishing by local fisherman or from downstream migration of the fish or both. Similar observation has been made by **Emmanuel and Modupe (2010)** in the rivers of Nigeria. **Acharjee and Barat (2010)** reported that over the years uncontrolled and often indiscriminate fishing in the largely unmanaged stream Relli has resulted in a sharp decline in catches of the important sport and subsistence fish.

Fast flowing river Teesta and the hill-stream Relli calls for a special modification of the fish fauna. The individual modification is chiefly manifested in being small sized and development of structure of adhesion. Fish species found in the present study may be categorised into six major groups on the basis of morphological characteristics in relation to distributional pattern which enable them to inhabit the torrential streams. These are, a) fish dwelling in shallow, clear cold waters in the foothills without any striking modifications to current: *Barilius* spp; b) fish inhabiting the bottom water layers in deep fast current, with powerful muscular cylindrical bodies: *Schizothorax* spp, *Neolissocheilus* spp; c) fish sheltering among pebbles and stones to ward off the strong current: *Crossocheilus latius*; d) fish sheltering among pebbles and shingles in shallows, with special attachment devices: the loaches, *Nemacheilus* spp, *Schistura* spp, *Canthophrys gongota*, *Aborichthys elongates*, *Acanthocobitis botia*; e) fish which cling to exposed surface of bare rocks in slower current, with adhesive organs on their ventral surface for attachment to rocks: *Garra* spp, *Glyptothorax cavia*, *Pseudecheneis sulcata*; and f) fish which cling to the exposed surfaces of bare rocks in fast current, with limpet shaped bodies and mouth, gills and fins highly modified to suit the habitat: *Parachiloganis hodgarti*. Similar six major groups have been recognised by **Menon (1954)** in Himalayan fish. Both the stream has pool-run-riffle geomorphology, high substrate diversity (Bedrock, cobble, gravel, sand and terrestrial litter), and the stream is subjected to seasonal discharge variation, including periodic spates and flash-floods during the wet season. **Dudgeon (2008)** mentioned that high elevation streams in the tropics have fast currents, and are characterized by plunge pools, riffles and rapids dominated by boulders and cobbles, with few or no aquatic macrophytes. The present study revealed that almost all the cyprinid fishes especially *Barilius* spp, *Devario aequipinnatus* are generally distributed in the pools, pool edges and in the side pools. Small fry of various fish species such as *Barilius* spp, *Garra* spp, *Neolissocheilus* spp, *Tor* spp, *Schizothorax* spp, *Nemacheilus* spp, etc. were found in the side pools. *Nemacheilus* spp, *Schistura* spp, *Aborichthys elongatus* were generally abundant in riffle type microhabitat and found below stones.

All the 25 species found in tributary stream Relli were also found in the river Teesta. Thus, a total of 65 species of fish were recorded in the stretch of river Teesta and its tributary stream Relli. References to conservation status categories are based on IUCN classification as per CAMP-NBFGR (**Molur and Walker, 1998**). Thus, out of recorded species, 11 (17%) endangered (EN), 18 (28%) vulnerable (Vu), 19 (29%) low risk near threatened (LR-nt), 1 (1%) low risk least concern (LC-lc), 1 (2%) data deficient (DD) and rest 15 (23%) were not evaluated (NE). But recent revise by NBFGR (**Lakra et al., 2010**) included species like *Chagunius chagunio*, *Crossocheilus latius*, *Nangra nangra* and *Amblyceps mangois* under endangered (EN) category and *Garra lamta*, *Labeo pungusia*, *Glyptothorax telchitta* and *Olyra longicauda* under vulnerable (Vu) category. Thus, about 55% fish species of the river Teesta and its tributary belong to threatened category. This categorization may be useful for planning conservation strategies for genetic resources of ichthyofauna.

#### 5.4.2. Density and Diversity Indices

In the present study, range (21 - 64 individuals. 100m<sup>-2</sup>) and mean (36.9 individuals. 100m<sup>-2</sup>±10.3) of fish catch per unit effort (CPUE) in the glacier fed river Teesta was higher than the range (11 - 53 individuals. 100m<sup>-2</sup>) and mean (27.8 individuals. 100m<sup>-2</sup>±9.7) of the spring feed stream Relli. Mean difference was highly significant ( $|t|=5.80$ ,  $p < 0.01$ ). **Pokharel (2011)** have reported similar low fish CPUE (Ranged from 246.95/0.1 ha to 510.70/0.1 ha) in Seti Gandaki river of Nepal. Range (74 - 789 individuals. 1000m<sup>-2</sup>) and mean (265.6 individuals. 1000m<sup>-2</sup>±155.2) of estimated fish population size (N) in the glacier fed river Teesta was higher than the range (55 - 312 individuals. 1000m<sup>-2</sup>) and mean (147.2 individuals. 1000m<sup>-2</sup>±59.9) of the spring feed stream Relli. Mean difference was significant ( $|t|=6.11$ ,  $p < 0.01$ ). Even, the range (05 - 26) and mean (13.6±3.9) of number of fish species in the glacier fed river Teesta was higher than the range (04 - 13) and mean (7.9 ±2.2) of the spring feed stream Relli. Mean difference was significant ( $|t|=11.19$ ,  $p < 0.01$ ). Indicating biomass and productivity of ichthyofauna is very low in Himalayan streams, they are even low in low order streams. High ichthyofaunal CPUE, estimated population size (N) and number of fish species in the glacier-fed Teesta with high velocity may be explained on the basis of large water shed, many tributary streams and various microhabitats. Fish catch per unit effort (CPUE) in both the streams had significant positive correlations with estimated fish population size ( $r = 0.885$ ,  $P < 0.01$  in Teesta and  $r = 0.867$ ,  $P < 0.01$  in Relli) and number of fish species ( $r = 0.594$ ,  $P < 0.01$  in Teesta and  $r = 0.695$ ,  $P < 0.01$  in Relli). Interestingly, fish CPUE showed negative correlation with phytoplankton ( $r = -0.099$  in Teesta and  $r = -0.160$  in Relli) and zooplankton density ( $r = -0.070$  in Teesta and  $r = -0.791$ ,  $P < 0.01$  in Relli) in both

the streams. This may be due to trophic relationship between fish, phytoplankton and zooplankton.

Species diversity has two basic components: richness, or number of species in a given area, and evenness, or how relative abundance or biomass is distributed among species (**Huston, 1994; Purvis and Hector, 2000; Magurran, 1988**). These components are combined in Shannon-Wiener species diversity index ( $H'$ ). Range (2.170 – 4.435 bits per individual) and mean (3.435 bits per individual  $\pm 0.43$ ) of Shannon-Wiener species diversity index of ichthyofauna in the glacier-fed river Teesta was higher than the range (1.905 – 3.496 bits per individual) and mean (2.735 bits per individual  $\pm 0.38$ ) found in the spring-fed stream Relli. Mean difference was highly significant ( $|t|=10.59$ ,  $p < 0.01$ ). In the present investigation Shannon-Wiener species diversity index ( $H'$ ) exhibited positive significant correlations with fish CPUE ( $r = 0.444$ ,  $P < 0.01$  in Teesta and  $r = 0.652$ ,  $P < 0.01$  in Relli), estimated population size ( $r = 0.372$ ,  $P < 0.01$  in Teesta and  $r = 0.971$ ,  $P < 0.01$  in Relli) and number of fish species ( $r = 0.941$ ,  $P < 0.01$  in Teesta and  $r = 0.623$ ,  $P < 0.01$  in Relli) in both the streams. **Patra et al., (2011)** found Shannon-Wiener species diversity index of ichthyofauna ranged from 3.18-3.75 in Karala river, a tributary of Teesta river near Jalpaiguri town. **Murugan and Prabaharan (2012)** reported Shannon-Weiner index for fish diversity in Kamala reservoir ranged from 2.2 to 4.10. **Pereira (2000)** used this same index to evaluate the diversity of Camaleao Lake, finding values varying from 3.9 to 4.1. In Central Amazonian lakes, **Barthem (1981)** found variation in the Shannon index of from 2.2 to 3.2. Average value of S-W species diversity index of ichthyofauna found in the studied stretch of both the streams were more than 2.5 bits per individual, indicated that the ecosystem does not suffer any exogenous disturbance during the period, and the settlements diversified over time. Similar view was also expressed by **Faurie et al. (2001)**. In Shannon-Wiener legislation, the aquatic environment (soil/water) is classified as – very good when  $H'$  is  $> 4$ , good quality 4- 3, moderate quality 3-2, poor quality 2-1 and very poor quality  $< 1$  (**Mishra et al., 2010**). A scale of pollution in terms of species diversity (3.0 - 4.5 slight, 2.0 - 3.0 light, 1.0 - 2.0 moderate and 0.0 - 1.0 heavy pollution) has been described by **Staub et al. (1970)**.

Margalef's Species richness index is a simple and easily interpretable indicator of biological diversity (**Peet, 1974**). In the present investigation range (1.214 – 6.269) and mean (3.508  $\pm 0.962$ ) of species richness index for ichthyofauna in the glacier-fed river Teesta is slightly higher than the range (0.985 – 3.396) and mean (2.093  $\pm 0.55$ ) found in the spring-fed stream Relli. Mean difference was highly significant ( $|t|=11.14$ ,  $p < 0.01$ ). As the Species diversity index ( $H'$ ) and species richness index ( $d$ ) depend upon the number of species as well as number of individuals in each species and contribute equally to the values of  $H'$  and  $d$

(Ludwig and Reynolds, 1988). Hence if any one of these two variables decreases or increases, it will affect the overall values of Species diversity index ( $H'$ ) and species richness index ( $d$ ). Margalef's Species richness index in the present study showed positive significant correlations with fish CPUE ( $r = 0.354$ ,  $P < 0.01$  in Teesta and  $r = 0.441$ ,  $P < 0.01$  in Relli), estimated population size ( $r = 0.328$ ,  $P < 0.01$  in Teesta and  $r = 0.949$ ,  $P < 0.01$  in Relli) and number of fish species ( $r = 0.949$ ,  $P < 0.01$  in Teesta and  $r = 0.434$ ,  $P < 0.01$  in Relli) in both the streams.

Most of the fish communities, as in the present investigation, contain a few dominant species and many species that are relatively uncommon. Evenness measures attempt to quantify this unequal representation against a hypothetical community in which all species are equally common. Pielou (1966) proposed that 'evenness' be measured by the ratio between the diversity  $H'$  calculated and that which would be obtained, for the number of species surveyed, in case of equiproportionalities. Evenness indices standardize abundance and range from near 0 when most individuals belong to a few species, to close to 1, when species are nearly equally abundant (Smith and Wilson 1996). In the present study, mean value ( $0.924 \pm 0.033$ ) of evenness index for ichthyofauna in the glacier-fed river Teesta was lower than the mean value ( $0.941 \pm 0.026$ ) found in the spring-fed stream Relli. Mean difference was highly significant ( $|t|=3.47$ ,  $p < 0.01$ ). Patra *et al.*, (2011) reported evenness index for ichthyofauna ranged from 0.887 – 0.949 in the Karala river. Stirling and Wilsey (2001) found that species richness and evenness were positively correlated in vertebrate communities. In the present study, Margalef's Species richness index showed positive significant correlation with ichthyofaunal evenness in the river Teesta ( $r = 0.232$ ,  $P < 0.05$ ) but negative correlation in Relli ( $r = -0.129$ ). Evenness and richness will be positively correlated in the absence of species interactions (Caswell, 1976).

Simpson index measures the strength of dominance, because it weights towards the abundance of the most common species and varies inversely with species diversity (Whittaker, 1972). A value of this index ranges from 0-1; zero represents no dominance and 1, for maximum dominance; viz: only one species in the sample (Greenberg, 1956; Berger and Parker, 1970). In the present study range (0.055 – 0.240) and mean ( $0.113 \pm 0.037$ ) of dominance index for ichthyofauna in the glacier-fed river Teesta was low to the range (0.098 – 0.281) and mean ( $0.168 \pm 0.043$ ) found in the spring-fed stream Relli. Mean difference was highly significant ( $|t|=8.65$ ,  $p < 0.01$ ). According to Whittaker (1963) the value of dominance index is always higher where the community is dominated by a fewer number of species and when the dominance is shared by a large number of species. The present investigation also

indicated that, evenness index and index of dominance have significant negative correlation ( $r = -0.567$ ,  $P < 0.01$  in Teesta and  $r = -0.115$  in Relli) in the river Teesta.

### 5.4.3. Seasonal Variation of Density and Diversity Indices

Overall seasonal variations of CPUE and estimated population size (N) in the studied stretch of both the streams exhibited highest value in post monsoon months and lowest value in winter months. Increased water temperature during March, April and May (pre monsoon), availability of fish food (macro invertebrates, plankton) may have a role in the slight upraised population and species richness. Increases in discharge during the monsoon (June, July and August) coincided with increased movement and upstream spawning migrations of many adult fishes, such as *Schizothorax richardsonii*, *Schizothorax progastus*, *Neolissocheilus hexagonolepis*, *Neolissocheilus hexastichus*, *Garra spp.*, *Cyprinion semiplotum* etc. Similar spawning migrations occur with increased discharge of rivers in Nepal (Edds, 1993) Africa and South America (Lowe-McConnell, 1975; Goulding, 1980). Hora and Gupta (1940) opined that the fish species of this region breed during and after the monsoon months. Spawning and breeding of *Katli* (*Neolissocheilus hexagonolepis*) season lasts from June to September (Barat *et al.*, 2005). Due to breeding migration and availability of basic fish food items a good variety of fishes attracted to hill stream (Bahuguna and Badoni, 2002). Similar opinion has also given by Singh and Kumar (2000). During the post monsoon months (September, October and November) temperature decreases slowly and migratory brood fishes along with year old young could have started their downward march to return to winter habitat in Teesta. As reported by Sen and Biswas (2006) in case of Mahseer (*Tor putitoa*). Huge input of allochthonous organic food materials and inorganic nutrients during monsoon months enriches the stream and fish spawn grows well in the post monsoon months. All these factors may operate in a coordinated fashion in low water level, thus diversity and density of ichthyofauna increases in post monsoon months. This could be the reason for highest seasonal value of number of fish species (S), Shannon-Wiener species diversity index (H'), Margalef's Species richness index (R) found in the post monsoon months in both the streams. During winter months (December, January and February) the average temperature drops down causing a cold weather. When, most of the fishes migrated down from the stream to winter habitat where most of the fishes lie in the deep pools (Sen and Biswas, 2006) of either river Relli or Teesta. Traps, like *Tip* and *Thokre*, are used during downward migration of fishes (September to November) thus, most of the juvenile and adult fishes are killed. Hammering, dynamiting, river channel diverting, river poisoning, and electro-fishing are used mainly during winter months in the pools of the river causing indiscriminate killing of fishes especially in the hill stream Relli (Acharjee and Barat, 2010). Electro-fishing and

dynamiting are adopted mainly by picnickers. Selective fishing may have resulted increased ichthyofaunal evenness index during the winter season in both the streams. Lowest value of evenness index and highest value of dominance index found during monsoon months in the river Teesta, where fishing pressure was less. The dependence on large migratory fish species and seasonal variation on fishing strategies are usual features of river fisheries (**Welcomme, 1985; Petrere, 1989**). Two factors, downward migration and indiscriminate fishing may be responsible for low density and diversity during winter months.

#### **5.4.4. Altitudinal Variation of Density and Diversity Indices**

Along the elevational gradient of the hill stream Relli *i.e.*, along RR-I (704 m asl), RR-II (566 m asl) and RR-III (340 m asl) Catch per unit effort (CPUE), population size (N), number of species (S), and Shannon-Wiener species diversity index (H') of ichthyofauna showed highest value at RR-III followed by RR-I and RR-II. Margalef's species richness index (d) found to be highest at RR-I followed by RR-III and RR-II. Evenness index (J') highest at RR-II followed by RR-I and RR-III but Species dominance index ( $\lambda$ ) was found to be highest at RR-II followed by equal values at RR-I and RR-III. Similarly, along the elevational gradient of the river Teesta *i.e.*, along TR-I (224 m asl), TR-II (216 m asl), TR-III (168 m asl) and TR-III (147 m asl) number of species (S), Shannon-Wiener species diversity index (H'), Evenness index (J') and Margalef's species richness index (d) exhibited decreasing tendency with the increase of altitude in the selected stretch. Species dominance index ( $\lambda$ ) increased with the increase of altitude. The abundance and diversity of fish assemblages along the gradient of the river Teesta and its tributary hill stream Relli appear to be in agreement with the "River Continuum Concept" (**Vannote *et al.*, 1980**). Central to the River Continuum Concept (RCC) are the linked concepts that: (a) physical variables within a river network present a 'continuous gradient' of physical conditions from headwaters to a river's mouth; and (b) this longitudinal gradient ' . . . should elicit a series of responses within the constituent populations resulting in a continuum of biotic adjustments and consistent patterns of loading, transport, utilization and storage of organic matter along the length of a river'. Such concept involving energy sources and allocation (**Vannote *et al.*, 1980**) *i.e.*, at lower altitudes, there are higher amounts of energy available because of more solar radiation, more resources (for example, minerals and water); as a result, even higher levels of species richness can be allowed at lower altitudes. Interestingly, in the present investigation the values of CPUE, N, S, H', d of ichthyofaunal community were recorded lowest at RR-II, but on the contrary values of J' and  $\lambda$  were found highest. Similar lowest value of CPUE, N, S, H', d and highest value of  $\lambda$  found at TR-II. Thus, the current pattern of species richness, diversity and abundance of fishes contrasts sharply with the typical pattern. This pattern is

unlikely to result from sampling variation, because the same sampling gears were used in studies. The pattern found in this river suggests cumulative temporal and spatial effects of habitat loss or environmental degradation (**Scrimgeour and Chambers, 2000; Wolter *et al.*, 2000**). Habitat loss or environmental degradation may have occurred due to indiscriminate fishing, car and cloth washing, sand and boulder mining etc. **Sreekantha & Ramachandra (2005)** recorded the low fish richness due to degradation of breeding ground from Linganamakk reservoir on Sharavathi River, India. According to **Bunn and Arthington (2002)** many types of river ecosystem have been lost and populations of many riverine species have become highly fragmented due to human intervention. Anthropogenic disturbances like sand and boulder mining, car and cloth washing and intensive fishing activities may affect adversely the ichthyofaunal density and diversity at TR-II and RR-II of the river Teesta ad hill stream Relli respectively.

#### **5.4.5. Annual Variation of Density and Diversity Indices**

In the present study, slight annual variation of CPUE, population size, number of species, S-W species diversity index, evenness index, richness index and index of dominance of ichthyofaunal community in both the streams indicated that seasonal variations might occur year after year in a predictable manner. Monsoonal floods in such areas will qualify as disturbance. Spates and periodic scouring floods displace aquatic organisms, increase mortality (especially on juveniles), move sediments and restructure habitats, decrease the availability of benthic food resources and influence on the intensity of biotic interactions involving fishes (**Dudgeon, 1993**). The natural diversity of fish species complicates the impacts of flooding on stream fish assemblages. Certain fish species benefit from, and actually depend upon, seasonal or periodic extreme flooding. Seasonal flooding coordinates natural systems by providing environmental cues for spawning and migration processes (**Leitman *et al.*, 1991; John, 1963; Poff and Ward, 1989**). Numerous studies have concluded that juvenile life stages are particularly susceptible to heavy losses during extreme floods in high-gradient systems (**Elwood and Waters, 1969; Hoopes, 1975; Jowett and Richardson, 1989**). Large numbers of young fish are even lost during average seasonal flooding in systems where the timing of high flows coincides with fragile life stages (**Nehring and Miller, 1987**). The timing and duration of the extreme event and the environmental state of the natural system determine fish population responses in both the torrential streams.

#### **5.4.6. Ichthyofaunal Diversity in Relation to Water Quality**

Individual relationship between physico-chemical variables and values of

ichthyofaunal density and diversity index reflected in the Pearson correlation matrix. The natural waters in tropical areas generally show a higher fish production due to more heat budget in the ecosystem. **Probst (1950)** found an average increase in carp yield of 22 kg per hectare for 1<sup>0</sup>C rise of water temperature. Temperature plays a very important role in some physiological processes like release of stimuli for breeding mechanisms in fish, both under natural and artificial conditions (**Hora, 1945; Chaudhuri, 1964**). In the present investigation catch per unit effort (CPUE) ( $r = 0.168$ , in Teesta and  $r = 0.369$ ,  $P < 0.01$  in Relli), estimated population size (N) ( $r = 0.178$  in Teesta and  $r = 0.310$ ,  $P < 0.01$  in Relli) of fish fauna exhibited positive and evenness index showed negative correlation with water temperature in both the streams. In the hill stream Relli number of fish species, S-W species diversity index and Margalef's richness index had positive correlation with water temperature but in the river Teesta number of fish species, S-W species diversity index and Margalef's richness index. Increased water temperature in the stream Relli might have preferred by some species of fish and migrated from the river Teesta for breeding. This could be the probable reason for positive correlation in Relli and negative correlation in Teesta between number of fish species and water temperature. As a result, S-W species diversity index and Margalef's richness index was positively correlated in Relli and negatively correlated in Teesta with water temperature. Interestingly, this was reflected in the correlation between species dominance index and water temperature which was positive ( $r = 0.266$ ,  $P < 0.01$ ) in Teesta and negative in Relli. Stream flow is probably the most important physical variable affecting chemical characteristics and biological communities, and all biota must adapt to survive harsh conditions produced by desiccation or seasonal spates (**Matthews, 1988; Zale et al., 1989**). In the present study, fish catch per unit effort (CPUE) and index of dominance had positive and number of fish species, S-W species diversity index and Margalef's richness index showed negative correlation with water velocity in both the streams. Ecologically phosphorus is often considered as the most critical single element in the maintenance of aquatic productivity. **Moyle (1946)** found good production of fish in the ponds having phosphorus concentration 0.02-0.05 ppm. As a constituent of protein, nitrogen occupies a highly important place in aquatic eco-system. **Chu (1943)** concluded from the results of laboratory experiments that nitrogen and phosphorus naturally occur in quantities far below the upper limit for optimal growth of plankton and often do not reach lower optimal concentrations, the optimal limit of nitrogen being given by him as 0.3 to 1.3 ppm; these, however, may not be applicable to natural conditions. Present study exhibited positive correlation of fish CPUE, estimated population size, number of fish species, S-W species diversity index and Margalef's richness with PO<sub>4</sub>-P, NH<sub>4</sub>-N, NO<sub>2</sub>-N and NO<sub>3</sub>-N in both the streams. **Patra et al.**

(2011) observed similar positive correlation of fish population and phosphate and nitrate at two sampling sites of the Karala river of Jalpaiguri. Nitrogen cycle in streams required dissolved oxygen and increased water temperature had comparatively less temperature. Both the phenomenon might have probable role in significant negative correlation of CPUE and estimated fish population with dissolved oxygen in both the streams. **Shivshankar and Venkatramana (2012)** found negative correlation of pH with fish catch per unit effort (CPUE), estimated fish population, number of fish species, S-W species diversity index and Margalef's richness index in the Bhadra river of Western Ghat as found significantly in Relli. But positive correlation found in the Teesta could be due to migration of fish. Individual relationship between physico-chemical variables and values of ichthyofaunal density and diversity index reflected in the Pearson correlation matrix was failed to explain causal relationships.

The main tendencies of physico-chemical variables reflected in two principal components (PC-1 and PC-II) for the river Teesta. Ordinary Least Square (OLS) or linear regression analysis shows causal relationship between the principal components of physico-chemical parameters and density and diversity of ichthyofauna. Fish CPUE, estimated population size and number of fish species in the river Teesta was regulated by physico-chemical water quality probably in two different modes. In one hand, increased water temperature and loading of nutrients ( $\text{CO}_2$ ,  $\text{PO}_4\text{-P}$ ,  $\text{NH}_4\text{-N}$ ,  $\text{NO}_2\text{-N}$  and  $\text{NO}_3\text{-N}$ ) with decreased value of dissolved oxygen and specific conductance augmented fish CPUE, estimated population size and number of fish species. Nutrients loading during high water discharges and temperature may require more oxygen for aerobic decomposition of organic compounds. **Norris and Charlton (1962)** are of opinion that dissolved oxygen in the water bodies may be depleted during conversion of ions from a lower reductive state to higher oxidative state. Inverse relation of conductivity with water level has been reported by **Imevbore (1978)**, **Adebisi (1980)** and **Mishra (1999)** which corroborates present findings. On the other hand, increased value of pH, total alkalinity, Chloride and total hardness enhances fish CPUE, estimated population size and number of fish species, when water velocity was less. The higher values of  $\text{H}^+$  and  $\text{OH}^-$  (pH),  $\text{HCO}_3^-$  (total alkalinity), Ca and Mg salts with,  $\text{CO}_3^{=}$ ,  $\text{HCO}_3^-$ ,  $\text{SO}_4^{=}$ ,  $\text{Cl}^-$  and other anions of mineral acids (total hardness) might have augmented more mineralized water (TDS) for stream metabolism when water velocity is less. Numerous studies have concluded that juvenile life stages are particularly susceptible to heavy losses during extreme floods in high-gradient systems (**Elwood and Waters, 1969**; **Hoopes, 1975**; **Jowett and Richardson, 1989**) with high water velocity. Fish species diversity index and Margalef's richness index in the hill stream Relli were also augmented in

low water velocity and by the higher values of  $H^+$  and  $OH^-$  (pH),  $HCO_3^-$  (total alkalinity), Ca and Mg salts with,  $CO_3^{=}$ ,  $HCO_3^-$ ,  $SO_4^{=}$ ,  $Cl^-$  and other anions of mineral acids (total hardness). Conversely, river water with low water velocity and with the higher values of  $H^+$  and  $OH^-$  (pH),  $HCO_3^-$  (total alkalinity), Ca and Mg salts with,  $CO_3^{=}$ ,  $HCO_3^-$ ,  $SO_4^{=}$ ,  $Cl^-$  and other anions of mineral acids (total hardness) could have role in dropping off fish dominance index. No significant influence of principal components on fish evenness index indicated that other factors like fishing might have role in the regulation of evenness.

Fish CPUE in the hill-stream Relli was regulated by physico-chemical water quality in two probable modes. In one hand, increased water temperature, velocity and loading of nutrients ( $CO_2$ ,  $PO_4-P$ ,  $NH_4-N$ ,  $NO_2-N$  and  $NO_3-N$ ) with decreased value of dissolved oxygen, pH, specific conductance, total alkalinity, chloride and total hardness augmented fish CPUE. On the other hand, increased value of total alkalinity, Chloride and total hardness enhances fish CPUE. High water discharges with associated with high temperature, velocity and low dissolved oxygen, pH, specific conductance, total alkalinity, chloride and total hardness responsible for loadings of nutrients from allochthonous sources. Nutrients loading during high water discharges and temperature may require more oxygen for aerobic decomposition of organic compounds. Estimated fish population size, number of fish species, species diversity index and Margalef's richness index were augmented by the higher values of  $HCO_3^-$  (total alkalinity), Ca and Mg salts with,  $CO_3^{=}$ ,  $HCO_3^-$ ,  $SO_4^{=}$ ,  $Cl^-$  and other anions of mineral acids (total hardness) in the stream water. Conversely, stream water with the higher values of  $HCO_3^-$  (total alkalinity), Ca and Mg salts with,  $CO_3^{=}$ ,  $HCO_3^-$ ,  $SO_4^{=}$ ,  $Cl^-$  and other anions of mineral acids (total hardness) could have role in dropping off fish dominance index. No significant influence of principal components on fish evenness index indicated that other factors like fishing might have role in the regulation of evenness.

# *Chapter 6*



## *Summary*

## 6. Summary

---

The present *thesis* entitled “**Diversity of Plankton and Ichthyofauna in Relation to Limnochemistry of River Teesta and Relli in the Darjeeling Himalaya of West Bengal**” was conducted for a period of two years (March 2007 to February 2009). The objective of the study was to compare diversity of plankton and ichthyofauna and their relationship with water quality in glacier-fed river Teesta and its spring-fed tributary hill-stream Relli. The whole work was embodied in this thesis incorporating seven chapters. The methods and important findings of this study are as follows:

- ❖ Four sampling stations in the river Teesta and three sampling stations in the hill-stream Relli were selected for collection of water samples, plankton and fishes. Samples were collected at monthly intervals from March 2007 to February 2009, and collections were generally carried out between 7.00 AM and 10 AM. Water samples, plankton and fishes were collected, preserved and analysed following standard methods. Data on physico-chemical water quality were subjected to descriptive statistics, Fisher’s t test and Pearson’s correlation. Principal Component Analysis has been carried out to comprehend the main tendencies of physico-chemical water quality. Density and diversity indices of plankton and ichthyofauna were calculated. Data on density, diversity indices of plankton and ichthyofauna were subjected to the descriptive statistics, Fisher’s t test and Pearson’s Correlation. To understand causal relationship between water quality variables (independent) and density and diversity indices (dependent) of plankton and fish, regression analyses were performed.
- ❖ The mean values of water temperature ( $18.2^{\circ}\text{C}$ ), pH (7.6), specific conductance ( $70.5\ \mu\text{S cm}^{-1}$ ), dissolved oxygen ( $9.49\ \text{mg L}^{-1}$ ), free  $\text{CO}_2$  ( $2.48\ \text{mg L}^{-1}$ ) and chloride ( $4.5\ \text{mg L}^{-1}$ ) in Teesta river water were found lower than those of the hill-stream Relli ( $21.4^{\circ}\text{C}$ ; 7.8;  $77.5\ \mu\text{S cm}^{-1}$ ;  $9.71\ \text{mg L}^{-1}$ ;  $3.11\ \text{mg L}^{-1}$  and  $5.9\ \text{mg L}^{-1}$  respectively). But, the mean values of water velocity ( $2.75\ \text{m sec}^{-1}$ ), total alkalinity ( $34.2\ \text{mg L}^{-1}$ ), total hardness ( $24.7\ \text{mg L}^{-1}$ ),  $\text{NH}_4\text{-N}$  ( $0.024\ \text{mg L}^{-1}$ ),  $\text{NO}_2\text{-N}$  ( $0.013\ \text{mg L}^{-1}$ ),  $\text{NO}_3\text{-N}$  ( $0.046\ \text{mg L}^{-1}$ ) and  $\text{PO}_4\text{-P}$  ( $0.025\ \text{mg L}^{-1}$ ) were found higher in Teesta river than those of the Relli ( $0.90\ \text{m sec}^{-1}$ ;  $33.5\ \text{mg L}^{-1}$ ;  $22.7\ \text{mg L}^{-1}$ ;  $0.016\ \text{mg L}^{-1}$ ,  $0.009\ \text{mg L}^{-1}$ ,  $0.038\ \text{mg L}^{-1}$  and  $0.016\ \text{mg L}^{-1}$  respectively). Apparent water colour of the river Teesta was sea-green but, that of Relli was bluish in winter. During monsoon, apparent colour in both the stream was muddy brown. Untreated and unfiltered water of both Teesta and Relli couldn’t be accepted as everyday drinking water because of strong earthy or sandy flavour especially in monsoon.

- ❖ Seasonal values of physico-chemical parameters of water quality of both the streams showed strong seasonal dynamics of water quality. Significant correlation, altitudinal variations and weak annual dynamics of water quality parameters in both the streams pointed towards a unique pattern. Principal Component Analysis (PCA) reduced all the physico-chemical variables to two sets of uncorrelated transformed variables in the river Teesta, i) Principal Component-I (PCI) that is More Physical and Nutrients, Less Chemicals. ii) Principal Component-II (PCII) that is More Chemicals and less physical. But, in the stream Relli three Principal Components were found- i) Principal Component-I (PCI) that is more physical and nutrients, less chemicals. ii) Principal Component-II (PCII) that is more nutrients, less physical. iii) Principal Component-III (PCIII) that is more chemicals.
- ❖ A total of 47 genera of phytoplankton found in the river Teesta was higher than 34 genera observed in Relli. Both the streams were dominated by Bacillariophyceae followed by Chlorophyceae, Cyanophyceae and Euglenophyceae. Value of similarity Index (Sorensen's Coefficient of Community) of phytoplankton between two streams was 0.84. The average values of phytoplankton density ( $67.9 \text{ unit L}^{-1}$ ), number of phytoplankton genera (21.1), Shannon-Wiener Diversity Index (3.96 bits per individual) and Margalef's Richness Index of phytoplankton (4.82) in the Teesta were higher than those of Relli (mean  $48.6 \text{ unit L}^{-1}$ , 17.8, 3.87 bits per individual and 4.35 respectively). On the contrary, Evenness Index of phytoplankton with a mean value of 0.91 in Teesta was slightly lower than that of Relli (0.94). Interestingly, same mean values (0.081) of Index of Dominance of phytoplankton were observed in both the streams.
- ❖ A total of 22 genera of zooplankton found in Teesta were higher than 18 genera observed in Relli. The river Teesta was dominated by Rotifera followed by Cladocera, Protozoa, and Copepoda. But in Relli zooplankton community was dominated by Rotifera followed by Protozoa, Copepoda and Cladocera. Value of similarity Index (Sorensen's Coefficient of Community) of zooplankton between two streams was 0.80. Average values of zooplankton density ( $17.5 \text{ organisms L}^{-1}$ ), number of zooplankton genera (9.6), Shannon-Wiener diversity index (3.07 bits per individual), Evenness Index (0.960) and Margalef's richness index (3.02) in Teesta were higher than that of Relli ( $7.1 \text{ organisms L}^{-1}$ ; 5.2; 2.18 bits per individual, 0.955 and 1.96). On the contrary, Dominance Index of zooplankton with a mean value of 0.136 in Teesta was lower than that of Relli (0.255).
- ❖ A total of 65 species of fish belong to 3 orders, 10 families and 39 genera found in *Teesta* were higher than 25 species of fish belong to 5 families and 15 genera observed in *Relli*.

Maximum number of rheophilic, cold water hill stream species belongs to order Cypriniformes followed by Siluriformes in both the streams. Value of similarity Index (Sorensen's Coefficient of Community) of ichthyofauna between two streams was 0.56. Out of recorded species, 11 (17%) endangered (EN), 18 (28%) vulnerable (Vu), 19 (29%) low risk near threatened (LR-nt), 1 (1%) low risk least concern (LC-lc), 1 (2%) data deficient (DD) and rest 15 (23%) were not evaluated (NE) (Molur and Walker, 1998). But recent revise by NBFGR (Lakra *et al* 2010) included species like *Chagunius chagunio*, *Crossocheilus latius*, *Nangra nangra* and *Amblyceps mangois* under endangered (EN) category and *Garra lamta*, *Labeo pungusia*, *Glyptothorax telchitta* and *Olyra longicauda* under vulnerable (Vu) category. Thus, about 55% fish species of the river Teesta are threatened. Some species like *Crossocheilus latius*, *Psilorhynchus sucatio*, *Psilorhynchus homaloptera*, *Aborichthyes elongatus*, *Acanthocobitis botia*, *Schistura rupicola*, *Schistura scaturigina*, *Nemacheilus devdevi*, *Bagarius bagarius* and *Pseudolaguvia shawi* are endemic to India (Molur and Walker, 1998). Mean values of Fish Catch Per Unit Effort (36.9 individuals 100m<sup>-2</sup>), estimated population size (265.6 individuals 1000m<sup>-2</sup>), Number of Fish Species (13.6), Shannon-Wiener Species Diversity Index (3.435 bits per individual) and Margalef's Species Richness Index (3.508) in *Teesta* were higher than those of the *Relli* (27.8 individuals. 100m<sup>-2</sup>, 147.2 individuals. 1000m<sup>-2</sup>, 7.9, 2.735 bits per individual and 2.093 respectively). On the contrary, mean values of Evenness Index (0.924) and Dominance Index (0.136) of ichthyofauna in *Teesta* were lower than those of *Relli* (0.941 and 0.255).

- ❖ Seasonal values of abundance and diversity indices of phytoplankton, zooplankton and ichthyofaunal community in both the streams showed strong seasonal dynamics, strong altitudinal variations, weak annual dynamics and significant correlation amongst themselves and with water quality parameters, all pointing towards a unique pattern. Regression analysis showed causal relationship between the principal components of physico-chemical parameters and density and diversity indices of phytoplankton, zooplankton and ichthyofaunal community. Seasonality driven physical factors such as water velocity and water temperature were responsible for more mineralization of stream water by dissolving inorganic ions and nutrients which in turn regulating dynamics of density and diversity of plankton and ichthyofauna in a predictable fashion year after year until a big natural calamity.
- ❖ Present study also revealed that out of 65 species recorded 41 species considered as food fish with ornamental value, 7 species of food fish with sport value, 5 species of food fish and 12 species with ornamental value. The fish species available in both the streams

provide nutrition and recreation (rarely income generating) for a large number of people residing along the river bank and nearby villages and towns. Killing of large number of fish by unscientific fishing methods such as hill stream poisoning adversely affect the water quality. Over the years uncontrolled and often indiscriminate fishing in the unmanaged hill-stream has resulted in a sharp decline in fish resources.

- ❖ Several positive and negative environmental impacts were anticipated due to the construction and operation of the Teesta Low Dam Projects (TLDP-III and TLDP-IV) in Darjeeling Himalaya. The present study may provide baseline data for comparison of future studies. Migration pattern of fishes, density and diversity of phytoplankton, benthos, periphyton, zooplankton and ichthyofauna may be investigated on both the upstream and downstream stretches of the barrage along with physico-chemical parameters of water quality.
- ❖ The array of juveniles and sub-adults in the present study may suggests the hill-stream 'Relli' is ideal place for breeding of loaches, *Garra* spp, Snow trouts, *Neolissocheilus* spp and *Danio* sp along with other high priced fish. Teesta serve as the high-way for migration. Exploitation of breeding zones with conservation will flourish the population of these fishes in the stream. So propagation and conservation of such species can change the economic condition of the local people by trading in market. The 'Reyang fish seed farm' in the lower Reyang region may be operated effectively to breed high priced coldwater fishes along with coldwater ornamental fishes.
- ❖ The present study provides informative data and help to understand the pristine health of section of a glacier-fed river and a spring-fed torrential hill-stream in the Darjeeling Himalaya. From the overall study it is observed that seasonality of this region affects the physico-chemical water quality of the glacier-fed river and spring-fed hill-stream in different ways which as a far-reaching consequence alter the density and diversity of phytoplankton, zooplankton and ichthyofauna in a predictable manner. Monsoonal flood appeared to be acted as a moderate disturbance and driving force of diversification. The cycle might be operating year after year in a predictable manner except in case of big natural calamity.
- ❖ It may be concluded, that the seasonality, geomorphology, natural disturbances of this region and physico-chemical water quality along with plankton and ichthyodiversity of both the streams might have been co-evolving during the course of Himalayan evolution.

# *Chapter 7*



## ***Bibliography***

## 7. Bibliography

---

- Acharjee, M. L., Barat, S.,** 2010. Impact of fishing methods on conservation of ichthyofauna of river Relli in Darjeeling Himalaya of West Bengal. *Journal of Environmental Biology* 31: 431-434.
- Adebisi, A. A.,** 1980. The physico-chemical hydrology of a tropical season river- upper Ogun, Nigeria. *Hydrobiologia*. 79, 157-165.
- Adoni, A. D., Joshi, G., Ghosh, K., Chourasia, S. K., Vaishya, A. K., Yadava, M., Verma, H. G.,** 1985. *Workbook on limnology*. Pratibha Publication. C-10, Garunagar, Sagar (MP).
- Agarwal N.K., Thapliyal, B.L.,** 2005. Preimpoundment hydrological study of Bhilangana River from Tehri Dam reservoir area in Uttaranchal. *Environmental Geochemistry*. 8, 143-148.
- Agarwal N.K., Rawat, U.S., Thapliyal, B.L., Raghuvanshi, S.K.,** 2003. Seasonal variation in physico-chemical characteristics of the River Bhagirathi and its impact on phytoplankton and benthic entomofauna. *Proceedings of 12th National Symposium on Environment*, pp. 430-437.
- Agarwal, A. K., Rajwar, G. S.,** 2010. Physico-Chemical and Microbiological Study of Tehri Dam Reservoir, Garhwal Himalaya, India. *Journal of American Science*. 6(6), 65-71.
- Agostinho, A. A., Thomaz, S. M., Gomez, L. C.,** 2005. Conservation of the Biodiversity of Brazil's inland waters. *Conser. Biol.* 19: 646-652.
- Ahmad, S., Ajmal, M., Norman, A.A.,** 1996. Organochlorines and polycyclic aromatic hydrocarbons in the sediments of Ganges River (India). *Bulletin of Environmental*
- Ajmal, M., Normani, A.A., Khan, M.A.,** 1984. Pollution in the Ganges River, India. *Water Science and Technology* 16: 347-358.
- Akin-Oriola, G. A.,** 2003. Zooplankton associations and environmental factors in Ogunpa and Ona Rivers, Nigeria. *Rev Biol Trop*. 51(2): 391-8.
- Ali, M., Mageed, M., Heikal, A. A. M.,** 2003. Importance of aquatic macrophyte for invertebrate diversity in large subtropical reservoir. *Limnologica* ; 37: 155-69.
- Allan, D. J., Castillo, M. M.,** 2007. *Stream Ecology*. 2<sup>nd</sup> edn. Spring Publishers, Netherlands. 436pp.
- Allen, D. J.,** 1995. *Stream Ecology: structure and function of running waters*. Chapman and Hall, London. 388.
- Allen, D. J., Molur, S., Daniel, B.A.,** 2010. *The Status and Distribution of Freshwater Biodiversity in the Eastern Himalaya*. Cambridge, UK and Gland, Switzerland: IUCN, and Coimbatore, India: Zoo Outreach Organisation.

- Allen, J.D., Abell, R., Hogan, Z., Revenga, C., Taylor, B.W., Welcomme, R.L., Winemiller, K.,** 2005. Overfishing of inland waters. *Bioscience* 55: 1041–1051.
- Anand, N.,** 1998. *Indian Freshwater Microalgae*, First edition. Bishen Singh Mahendra Pal Singh, Dehra Dun, India.
- Ananthan G.,** 1995. Plankton ecology and heavy metal study in the marine environs of Pondicherry, Ph.D. Thesis, Annamalai University, India, P. 125.
- Anderson. R. S.,** 1971. Crustacean plankton of 146 alpine and subalpine lakes and ponds in Western Canada. *J. Fish- Res. Bd. Can.* 2K: 311-321,
- Anderson. R. S.,** 1974- Crustacean plankton communities of 340 lakes and ponds in and near the national park of the Canadian Rocky Mountains. - *J. Kish. Res- Bd. Can.* 31: 855-869 .
- Angelier, E.** 2003. *Ecology of Streams and Rivers*. Science Publishers, Inc., Enfield. Pp. 215.
- Angermeier, P. L.,** 1987. Spatiotemporal variation in habitat selection by fishes in small Illinois streams. In; W. J. Matthews and D. C. Heins, (eds). *Community and evolutionary ecology in North American stream fishes*. University of Oklahoma press, Norman, Oklahoma, USA. pp 52-60.
- Ankur, K., Siddiqui, N.A., Gautam, A.,** 2011. Assessment of heavy metals and their interrelationships with some physicochemical parameters in Ecoefficient rivers of Himalayan Region. *International Jour. of Environ Sci.* 2 (2), 440-450.
- Anonymous.,** 2002. *Environment Impact Assessment, Teesta Low Dam Project, Stage-III, West Bengal (vol-1)*. University of North Bengal, Darjeeling and NHPC Faridabad, Haryana, 8-17.
- Anonymous.,** 2005. *Endangered fishes of West Bengal, with special reference to North Bengal- A documentation on research, restoration and future plan of action*. Department of Fishery, Aqua Culture, Aquatic Resources and Fishing Harbour. 54p.
- Anonymous.,** 2001. *Preparation of Master Plan for Flood Management and Erosion Control in North Bengal, Phase-I, Draft final Report, Volume-I and II*. Uttarbanga Unnayan Parshad. Office of the Commissioners. Jalpaiguri Division, By Water and power Consultancy Services (India) Limited. New Delhi, pp. 9.6 (I) and 7.5 (II).
- APHA.** 2005. *Standard method for the examination of water and waste water*. APHA, AWWA, WPEC, 21<sup>st</sup> edition, Washington DC, USA.
- Arimoro F.O., Oganah A.O.,** 2010. Response of Zooplankton to abattoir wastes and other anthropogenic activities in a stream in the Niger Delta The Open Environmental & Biological Monitoring 3:1-11 doi: 10.2174/1875040001003010001 Bentham Science Publishers Ltd., USA.
- Arrignon, J.,** 1998. *Amenagement piscicole des eaux douces*, 5<sup>th</sup> ed. Tec et Doc Lavoisier.\*
- Arthington, A. H., Welcomme, R. L.,** 1995. The condition of large river systems of the world. In C.W. Voigtlander (ed) *Proceedings of the world fisheries congress*. New Delhi. Oxford and IBH Publishing Co. Pvt. Ltd. pp. 44-75.

- Aryal, S., Lacoul, P.,** 1996. Water quality and diversity of diatoms in Punyamati river, Nepal. *Ecoprint* 3: 45-49.
- Atkore, V. M., Sivakumar, K., Johnsingh, A. J. T.,** 2011. Patterns of diversity and conservation status of freshwater fishes in the tributaries of River Ramganga in the Shiwaliks of the Western Himalaya. *Current Science*, 100 (5). 731-736.
- Ayoade, A. A., Agarwal, N. K., Chandola-Saklani, A.,** 2009. Changes in physico-chemical features and plankton of two regulated high altitude rivers, Garhwal Himalaya, India. *Euro. Jour. of Sci. Res.* 27(1), 77-92.
- Ayyappan, S.,** 2006. Deputy Director-General (Fisheries) ICAR, Hand Book of Fisheries and Aquaculture.
- Baba, A. I., Sofi, A. H., Bhat, S. U., Pandit. A. K.,** 2011. Periphytic Algae of River Sindh in the Sonamarg Area of Kashmir Valley. *Journal of Phytology* 3(6): 01-12.
- Badola, S.P.,** 1979. Ecological studies on the Ichthyofauna of freshwater resources of Garhwal region. H.N.B. Garhwal University, Srinagar Garhwal. (D.Phil. Thesis)\*.
- Badola, S.P., Singh, H.R.,** 1981. Hydrobiological studies of the river Alaknanda of Garhwal Himalaya. *Indian. J. Ecol* 8 (2): 269-276.
- Badoni, K., Nautiyal, R., Bhatt, J. P., Kishore, B., Nautiyal, P.,** 1997. Variation in the epilithic Diatom community structure due to river valley projects on the Ganga between Rishikesh and Hardwar. *Proc. Indian Natn. Sci. Acad.* B68 No. 6: 523-536.
- Bagra, K., Das, D.N.,** 2010. Fish Diversity of River Siyom of Arunachal Pradesh India: A case study. *Our Nature.* 8, 164-169.
- Bagra, K., Kadu, K., Sharma, K.N., Laskar, B.A., Sarkar, U.K., Das, D.N.,** 2009. Ichthyological survey and review of the checklist of fish fauna of Arunachal Pradesh, India. *Check List* 5(2): 330-350.
- Bahuguna, S. N., Badoni, A. K.,** 2002. Qualitative and quantitative productivity of fish food from three important tributaries of river Alaknanda. *Himlayan Journal of Environmental Zoology* 16(2): 215-222.
- Bahuguna, B.K., Nautiyal, R., Nautiyal, P., Singh, H.R.,** 2004. Stream regulation; variations in the density, composition and diversity of benthic macroinvertebrates occurring in the up and downstream sections of the impounded zone of the river Ganga in the foot-hills. *Tropical Ecology*, 45 (2). 251-261.
- Bain, M. B.,** 1995. Habitat at the local scale: multivariate patterns for stream fishes. *Bull Fr Peche Piscicult* 337-339:165-177.
- Bais, V.S., Agrawal, N.C., Tazeen, A.,** 1995. Comparative study on seasonal changes in phytoplankton community in the Sagar lake and Military Engineering lake (M.P.). *J. Freshwater Biol.* 7: 19-25.
- Balian, E.V., Segers, H., Leveque, C., Martens, K.,** 2008. The Freshwater Animal Biodiversity Assessment: an overview of results. *Hydrobiologia* 595: 627-637.

- Balloch, D., Davies, C.E., Jones, F.H.,** 1976. Biological assessment of water quality in the three British river: The noth Esk (Scotland), the Ivel (England) and the Taff (Wales). *Water Pollution Control* 75: 92-114.
- Bamforth, S. S.,** 1958. Ecological studies on the planktonic protozoa of a small artificial pond. *Limnol. Oceanogr.* 3: 398-412.
- Barat, S., Jha, P.,** 2002. Changes in the water quality and total coliform bacterial load in a stretch of River Mahananda at Siliguri city, West Bengal, India. *Asian J. Microbiol. Biotech. Env. Science*, 4(4): 571-575.
- Barat, S., Jha, P., Lepcha, R.F.,** 2005. Bionomics and cultural prospects of Katli, *Neolissocheilus hexagonolepis* (McClelland) in Darjeeling district of West Bengal. In: *Coldwater fisheries research and development in north-east region of India* (Eds.: B. Tyagi, Shyam Sunder and M. Mohun). NRCCWF, Bhimtal. Vikrant Computers, Haldwani. pp. 66-69
- Barthem, R. B.,** 1981. *Consideracoes sobre a pesca experimental com rede de espera em lagos da Amazonia Central.* Dissertacao de Mestrado, INPA/FUA, Manaus.
- Battish, S .K.,** 1992. *Freshwater Zooplankton in India*, Oxford & IBH Publishing Co .Pvt. Ltd. New Delhi.
- Bays, J.S., Crisman, T.L.,** 1983. Zooplankton and trophic state relationships in Florida lakes. *Canadian Journal of Fisheries and Aquatic Science* 40, 1813–1819.
- Bayley, P., Li, H.,** 1994. Riverine fisheries. In: Calow P, Petts GE (eds) *The river handbook: hydrological and ecological principles.* Blackwell, Boston, pp 251–281.
- Beaver, J.R., Crisman,, T.L.,** 1982. The trophic response of ciliated protozoans in freshwater lakes. *Limnology and Oceanography* 27, 246–253.
- Begossi, A., Silvano, R.A.M., Amaral, B.D., Oyakawa, O.T.,** 1999. Use of local resources by fishers and hunters in an extractive reserve (Upper JuruaÂ, Acre, Brazil). *Environ. Dev. Sust.*1: 73-93.
- Bell, G.,** 2000. The distribution of abundance in neutral communities. *Am. Nat.* 155:606–617
- Bellinger, E. G., Sigeo, D. C.,** 2010. *Freshwater algae:identification and use as bioindicators.* John Wiley & Sons, Ltd.
- Benoit, R. J.,** 1969. Geochemistry of Eutrophication. In *Eutrophication: causes, consequences, Correctives.* National Academy of Sciences, Washington, DC. pp 614-630.
- Berger, W. H., Parker, F. L.,** 1970. Diversity of planktonic Foramenifera in deep sea sediments. *Science* 168: 1345-1347.
- Berzin, B., Pejlar, B.,** 1987. Rotifer Occurence in Relation to pH. *Hydrobiologia* 147: 107-116.
- Berzin, B., Pejlar, B.,** 1989. Rotifer Occurence in Relation to Oxygen Content. *Hydrobiologia* 183: 165-172.

- Berzins, B., Pejler, B.,** 1987. Rotifer occurrence in relation to pH. *Hydrobiologia* 147, 107-116.
- Bhadra, B., Mukherjee, S., Chakraborty, R., Nanda, A. K.,** 2003. Physico-Chemical and bacteriological investigation on the river Torsa of North Bengal. *J. Environ. Biol.* 24: 125-133.
- Bhadra, B., Chakraborty, R., Das, S., Nanda, A. K.,** 2005. Investigation of some basic water quality parameters of the north Bengal Terai river Kaljani- a tributary of river Torsa, and comparison thereof with the mainstream. *J. Environ. Biol.* 26: 277-286.
- Bhakta, J.N., Bandyopadhyay, P.K.,** 2007. Exotic fish biodiversity in Churni River of West Bengal, India. *Electronic Journal of Biology* 3: 13–17.
- Bhandari, N. S., Nayal. K.,** 2008. Correlation Study on Physico-Chemical Parameters and Quality Assessment of Kosi River Water, Uttarakhand. *E-Journal of Chemistry* 5 (2), pp. 342-346, <http://www.e-journals.net>. Accessed on 30<sup>th</sup> March 2012.
- Bharati, R.,** 2004. *Rivers of India*. English Translation (Translated by S. Sinha). National Book Trust, India. 1p.
- Bharati, S. G., Kore, A. P.,** 1975. Limnological studies in ponds and lakes. *Karnataka University Journal of Science*, 20: 157-167.
- Bhat, M.P., Masuzawa, T., Yamamoto, M., Gardner. K.H.,** 2008. Spatial variations in chemical compositions along Langtang-Narayani river system in Central Nepal. *Environ Geol.* 20(5):593-598.
- Bhat, S.U., Sofi, A.H., Yaseen, T., Pandit, A.K., Yousuf, A.R.,** 2011. Macroinvertebrate community from Sonamarg streams of Kashmir Himalaya. *Pakistan Journal of Biological Sciences.* 14(3): 182-194.
- Bhatt, S. D., Pathak, J. K.,** 1989. Hydrological profile of river Sarju draining upland of Kumaun (Greater Himalaya). *Journal of Freshwater Biology*, 1: 33- 42.
- Bhatt, S. D., Pathak, J. K.,** 1990. Hydro-environmental Indicators in the Kali Riverine Ecosystem of the Central Himalaya. In: N. K. Sah, S. D. Bhatt and R. K. Pande (eds.), *Himalaya: Environment, Resources and Development*. Shree Almora Book Depot, Almora. pp,111-120.
- Bhatt, S.D., B. Yashodhara, B., Usha, A N.** 1985. Hydrobiology and phytoplankton population in river Kosi of the Western Himalaya (Utter Pradesh). *Indian. J. Ecol.*, 12 (1): 141-146.
- Bhattacharjya, B.K., Choudhury, M., Sugunan, V. V., Pathak, V., Sarkar, A.** 2002. Ecology and Fisheries of Selected Coldwater Streams of Assam. Abstract Proceedings, *National Seminar on Aquatic Resource Management in Hills*, NRC on Cold water Fisheries (ICAR), Nainital, pp 88-89.
- Bhattacharya, B.K.,** 2005. Ecology and fisheries of coldwater resources of Assam. In, Tyagi, B. C., S. Sunder., and M. Mohan (eds) *Coldwater fisheries research and development in North East region of India*. National Research Centre on Cold Water Fisheries (ICAR) Bhimtal, Uttaranchal. pp 20-24.

- Bidwell, A., Clarke, N.V.**, 1977. The invertebrate fauna of Lake Kainji. *Nigeria Field* 42: 104-110.
- Biggs, B. J. F.**, 1996. Patterns in benthic algae of streams. In *Algal Ecology: Freshwater Benthic Ecosystems* (eds. Stevenson RJ, Bothwell ML, Lowe RL), Academic Press, New York. 256-96.
- Biswas, S. P., Boruah, S. P.**, 2000. Fisheries ecology of the northeastern Himalayas with special reference to the Brahmaputra River. *Ecological Engineering*, 16. 39-50.
- Bishop, J. E.**, 1973. *Limnology of small Malayan river, Sungai Gombak*. Dr. W. Junk Publishers. The Hague.
- Bisht KL.**, 1993. Environmental parameters and seasonal succession in planktonic biomass in the River Pinder of Garhwal Himalaya. In *Advances in Limnology*. Ed. H. R. Singh, Narendra Publishing House, Delhi.
- Bisht, B., Badoni, A. K., Bahuguna, S. N.**, 2009. Seasonal distribution and relative abundance of fish fauna of a small hill-stream Dangchaura (Takoli) Gad, along the river Alaknanda. *Our Nature* 7: 182-186.
- Biswas, S.P., Boruah, S.**, 2000a. Fisheries ecology of the northeastern Himalayas with special reference to the Brahmaputra River. *Ecological Engineering* 16, 39–50.
- Biswas, S. P., Boruah, S.**, 2002. Ecohydrology and Fisheries of the upper Brahmaputra basin. *The Environmentalist*, 22 119-131
- Bohra, C., Kumar, A.** 1999. Comparative Studies of Phytoplankton in two ecologically different lentic fresh water ecosystem. In: Kumar, A. (ed). *Modern Trends in Environmental Pollution and Ecoplanning*. ABP Publishers, Jaipur. pp 220-242.
- Boon, P. J.**, 1998. River restoration in five dimensions. *Aquatic conservation: Marine and Freshwater Ecosystems* 8: 257–264.
- Boruah, S.**, 1999. Investigation on certain aspects of hydrobiology in relation to fisheries in the upper stretches of the River Brahmaputra. *Ph.D. thesis, Dibrugarh University*.
- Boruah, S., Biswas, S.P.**, 2002. Ecohydrology and fisheries of the upper Brahmaputra basin. *The Environmentalist*, 22. 119–131.
- Bose, S.K., Gorai, A.C.**, 1993. Seasonal fluctuations of plankton in relation to physicochemical parameters of a freshwater tank of Dhanbad, India. *J. Freshwater Biol.* 5: 133-140.
- Boyd, C. E.**, 1982. *Water Quality Management for Pond Fish Culture*. Elsevier, U.K.
- Breitburg, D.L., Sanders, J.G., Gilmour, C.C., Hatfield, C.A., Osman, R.W., Riedel, G.F., Seitzinger, S.P., Sellner, K.G.**, 1999. Variability in responses to nutrients and trace elements, and transmission of stressor effects through an estuarine food web. *Limnology and Oceanography* 44, 837–863.
- Brewin, P.A., Newman, T.M.L., Ormerod, S.J.**, 1995. Patterns of macroinvertebrate distribution in relation to altitude, habitat structure and land use in streams of the Nepalese Himalaya. *Archiv für Hydrobiologie* 135: 79–100.

- Bright, D.A., Addison, J.,** 2002. Derivation of matrix soil standards for salt under the British Columbia Contaminated Sites Regulation. Royal Roads University. Prepared for BC Ministry of Water, Land and Air Protection, BC Ministry of Transportation and Highways, BC Buildings Corp., and the Canadian Association of Petroleum Producers. Victoria, BC.
- Bronmark, C., Hanson, L. A.,** 2002. Environmental Issues in Lakes and Ponds; Current Status and Perspectives. *Environ. Conserv.* 29: 290-307.
- Brower, J. E., Zar, J. H.,** 1977. *Field and laboratory methods for general ecology*, W. M. C. Brown Co. Publ., Dubuque, Iowa.
- Brown, A.L.,** 1987. *Freshwater Ecology*. Heinemann Educational Books, London. Pp. 163.
- Bruton, M.N.,** 1985. The effects of suspensoids on fish. *Hydrobiologia* 125: 221–241.
- Buck, H. D.,** 1956. Effects of turbidity on fish and fishing. *Transactions of the North American Wildlife and Natural Resources Conference.* 21, 249-261.
- Bunn, S. E., Arthington, A. H.,** 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environ Manag.* 30, 492–507.
- Burton, P. J., Balinsky, A. E., Coward, L. P., Cumming, S. G., Kneeshaw, D. D.** 1992. The value of managing for biodiversity. *The Forestry Chronicle* 68 (2): 225-237.
- Busulwa, H.S., Bailey, R.G.,** 2004. Aspects of the physicochemical environment of the Rwenzori rivers, Uganda. *African Journal of Ecology* **42**, 87–92.
- Byars, J. A.,** 1960. A freshwater pond in Newzealand. *Australian Journal of Marine and Freshwater Resources*, 11, 220–240.
- Caissie, D.,** 2006. The thermal regime of rivers: a review. *Freshwater Biology* 51: 1389–1406.
- Calow, P., Petts, G. E.,** 1992. *The rivers handbook*. Blackwell Scientific Publications. London.
- Cantonati, M., Corradini, G., Juttner, I., Cox, E. J.** 2001. Diatom assemblages in higher mountain streams of the Alps and the Himalaya. *Beiheft Zur Nova Hedwigia*, 123: 37-61.
- Carpenter, S., Kitchell, J. and Hodgson, J.,** 1985. Cascading trophic interactions and lake productivity. *BioScience* 35: 634-638.
- Cascallar, L., Mastranduono, P., Mosto, P., Rheinfeld, M., Santiago, J., Tsoukalis, C., Wallace, S.,** 2003. Periphytic algae as bioindicators of nitrogen inputs in lakes. *Journal of Phycology.* 39:7-8.
- Cato, J.C., Brown, C.L.,** 2003. Marine Ornamental Species: Collection, Culture, and Conservation. Ames, IA: Iowa State Press.
- CEPF. 2005.** *Ecosystem Profile: Eastern Himalayas Region*. Critical Ecosystem Partnership Fund. Available at: <http://www.cepf.net/Documents/final.ehimalayas.ep.pdf>.

- Chakrabarty, R.D., Ray, P., Singh, S.B.,** 1959. A quantitative study of the plankton and physico-chemical conditions of river Jamuna at Allahabad in 1954 - 55. *Indian J. Fish.* 6 (1): 186 - 203.
- Chakraborty, D.,** 1998. A study on the water and sediment quality as well as macro population of a natural hill stream in the Darjeeling hill. *Indian J. Env. And Ecoplan.* 1 (3): 69-72.
- Chakraborty, D.,** 1998a. Limnological studies on Lake Sinchel, a mountain lake in Darjeeling. *Environment and Ecology* 16(1): 31-33.
- Chakraborty, D.,** 1998b. A study on the water and sediment quality as well as macro population of a natural hill stream in the Darjeeling hill. *Indian J. Env. And Ecoplan.* 1 (3): 69-72.
- Chakraborty, D.,** 2000. Eco-health study of two high altitude water reservoirs of Eastern Himalayas during Monsoon season. *Geobios* 27: 17-20.
- Chakraborty, D., Saha, G. K.,** 1993. The Physico-Chemical and Hydro Biological features of three stagnant water sources in DarjeelingHills. *Geobios* 20: 61-65.
- Chakraborty, T., Bhattacharjee, S.,** 2008. The Ichthyofaunal Diversity in the Freshwater Rivers of South Dinajpur District of West Bengal, India. *Journal of Bombay Natural History Socieity*, 105(3): 292-298.
- Chandler, O. C.,** 1937. Fate of typical lake Plankton in streams. *Ecol Monogr*, 7: 445-75.
- Chaudhuri, H.** 1964. Technique of induced breeding in fishes with special reference to major carps of India. *Proc. Seminar Inland Fish. Div. U. P. :* 65-73.
- Chellappa, N. T., Chellappa, T., Camara, F. R. A., Rocha, O.,** 2009. Impact of Stress and disturbance factors on the phytoplankton communities in Northeastern Breazil reservoir. *Limnologica.* 39: 273-282.
- Chopra, A. K., Madhwal, B. P., Singh. H. R.,** 1993. Relationship between abiotic variables and benthic fauna of river Yamuna in Garhwal Himalaya. *Indian J Eco*, 20(1). Pp 53-58.
- Choudhury, M.,** 2005. Riverine fishery resources of Northeast India. In, Tyagi, B. C., S. Sunder., and M. Mohan (eds) *Coldwater fisheries research and development in North East region of India.* National Research Centre on Cold Water Fisheries (ICAR) Bhimtal, Uttaranchal. pp 17-19.
- Chu, S. P.,** 1943, The influence of the mineral composition of the medium on the growth of plankton algae. Part II. The influence of the concentration of inorganic nitrogen and phosphate phosphorus. *J. Ecol.* 31: 109–148.
- Colwell, R.K.,** 1974. Predictability, constancy, and contingency of periodic phenomena. *Ecology.* 55, 1148–1153.

- Conway, K. W., Edds, D. R., Shrestha, J., Mayden, R. L.,** 2011. A new species of gravel-dwelling loach (Ostariophysi: Nemacheilidae) from the Nepalese Himalayan foothills. *Journal of Fish Biology* 79, 1746–1759.
- Cornish, A.S., McKellar, D.,** 1998. A history of fishing with explosives and poisons in Hong Kong waters. *Naga, the Iclarm Quarterly*, 21, 4-9
- Cowx, I. G.,** 1998. *Rehabilitation of Rivers for fish*. Food and Agriculture Organization of the United Nations (FAO). Fishing News Book, London. pp 97.
- Cox, E. J.,** 1996. Identification of Freshwater Diatom Live Material. Chapman and Hall, London.
- Cozar, A., Garcia, C. M., Galvez, J. A.,** 2003. Analysis of Plankton size Spectra Irregularities in two sub-tropical shallow Lakes (Esteros del Ibera, Argentina). *Can. J. Fish. Aquat. Sci.* 60: 411-420.
- Crayton, W. M., Sommerfield, M. R.,** 1979. Composition and abundance of phytoplankton in tributaries of the lower Colorado river, Grand Canyon region. *Hydrobiologia*; 66:81-93
- Cummins, K. W.,** 1975. The ecology of running waters; theory and practice. pp. 277-293, In; *Proc. Of the Sandusky river basin symposium*. International joint commission on the great lakes, Heidelber College, Tiffin, Ohio, USA.
- Cummins, K. W.,** 1974. Structure and Function of Stream Ecosystems. *BioScience*, 24(11). pp. 631-641.
- Cummins, K. W., Minshall, G. W., Sedell, J. R., Cushing, C. E., Petersen, R. C.,** 1984 Stream ecosystem Theory. *Internale Vereinigung Fur Theoratischa and Angewandte Lomnologic Verhandlungen*. 22: 1818-1827.
- Cushing, E. C.,** 1965. Plankton and water chemistry in the Montreal River lake stream, Saskatchewan. *Ecology*, 45:306-13
- Cushing C. E., Cummins, K. W., Minshall, G. W.,** 1995. *River and stream ecosystems*. Ecosystems of the World V. 22. Elsevier. 8 17 p.
- Cushing, C.E., Allan, J.D.,** 2001. *Streams: their ecology and life*. Academic Press, San Diego. Pp. 366.
- Dadhick, N., Saxena, M. M.,** 1999. Zooplankton as indicators of trophical status of some desert waters near Bikaner. *Journal of Environment and Pollution* 6:251-254.
- Daimari, P., Choudhury, M., Dutta, A.,** 2005. Ecology and fishery of river Subansiri (Arunachal Pradesh). *Environment and Ecology*, 23(1). pp 49-54
- Daniels, R. J. R.,** 2002. *Freshwater Fishes of Peninsular India*. Universities Press (India) Private Limited. 288.
- Das, N. G.,** 1997. *Statistical Methods, Part –II*. M. Das and Co. Calcutta. 256p.
- Das, H., Dutta, A.,** 2011. Diversity And Abundance of Plankton In Pagladia River of Assam. *International Referred Research Journal*. III (35), 25-27.

- Das, R. C., Mukherjee, A. B.,** 2005. Important fish fauna of river Teesta, their biodiversity and the need of their conservation. In: P. C. Mahanta and A.K. Singh (eds). *Proceedings of the National Symposium on Reassessment of Fish Genetic resources in India and Needs to Evolve sustainable methodology for conservation*, organized by Asian Fisheries Society, Indian Branch and NBPGR, Lucknow. pp 39-40.
- Das, S. K., Chakrabarty, D.,** 2007. The use of fish community structure as a measure of ecological degradation: a case study in two rivers of India. *Bio Syst.* 90: 188–196.
- Das, S. M.** 1990. The Mahseer Fishes of India: Bioecology and the Problems of their Rapid Decline in Central Himalaya. In N. K. Sah, S. D. Bhatt and R. K. Pande (eds.) *Himalaya: Environment, Resources and Development*. Shree Almora Book Depot, Almora. pp,310-317.
- Dash, A.J.,** 1947. *Darjeeling District Gazetteer*. West Bengal Government Publication. Calcutta
- Datta, T.,** 2011. Zooplankton diversity and physico-chemical conditions of two wetlands of Jalpaiguri district, India. *International Journal of Applied Biology and Pharmaceutical Technology* 2 (3): 576-583.
- Dawes, C. J.,** 1981. *Marine Botany*, A Wiley- Interscience publication, USA.
- De, N. K., Bera, A.K.,** 1990. Soils of the Darjeeling Himalayas. In N. K. Sah, S. D. Bhatt and R. K. Pande (eds.) *Himalaya: Environment, Resources and Development*. Shree Almora Book Depot, Almora. pp, 151-163.
- Dejen, E., Vijverberg, J., Nagelkerke, L. Sibbing, F.,** 2004. Temporal and spatial distribution of microcrustacean zooplankton in relation to turbidity and other environmental factors in large tropical lake (L. Tana, Ethiopia). *Hydrobiologia* 513: 39-49.
- Desikachary, T. V.,** 1959. Cyanophyta. *Indian Council of Agricultural Research*. New Delhi, India.
- Dey, V. K.,** 1996. *Ornamental Fishes: Handbook of Aquafarming*. The Marine Products Export Development Authority, Kochi.
- Dhanapakiam, P., Sampoorani, V., Kavita, R.,** 1999 Assessment of water quality of the river Cauvery. *J. Environ. Biol.*, 20 (4) : 347-352.
- Dhanze, R., Sharma, I., Dhanze, J. R.,** 1998. Hydrobiology of sub temperate streams of Beas drainage system with reference to fish faunal resource. *J. Natcon*, 10(2): 133-143.
- Dhendup, T., Boyd, C.E.,** 1994. Chemical features of water and soil in fish farming areas of Bhutan. *J. Aqua. Trop.* 9: 35-41.
- Dijik, G.M.V., Zanten, B.V.,** 1995. Seasonal changes in zooplankton abundance in the diversity in the river Nayar of Garhwal Himalya. *J. Freshwater Biol.* 1: 1-6.

- Djurkovic, A., Miletic, A., Cadjo, S.,** 2006. Results Of Qualitative and Quantitative contents of Zooplankton of The Danube River Through The Territory Of Serbia. Balwois.
- Dobriyal A.K., Bahuguna, A.K., Neeraj, K., Kotnala, C.B.,** 1993. Ecology and seasonal diversity of plankton in a springfed stream Khandagad of Garhwal Himalaya. In *Advances in Limnology*. Ed. H. R. Singh, Narendra Publishing House, Delhi.
- Dobriyal, A. K., Singh, H. R.,** 1988. Ecological basis for Ichthyofaunal variation in the two Hill streams of Garhwal Himalayas. In: Joseph, M. M., (ed), *The first Indian fisheries forum proceeding Asian Fisheries society*, Indian Branch, Mangalore. pp. 313-317.
- Dobriyal, A.K., Singh, H.R.,** 1989. Observations on temporal trends of phytoplankton diversity in the river Nayar of Garhwal Himalaya. *J. Freshwater Biol. 1: 1-6*.
- Dobryal, A. K., Joshi, H.,** 1999. Faunal Diversity and its Determinant factors in some hill streams of Garhwal Himalaya. *Uttar Pradesh J. Zoo*, 19(1), 85-87.
- Dodds, W.K.,** 2002. *“Freshwater Ecology: Concepts and Environmental Applications.”* Elsevier India Pvt. Ltd.
- Dubey, G. P.,** 1978. Survey of the waters of Bhutan. Physiography and fisheries potential. Report.Rome, *FAO.38p*.<http://www.fao.org/docrep/field/003/L8853E/L8853E00.htm>. Retrieved March 30, 2012.
- Dudgeon, D.,** 2000. The ecology of tropical Asian rivers and streams in relation to biodiversity conservation. *Annual Review of Ecology and Systematics* 31: 239–263.
- Dudgeon, D.,** 2008. *Tropical Stream Ecology*. Academic Press is an imprint of Elsevier, U.K. 316pp.
- Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z., Knowler, D. J., Leveque, C., Naiman, R. J., Prieur-Richard, D. A., Stiassny, M. L. J., Sullivan, C. A.,** 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biol. Rev.* 81:163–182.
- Dumont, H.J.,** 1999. The species richness of reservoir plankton and the effect of reservoir on plankton dispersal (with particular emphasis on rotifers and cladocerans). In: Theroretical reservoir ecology and its applications (Eds.: J.G. Tundisi and M. Straskraba). *Internat. Inst. Ecol., Sao Carlos*. pp. 477-492.
- Dussart B.H., Fernando C.H., Matsumara-Tundis, T., Shiel R.J.,** 1984. A review of systematics, distribution and ecology of tropical freshwater zooplankton. *Hydrobiologia*, 113: 77–91.
- Dutta, S.P.S., Malhotra. Y.R.** 1986. Seasonal variations in the macrobenthic fauna of Gadigarh stream (Miran Sahib) Jammu. *Indian J. Ecol.*, 113(1): 138-145.
- Dutta, S.P.S., Malhotra, Y.R., Sharma, K.K., Sinha, K.,** 2000. Diel variations in physico-chemical parameters of water in relation to macrobenthic invertebrate in some pool adjacent to the River Tawi, Nagrota Bye Pass, Jammu. *Him. J. Environ. Zool.*, 14: 13-24.

- Dynesius, M., Nilsson, C.,** 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science* 266: 753-762.
- Edds, D. R.,** 1993. Fish Assemblage Structure and Environmental Correlates in Nepal's Gandaki River. *Copeia* (1): 48-60.
- Edds, D.R., Gillette, D.P., Maskey, T.M., Mahato, M.,** 2002. Hot-soda process paper mill effluent effects on fishes and macroinvertebrates in the Narayani River, Nepal. *Journal of Freshwater Ecology* 17: 543–554.
- Edema, E.U., Ayeni, J.O., Aruoture, A.,** 2002. Some observations on the zooplankton and macrobenthos of the Okhuo River, Nigeria. *J. Aquat. Sci.*, 7(2): 145–149.
- Elwood, J.W., Waters, T.F.,** 1969. “Effects of floods on food consumption and production rates of a stream brook trout population”, *Transactions of the American Fisheries Society*. 98(2), 253-262.
- Emmanuel, L. O., Modupe, O. O.,** 2010. Fish Diversity in Three Tributaries of River Ore, South West, Nigeria. *World Journal of Fish and Marine Sciences*. 2 (6): 524-531.
- Evans, J. W., Noble, R. L.,** 1979. The longitudinal distribution of fishes in an east Texas stream. *American Midland Naturalists* 101: 333-343.
- Evans, M., Frick, C.,** 2001. The effects of road salts on aquatic ecosystems. NWRI Contribution Series No. 01-000. National Water Research Institute, Saskatoon, Saskatchewan.
- FAO.** 2002. *The State of World Fisheries and Aquaculture 2002*. Rome.
- Farley, J., Daly, H. E.,** 2004. *Ecological Economics Principles and Applications*. Island Press. Washington.
- Faurie, C., Ferra, C., Medori, P., Devaux, J.** 2001. *Ecology Science and Practices*. Oxford & IBH Publishing Co. Pvt. Ltd. New Delhi.
- Fernando, C. H.,** 1980. The species composition of tropical fresh water zooplankton with special reference to the oriental region (South East Asia) . *Int Revue. ges. Hydrobiol.* 65:411-426.
- Finlay, J.C., Khandwala, S., Power, M. E.,** 2002. Spatial scales of carbon flow in a river food web. *Ecology*. 83:1845-1859.
- Forel, F. A. 1882, 1895, 1904.** *Le Lemane: Monographie Limnologique*, Vols. 1–3. Lausanne: F. Rouge.
- Forel, F. A. 1895.** *Le Lemane. Monographie limnologique. Vol. II. Lausanne*, 651 pp.
- Froese, R., Pauly, D.,** 2008. *FishBase*. Available at <http://www.fishbase.org> (version 07/2008). [Cited 12 April 2012].
- Fu, C., Wu, J., Chen, J., Wu, Q., Lei, G.** 2003. Fresh water fish biodiversity in the Yangtze River basin of China: patterns, threats and conservation. *Biodivers Conserv.*12: 1649–1685.

- Galloway, J. N., Dentener, F. J., Capone, D. G., Boyer, E. W., Howarth, R. W., Seitzinger, S. P., Asner, G. P., Cleveland, C. C., Green, P. A., Holland, E. A., Karl, D. M., Michaels, F., Porter, J. H., Townsend, A.R., Vo` Ro` Smarty, C. J.,** 2004. Nitrogen cycles : past, present, and future. *Biogeochemistry* 70, 153–226.
- Gautam, A.,** 1990. *Ecology and pollution of mountain water*. Ashish publishing house, New Delhi, India.
- Ghosh, S., Barinova, S., Keshri, J. P.,** 2012. Diversity and seasonal variation of phytoplankton community in the Santragachi Lake, West Bengal, India, *QScience Connect*, 3 <http://dx.doi.org/10.5339/connect.2012.3>
- Ghoshal, D. K.,** 2002. Scope for development of coldwater fisheries in the state of West Bengal. In: *Highland Fisheries and Aquatic Resource Management* (Eds. K. K. Vass and H. S. Raina). NRCCWF, Bhimtal. Yugantar Prakashan Pvt. Ltd., New Delhi: 73-75.
- Giller, S., Malmqvist. B.,** 1998. *The Biology of Streams and Rivers*. Oxford University Press, Oxford. Pp. 296.
- Gopal, B., Zutshi, D. P.,** 1998. Fifty years of hydrobiological research in India. *Hydrobiologia* **384**: 267–290, 1998.
- Gopal, B.,** 2003. State of degradation and approaches to restoration of floodplain rivers in India. In R.L. Welcomme & T. Petr. eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2*. Phnom Penh, Mekong River Commission.
- Gopal, K., Agarwal, A.,** 2003. *River Pollution in India and Its Management*. APH Publishing, New Delhi, India.
- Gordon, N. D., McMahon, T. A., Finlayson, B. L., Gippel, C. J., Nathan, R. J.,** 2004. *Stream Hydrology; An Introduction for Ecologists*. John Wiley & Sons Inc., 111 River Street, Hoboken, NJ 07030, USA
- Gowswami, C. S., Selvakumar, R. A.,** 1977. Plankton studies in the estuaries system. *Geo. Proc. Symp. Warm water. Zoopl. Spl Publication*. UNESCO pp.226-241.
- Goswami, U. C., Basistha, S. K., Bora, D., Shyamkumar, K., Saikia, B., Changsan, K.,** 2012. Fish diversity of North East India, inclusive of the Himalayan and Indo Burma biodiversity hotspots zones: A checklist on their taxonomic status, economic importance, geographical distribution, present status and prevailing threats. *International Journal of Biodiversity and Conservation* Vol. 4(15), pp. 592-613. DOI: 10.5897/IJBC11.228
- Goulding, M.,** 1980. *The fishes and the forest*. Univ. of California Press, Berkeley.
- Graham, L.E., Wilcox, L.W.,** 2000. *Introduction to the Algae*. Algae. Prentice-Hall, Inc Upper Saddle River, NJ, pp. 1-20.
- Greenberg, J. H.,** 1956. The measurement of linguistic diversity. *Language*. 32, 109-115.

- Gregory, S. V., Swanson, F. J., McKee, W. A., Cummins, K. W.,** 1991. An ecosystem perspective of riparian zones. *BioScience*, 41: 540-551.
- Gupta, A.** 1987. Large floods as geomorphic events in the humid tropics. In: *Flood Geomorphology* (eds V.R. Baker, R.C. Kochel & P.C. Patton). John Wiley & Sons, New York. pp. 301– 315
- Gupta, A.,** 1993. Life history of two species of *Baetis* (Ephemeroptera: Baetidae) in a small north-east Indian stream. *Arch. Hydrobiol.* 127: 105–114.
- Gurumahum S.D., Daimari, P., Goswami, B.S., Sakar, A., Choudhury, M.,** 2000. Physico chemical qualities of water and plankton of selected rivers in Meghalaya. *Journal Inland Fisheries Society of India* 34, pp36 - 42.
- Gusain, M. P., Gusain, O. P., Datt, R.** 2002. Biomass and secondary production of macroinvertebrate benthos in a small springfed stream, Garhwal Himalaya. Abstract Proceedings, *National Seminar on Aquatic Resource Management in Hills, NRC on Cold water Fisheries (ICAR)*, Nainital, pp. 62.
- Guy, D.** 1992. The ecology of the fish pond ecosystem with special reference to Africa. Pergamon press. 220-230pp.
- Hancock, F. D.,** 1973. Algal ecology of stream polluted through gold mining winter water stand. *Hydrobiol.* 43, 189-229.
- Hannan, H.H., Young, W.J.,** 1974. The influence of a deep-storage reservoir on the physicochemical limnology of a Central Texas river. *Hydrobiologia* 44:177-207.
- Happy-Wood, C. M.,** 1988. *Ecology of freshwater planktonic green algae*. In: Sandgren, C. D. (Ed), Growth and reproductive strategies of freshwater phytoplankton, Cambridge University Press. Cambridge, UK, pp. 175-226.
- Haque, N., Toppo, S., Rahman, H.,** 2010. Aquatic environment and riverine fish diversity in Sikkim. In: *Cold Water Fisheries Management*, edited by P.C. Mahanta and D. Sharma. pp. 141-156.
- Hart, R. C.,** 1996. Comparative ecology of plankton in cascading warm-water reservoirs: aspects of relevance to tropical limnology. In: *Perspectives in tropical limnology*. F. Schiemer & K. T. Boland (eds.). 113-130. SPB Academic Publishing, Amsterdam.
- Hauer, F. R., Lamberti, G. A.,** 2007. *Methods in Stream Ecology*. 2<sup>nd</sup> edition. Academic Press is an imprint of Elsevier.
- Hawkes, H. A.,** 1979. Invertebrates as indicator of river water quality, In: James, A., Evison, L., (eds), *Biological indicators of water quality*. John Wiley and Sons. Great Britain. pp.16-30.
- Hill, M.,** 1973. Diversity and evenness: A unifying notation and its consequences. *Ecology*, 54, 427-432.
- Hooker, J. D.,** 1854. *Himalayan Journals*. Vol. 1. Project Gutenberg Literary Archive Foundation, PMB 113, 1793 University Avenue, Oxford, MS 38655 4109, p 151. [www.scribd.com/doc/ HimalayanJournals-Volume-1-by-Hooker- J-D-Joseph Dalton-18171911](http://www.scribd.com/doc/HimalayanJournals-Volume-1-by-Hooker-J-D-Joseph-Dalton-18171911).

- Ho, M.H.**, 1981. *Hong Kong poisonous plants*. Urban Council, Hong Kong
- Hoopes, R. L.**, 1975. "Flooding as the result of Hurricane Agnes, and its effects on a native brook trout population in an infertile headwater stream in central Pennsylvania." *Transactions of the American Fisheries Society* 104(1): 96-99.
- Hora, S. L.**, 1947. Tista dam and its effect on the fisheries of the river. *J. Cent. Bd. Irri., Shimla*, 4:337-341.
- Hora, S. L., Gupta, J. C.**, 1940. On a Collection of Fish from Kalimpong Duars and Siliguri Terai, Northern Bengal. *Journal Royal Asiatic Society of Bengal. Science*. VI (8): 77-83.
- Hora, S. L., Nair, K. K.**, 1944. Pollution of Streams and conservation of fisheries; Effluent of the quinine factory at Mongpo, District Darjeeling, Bengal. *Current Science*. X(1), 147-164.
- Hora, S.L.** 1945. Symposium on the factors influencing spawning of Indian carps. *Proc. nat. Inst. Sci. India*, 11 (3).
- Hora, S.L.**, 1945. Fishes of Bengal. *Ind. Fmg.*, Delhi, 6; 163-167.
- Hossain, M.Y., Rahman, M.M., Ahmed, Z.F., Ohtomi, J., Islam, A.B.M.S.**, 2008. First record of the South American sailfin catfish *Pterygoplichthys multiradiatus* in Bangladesh.
- Hubbel, S. P.**, 2001. *The unified neutral theory of biodiversity and biogeography*. Princeton Univ. Press.
- Hussain, M. F., Ahmad, I.**, 2002. Variability in physico-chemical parameters of Pachin river (Itanagar). *Indian.J. Environ. Health*, 44(4):329-36.
- Huston, M. A.**, 1994. *Biological Diversity: The Coexistence of Species on Changing Landscapes*. Cambridge: Cambridge University Press.
- Hutchinson, G. E.**, 1957. A Treatise on Limnology. I Geography, Physics, and Chemistry. John Wiley and Sons, New York. 1015 pp.
- Hutchinson, G. E.**, 1961. The Paradox of the Plankton. *The American Naturalist*, Vol. 95, No. 882. pp. 137-145.
- Hutchinson, G. E., Deevey, E. S. Jr., Wollack, A.**, 1939. The oxidation-reduction potentials of lake waters and their ecological significance. *Proc. Nat. Acad. Sci.*, USA 25:85-99.
- Hynes, H. B. N.** 1970. *The Ecology of Running Waters*. Toronto: University of Toronto Press.
- Imevbore, A. M. A.**, 1975. Ecology of the newly formed Kainji lake. In: *The ecology of Lake Kainji. Transition from river to lake*. University of Ife Press. p. 203.
- Imoobe, T. O. T., Adeyinka M. L.**, 2010. Zooplankton-based assessment of the trophic state of a tropical forest river. *International Journal of Fisheries and Aquaculture* Vol. 2(2): 64-70.

- Ismael, A.A., Dorgham, M.M.,** 2003. Ecological indices as tool for assessing pollution in E1-Dekhaila Harbour (Alexandria, Egypt). *Oceanologia* 45: 121-131.
- IUCN,** 2012. IUCN Red List of Threatened Species. Version 2012.1. <www.iucnredlist.org>. Downloaded on 04 July 2013.
- IUCN,** 2013. IUCN Red List of Threatened Species. Version 2013.1. <www.iucnredlist.org>. Downloaded on 04 July 2013.
- Jacobsen, D.,** 2008. Tropical High-Altitude Streams. In *Tropical Stream Ecology*, ed. D. Dudgeon, pp. 219-256. Academic Press is an Imprint of Elsevier. London, UK.
- Jain, A., Rai, S. C., Pal, J., Sharma, E.,** 2005. Plankton Community Dynamics of a sacred lake in the Sikkim Himalaya. *Ecology, Environment and Conservation*, **11** 491-498.
- Jana, B. B., Barat, S.,** 1984. Ammonification as affected by the oxygen level of water. *Limnologica*. 16(1), 67-70.
- Jayaram, K. C.,** 1999. *The Freshwater Fishes of the Indian Region*. Narendra Publishing House, New Delhi, India.
- Jayaram, K. C.,** 2009. *Catfishes of India*. Narendra Publishing House. Delhi (India). Pp. 383.
- Jayaram, K. C.,** 2010. *The Freshwater Fishes of the Indian Region*. 2<sup>nd</sup> edition. Narendra Publishing House. Delhi (India). Pp. 616.
- Jayaram, K.C.** 1981. *The Freshwater Fishes of India, Pakistan, Bangladesh, Burma, Sri Lanka: a Handbook*, xxii +475, Zoological Survey of India (Calcutta).
- Jayaram, K.C.** 2010. *Fishes of the Indian Region*. Narendra Publishing House (New Delhi).
- Jayram, K.C.,** 1981. *Freshwater fishes of India; A hand book*. Zoological Survey of India, Calcutta.
- Jha P, Mandal, A., Barat, S.** 2003. Mahananda Reservoir, W. B.: Its Ichthyofauna, Fishery and Socio-economic Profile of Fish Production. *Fishing Chimes* 24(6). 14-17.
- Jha, P., Barat, S.,** 2003. Hydrobiological study of lake Mirik in Darjeeling Himalayas. *J. Environ. Biol.* 24(3): 339-344.
- Jha, P., Mandal, A., Barat, S.,** 2004. Mahananda Reservoir, W. B.: Its Ichthyofauna, Fishery and Socio-economic Profile of Fish Production. *Fishing Chimes*, 24(6): 14-17.
- Jha, P., Mandal, A., Barat, S.,** 2005. Ichthyofauna and Socio-economic profile of fishery in the Mahananda reservoir, West Bengal. *Fishing Chimes*, 25:10-13.
- Jhingran, V. G., Sehgal, K. L.,** 1978. *Cold water Fisheries of India*. 1<sup>st</sup> edition. Inland Fisheries Society of India, Barrackpore, West Bengal, India. Pp. ix+239.
- Jhingran, V.G.,** 1991. *Fish and Fisheries of India*. 3<sup>rd</sup> Edition. Hindustan Publishing Corporation (India), Delhi.

- Jolliffe, I.T.**, 2002, *Principal Component Analysis*, Second Edition, Springer Publication, New York, USA
- Johal, M. S.**, 2006. "On fishery potential of Western Himalayan Hill Streams", *Fishing Chimes April 06*.
- Johal, M. S., K. K. Tandon, A. K. Tyor & Y. K. Rawal**, 2002. Fish diversity in different habitats in the streams of lower middle western Himalayas. *Polish Journal of Ecology* 50:
- Johal, M. S., K. K. Tandon, Y. K. Rawal, A. K. Tyor, H. S. Banyal & H. S. Rumana**, 2001. Species richness of fish in relation to environmental factors. *Current Science* 80: 499–501.
- Johal, M. S., Rawal, Y. K.**, 2005. Key to the management of the western Himalayan Hill streams in relation to fish species richness and diversity. *Hydrobiologia*. 532: 225-232.
- John, K. R.**, 1963. The effect of torrential rain on the reproductive cycle of *Rhinichthys oculus* in the Chiricahua Mountains, Arizona. *Copeia*. (2), 286-291.
- Joshi, B. D.**, 1990. Problems and Prospects of Aqua-resources Management in Himalayas. In: Sah, N. K., S.D. Bhatt, R. K. Pande (Eds). *Himalaya: Environment, Resources and Development*. Sree Almorah Book Depot, Almorah. pp. 210-215.
- Joshi, B. D., Bisht, R. C. S., Joshi, N.**, 1996. Planktonic population in relation to certain physico-chemical feators of Ganga canal at Jawalapur (Hardwar). *Him. J. Env. Zool.* 10: 75-77.
- Joshi, B. D., Pathak, J. K., Singh, Y. N., Bist, R. C. S., Joshi, P. C.**, 1993. On the physico-chemical characteristics of river Bhagirathi in the upland of Garhwal Himalaya. *Him. J. Env. Zool.* 7: 69-75.
- Joshi, C. B., K. L. Sehgal and S. Sunder.** 1978. Observation on the fishery resources of the hill stream of Jammu province with special reference to Mahseer and other commercially important species. *Indian J. fish* (25): 197-206.
- Joshi, C. B., K. L. Sehgal and S. Sunder.** 1974. Observation on the fishery resources of the hill streams with special reference to the Mahseer and other commercially important species. *Indian jour. Fish.* 45–56.
- Joshi, D. M., Bhandari, N. S., Kumar, A., Agarwal, N.**, 2009. Statistical analysis of physico-chemical parameters of water of river Ganga in Haridwar district. *Rasayana J. Chem.* 2(3), 579-587.
- Joshi, S. N., T. N. Joshi, and K.C. Tewari.** 1994. Diurnal cycle of abiotic parameters of a hillstream, Kalpanigarh from Kumaun Himalaya. *Env Eco*, 12 (1). Pp18-21.
- Jowett, I.G., Richardson, C.**, 1989. "Effects of a severe flood on in stream habitat and trout populations in seven New Zealand rivers", *New Zealand Journal of Marine and Freshwater Research* 23: 11-17.

- Juday, C and E. A. Birge. 1933.** The transparency, the color and the specific conductance of the lake waters of northeastern Wisconsin. *Trans. Wis. Acad.Sci. Arts, Lett.* 28: 205-259.
- Junk, W.J., 2002.** Long-term environmental trends and the future of tropical wetlands. *Environmental Conservation*, 29(4): 414-435.
- Juttner, I., Sharma, S., Dahal, B. M., Ormerods, S.J., Chimonides, P. J., Cox. E. J., 2003.** Diatoms as indicators of stream quality in the Kathmandu Valley and Middle Hills of Nepal and India. *Freshwater Biology*, 48. 2065–2084.
- Kala, R., Sharma, R. C., 2001.** Seasonal abundance of Phytoplankton in the lotic ecosystem of Alaknanda, Garhwal Himalaya. *J Natural and Physical Sciences*, 15 (1-2): 71-80.
- Kalin, M., Cao, Y., Smith, M., Olaveson, M., 2000.** Development of phytoplankton community in a pit-lake in relation to water quality changes. *Water Res.* 35 (13), 3215–3225.
- Kamal, Y. M., 2006.** Conservation and Enhancements in upland Fisheries. In: Vass, K. K., K. Mitra, V. R. Suresh, P. K. Kathia, and N. P. Srivastava (eds.). *River Fisheries in India – issues and Current status*. Inland Fisheries Society of India. Barrackpore, W. B., pp. 295-298.
- Kannan, K., 1991.** *Fundamentals of environmental pollution*. S. Chand and Co. Ltd., New Delhi, India.
- Kant, S., Anand, V.K., 1978.** Interrelationship of phytoplankton and physical factors in Ansar lake, Jammu, India. *J. Ecol.* 5: 134-140.
- Kar, D., 2005.** Fish Genetic Resources and Habitat Diversity of the Barak drainage: pp. 68-76. In: *Aquatic Ecosystems, Conservation, Restoration and Management* (Eds.) Ramachandra, T.V.; Ahalya, N.; and, Rajsekara Murthy, C., xiii + 396, Capital Publishing Company (Bangalore).
- Khan, R.A., 2003.** Faunal diversity of zooplankton in freshwater wetlands of southeastern West Bengal. *Records of the Zoological Survey of India, Occasional Paper No.* 204: 1–107.
- Khan, I.A., Khan, A.A., 1985.** Physical and chemical conditions in Seikha Jheel at, Aligarh. *Ecol.*, 3, 269-274.
- Kiffney, P.M., Bull, J. P., 2000.** Factors controlling periphyton accrual during summer in headwater streams of southwestern British Columbia, Canada. *Journal of Freshwater Ecology.* 15:339-351.
- Kosygin, L., Dhamendra, H., Gyaneshwari, R., 2007.** Pollution status and conservation strategies of Moirang River, Manipur with a note on its aquatic bio-resources. *J. Environ. Biol.* 28(3):669-673.
- Kottelat, M., Whitten, T., 1996.** *Freshwater Biodiversity in Asia with special reference to Fish*: World Bank Tech. Paper No. 343. The World Bank, Washington, DC. Pp. 17-22.

- Krebs, C. J.**, 1985. *Ecology, the experimental analysis of distribution and abundance*, 3<sup>rd</sup> edition. Harper and Row, New York.
- Krebs, C. J.**, 1999. *Ecological Methodology*. 2<sup>nd</sup> edition. Addison Wesley Longman.
- Krebs, C. J.**, 2001. *Ecology*, 5<sup>th</sup> edition. Addison Wesley, San Francisco. Pp 695.
- Krebs, C.**, 1989. *Ecological Methodology*. Harper Collins, New York.
- Kumar, A., Dua, A.**, 2009. Water Quality Index for Assessment of water Quality of River Ravi at Madhopur (India). *Global Journal of Environmental Sciences*, vol. 8 (10). 49 – 57.
- Kumar, A., Bisht, B. S., Joshi, V. D.**, 2010. Chemical Report of Sediments, Phytoplanktons and Fishes of Bindal River Dehradun. *J. Biol. Environ. Sci.* 4(11), 53-58.
- Kumar, K., Bhagat, M. J.**, 1978. Observations on the ecology of two trout streams in Kashmir and its possible effect on the brown trout. *J. Inland Fish. Soc. India.*, 10: 1-8.
- Lacky, J. B.**, 1938. The manipulation and Counting of River Plankton and Changes in some Organisms due to formalin Preservation. *Pub. Health. Rep.* 53:2080-2093.
- Lakhotia, A. S.**, 2003. Fish vanish from Teesta. *The Telegraph*, Monday, September 29, 2003
- Lakra, W. S., Sarkar, U. K., Gopalkrishnan, A., Kathirvelpandian, A.**, 2010. *Threatened Freshwater Fishes of India*. National Bureau of Fish Genetic Resources, Lucknow. pp, 1-20.
- Lampert, W. and U. Sommer.**, 2007. *Limnoecology*. Oxford University Press Inc., New York.
- Lascar, H. S. and Gupta, S.** 2009. Phytoplankton diversity and dynamics of Chatla Floodplain Lake, Barak valley, Assam, north east India seasonal study. *J. Environ. Biol.* 30(6): 1007-1012.
- Leitman, H.M., Darst, M.R., Nordhaus, J.J.**, 1991. "Floodplain of the Ochlockonee River, Florida, during flood and drought conditions", U.S. *Geological Survey, Water-Resources Investigations*, Tallahassee, Florida. 90-4202
- Lenders, H. J. R., Knippenberg, L.**, 2005. The temporal and social dimensions of river rehabilitation: towards a multidimensional research perspective. *Archiv für Hydrobiologie (Large Rivers Supplement)* 155/15: 119–131.
- Lepcha, R. F., Mandal, A., Pradhan, A.**, 2006. Studies on Cold-water Fisheries in Hill areas of Darjeeling District. In: Proceedings of State Level Seminar on Prospects and Potentialities of Cold Water Fisheries in West Bengal Jointly organized by Department of Fisheries, Aquaculture, Aquatic resources, and Fishing harbours, Government of West Bengal and Department of Zoology, University of North Bengal, Siliguri. pp. 77-80.

- Lewis, W. M. Jr. 2008.** Physical and Chemical Features of Tropical Flowing Waters. In Dudgeon, D., (ed.), *Tropical Stream Ecology*. Academic Press is an Imprint of Elsevier. London, UK. Pp. 107-146.
- Li, H. W., Li, J. L., 2007.** Role of fish assemblages in stream communities. In: Hauer, F. R. & G. A. Lamberti (Eds.). *Methods in stream ecology*, 2<sup>nd</sup> edition. Academic Press, USA. 489-514.
- Likens, G. E., 1985.** An ecosystem approach to aquatic ecology; Mirror Lake and its environment. *Springer-Verlag*, New York, 516pp.
- Lind, O. T., 1979.** *Handbook of common methods in limnology*. St. Louis, Missouri: The C.V. Mosby Company.
- Livingstone, D. A. 1963.** Chemical composition of rivers and lakes. Chap. G. Data of Geochemistry. 6<sup>th</sup> Edition. Prof. Pap. U> S. Geol. Surv. 440-G, 64pp.
- Lloyd, M., Ghelardi, R. J., 1964.** A table for calculating the “equitability” component of species diversity. *J. Anim. Ecol*, 33:217–255.
- Lomolino, M. V., 2001.** Elevation gradients of species-density: historical and prospective views. *Global Ecology & Biogeography* 10: 3–13. doi: 10.1046/j.1466-822x.2001.00229.x.
- Lowe-McConnel, R. H., 1975.** Fish communities in tropical freshwaters. Longman, New York, New York.
- Ludwig, J. A., Reynolds, J. F., 1988.** *Statistical Ecology. A Primer on methods and computing*. A Wiley- Interscience Publication. John Wiley and Sons. U.S.A. Pp. 338.
- Lund, J. W. G., 1965.** The Ecology of Freshwater Phytoplankton. *J. Biol. Rev.* 40: 231-293.
- Lunn, K.E., Moreau, M.A., 2004.** Unmonitored trade in marine ornamental fishes: The case of Indonesia’s Banggai cardinal fish (*Pterapogon kauderni*), *Coral Reefs*, 23:344-351.
- Magurran, A.E. 1988.** *Ecological diversity and its measurement*. Princeton University Press, Princeton, New Jersey.179p.
- Mahanta, P. C., 2006.** Cold water Fisheries Development in India, Potential and prospects. *Fishing Chimes April 2006*.
- Malley, L.S.S. O., (1907).** Bengal District Gazetteer: Darjeeling. Rept. Logos Press, New Delhi, 1985.
- Mandal, D., Bhattacharya, B., Saha, M., Chakraborty, S., Mandal, T., 1985.** *Haemoproteus rupicola* sp. from the hill stream fish *Noemacheilus rupicola rupicola* (Mc Clelland) of Darjeeling area. *Acta Protozoological* 24: 41-45.
- Margalef, D. R., 1958.** Information theory in ecology. *Genetics and Systematics*.3: 36-71.

- Margalef, R.**, 1968. *Perspectives in Ecological Theory*. University of Chicago Press, Chicago p.112.
- Margalef, R.**, 1997. *Our biosphere*. Excellence in Ecology Books, Institute of Ecology, 10. pp. 176-178.
- Mariappan, P., Vasudevan, T.**, 2002. Correlation coefficients of some physico-chemical parameters of drinking water ponds in Eastern part of Sivagangi district, Tamil Nadu. *Poll. Res.* 21: 403-407.
- Mason, C. F.**, 1988. *Biology of Fresh water Pollution*. Longman scientific and technical.
- Masuda, K., Karki, K. B.**, 1980. Fish and fisheries of the Trishuli River; a report on the Trishuli River Conducted in 1979, Fisheries Dev. Section, HMG/Nepal.
- Mathur, R.P.**, 1991. Stretches of the Ganga covered in the study; Trends of physicochemical characteristics of the Ganga water. In: C. R. Krishnamoorti, K. S. Bilgrami, T. M. Das, R. P. Mathur (Eds.), *The Ganga—A Scientific Study*, pp. 19–20; 27–38. Northern Book Centre, New Delhi, for the Ganga Project Directorate, New Delhi.
- Matthews, W. J.**, 1988. North American prairie streams as systems for ecological study. *J. N. Am. Benthol. Soc.* 7:387-409.
- Mc Clain, M. E., Richey, J. E., Pimentel, T. P.**, 1994. Ground water nitrogen dynamics at the terrestrial- lotic interface of a small catchment in the central Amazon basin. *Biogeochemistry* 27, 113-127.
- McGregor, G.R., Nieuwolt, S.**, 1998. *Tropical Climatology: An Introduction to the Climates of the Low Latitudes.* 2nd Edition. Wiley, Chichester, UK.
- Mc Intosh, R.P.**, 1967, "The continuum concept of vegetation," *Bot. Rev.*, 33: 130-187.
- Menon, A. G. K.**, 1954. Fish geography of the Himalayas. Proceedings of the National Institute of Science of India. 20: 467-493.
- Menon, A. G. K.**, 1962. A distributional list of fishes of the Himalayas. *Journal of Zoological Society, India* 14 (1 & 2): 23-32.
- Menon, A. G. K.**, 1987. *Fauna of India and Adjacent Countries*. Pisces Vol. IV. Teleostei-Cobitoidea, Pt. I, Homalopteridae. ZSI Calcutta. pp. X+259, plates. 1-XV.
- Menon, A. G. K.**, 1992. *Fauna of India and Adjacent Countries*. Pisces Vol. IV. Teleostei-Cobitoidea, Pt. 2, Cobitidae. ZSI Calcutta. Pp. 113+Plate1-10.
- Menon, A. G. K., H. R. Singh & N. Kumar**, 2000. Present ecostatus of coldwater fish and fisheries. In Singh, H. R. & W. S. Lakra (eds), *Coldwater Aquaculture and Fisheries*. Narendra Publishing House, New Delhi, India: 1–36.
- Meybeck, M.**, 1982., Carbon, nitrogen, and phosphorus transport by world rivers. *Am. J. Sci.* 282, 401-450.

- Meybeck, M.**, 1993., Natural sources of C, N, P and S. In Wollast, R. Mackenzie, F. T., Chou, I. (eds.), *Interactions of C, N, P and S biogeochemical cycles and global change*. Springer- Verlag, Berlin. pp.163-193.
- Meybeck, M., Helmer, R.**, 1989. The quality of rivers: From pristine stage to global pollution. *Paleogeogr, Paleoclimatol. Paleoecol*, 75: 283-309.
- Meybeck, M., Green, P., Vörösmarty, C.** 2001. A new typology for mountains and other relief classes. *Mountain Research and Development* 21, 34–45.
- Michael, R.G., Sharma, B.K.**, 1988. Indian Cladocera: Fauna of India and Adjacent Countries Series, x + 261, Zoological Survey of India (Calcutta).
- Miller, A. M., Golladay, S.W.**, 1996. Effects of spates and drying on macroinvertebrate assemblages of an intermittent and perennial prairie stream. *Journal of the North American Benthological Society*, 15, 670–689.
- Mishra, A. P., Bora, B. K., Sharma, M.**, 1999. Limnological investigation of a freshwater tributary Assam, India. *J. Freshwater Biol.* 11, 1-5.
- Mishra, A., Chakraborty, S. K., Jaiswar, A. K., Sharma, A. P., Deshmukhe, G., Mohan, M.**, 2010. Plankton diversity in Dhaura and Baigul reservoirs of Uttarakhand. *Indian J. Fish.* 57(3): 19-27.
- Mishra, R. R., Tiwari, B. K.**, 1983. Fungi and bacteria associated with pine (*Pinus kesiya* Royle) needles and teak (*Tectona grandis* L.) leaf litters during processing in a freshwater lake. *Hydrobiologia* 102: 123–129.
- Mishra, S.S., Acharjee, S.K., Chakraborty, S.K.** 2009. Development of tools for assessing conservation categories of siluroid fishes of fresh water and brackish water wetlands of south West Bengal, India. *Environmental Biology of Fishes.* 84: 395-407
- Mittermeier, R. A., Mittermeier, C.G.**, 1997. Megadiversity: Earth's Biologically Wealthiest Nation. In: McAllister, D. E., Hamilton, A. L and Harvey B. (Eds.). *Global Freshwater Biodiversity*. Sea Wind, Cemex, Mexico City, 11: 1-140.
- MOEF.**, 2002. Carrying Capacity Studies of Teesta Basin in Sikkim. Volume VI. *Biological Environment Terrestrial and Aquatic Resources*. Ministry of Environment and Forests, Government of India. National Hydroelectric Power Corporation Ltd, Faridabad. Centre for Inter-Disciplinary Studies of Mountain and Hill Environment, University of Delhi, pp 1 259.
- Moitra, S. K., Bhattacharya, B. K.**, 1965. Some hydrobiological factors affecting plankton production in fish pond at Kalyani, W. B. India. *Ichthyol.* 4, 8-12.
- Molur, S., Walker, S.**, 1998. Report of the Workshop “*Conservation Assessment and Management Plan (CAMP) for Freshwater Fishes of India*”. Report # 18. Zoo Outreach Organisation/Conservation Breeding Specialist Group, India, Coimbatore, India and NBFGR, Lucknow, India.

- Mondal, D.**, 2009. Some aspects of Hydrobiological study of Mirik lake of the Darjeeling hills. Ph. D. Thesis. University of North Bengal.
- Morris, I.**, 1980. Studies in ecology. Vol. 7. The Physiological Ecology of Phytoplankton. Blackwell Scientific Publications, Oxford.
- Motwani, M.P., Jayaram, K.C., Sehgal, K.L.**, 1962. Fish and Fisheries of Brahmaputra River System, Assam, I. Fish Fauna with observation on their zoogeographical significance. *Trop. Ecol.*, 3: 17- 43.
- Moyle, J.B.**, 1946. Some indices of lake productivity. *Trans. Amer. Fish. Soc.*, 76: 322-334.
- MPEDA.** 2007. MPEDA statistics review, Kochi, Kerala, India, pp. 131-132.
- Mukherjee, M.**, 2004. The present status of ornamental fish exporters and business groups in West Bengal. In: *Prospects of Ornamental Fish Breeding and Culture in Eastern and North eastern India* (ed. by R. C. Das, A. Sinha, S. Datta and S. Ghosh), pp.79-92. Central Institute of Fisheries Education, Kolkata.
- Mukherjee, M., Lepcha, R. F., Chakraborty, C.**, 2011. *Fish and Fisheries of Himalayan and Terai Region of West Bengal with Ornamental touch.* Daya publishing House. Delhi, pp. 342.
- Mukherjee, M., Sarkar, G.**, 2005. *Endangered Fishes of West Bengal, with a special reference to North Bengal on Research, restoration, and Future plan of action.* Published by Department of Fisheries, Aquaculture, Aquatic Resources and Fishing Harbour.
- Mukhopadhyay, S. K.**, 1996. Limnological investigation in lotic and lentic fresh water bodies in and around Darjeeling, West Bengal, India. *Geobios* 23: 101-106.
- Mukhopadhyaya, S. C.**, 1990. Drainage Analysis of the Upper Tista Basin, Sikkim: A Hydromorphic Study. In N. K. Sah, S. D. Bhatt and R. K. Pande (eds.) *Himalaya: Environment, Resources and Development.* Shree Almora Book Depot, Almora. pp,139-150.
- Mulholland, P. J., Steinman, A. D., Elwood, J. W.**, 1990. Measurement of phosphorus uptake length in streams: Comparison of radiotracer and stable PO<sub>4</sub> release. *Can. J. Fish. Aquat. Sci.* 47; 2351-2357.
- Murugan, A. S., Prabakaran, C.**, 2012. Fish Diversity In Relation To Physico-Chemical Characteristics of Kamala Basin of Darbhanga District, Bihar, India. *International Journal of Pharmaceutical & Biological Archives*, 3(1):211-217 .
- Murugan, N., Murugavel, P., Kodarkar, M.S.**, 1998. Cladocera: The biology, classification, identification and ecology. Indian Association of Aquatic Biologists (IAAB), Hyderabad.
- Mwebaza-Nadwula, L., Sekiranda, S.B.K., Kiggundu. V.**, 2005. Variability in zooplankton community along a section of the Upper Victoria Nile, Uganda. *Afr. J.Ecol.* 43: 251-257.

- Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Kent, J., 2000.** Biodiversity hotspots for conservation priorities. *Nature* 403: 853–0858.
- Naselli-Flores, L., Barone, R., 2000.** Phytoplankton dynamics and structure: a comparative analysis and man-made water bodies of different trophic state. *Hydrobiologia*, 438(1/3): 65-74. doi:10.1023/A:1004109912119.
- Nath, P., Dey, S. C., 2000.** *Fish and Fisheries of Northeastern India (Arunachal Pradesh)*. Narendra Publishing House. Delhi (India). Pp. xviii + 217.
- Nautiyal P., 1985.** Studies on the riverine ecology of torrential waters in the Indian uplands of Garhwal region. I. Seasonal variations in percentage occurrence of planktonic algae. *Uttar Pradesh Journal of Zoology* 5, pp14-19.
- Nautiyal, P., Verma, J., 2009.** Taxonomic richness and diversity of the epilithic diatom flora of two biogeographic regions of the Indian sub continent. *Bulletin of National Institute of Ecology* 20: 15-21.
- Nautiyal, P., 1990.** Ecology of the Ganga riversystem in the uplands of Garhwal. In N. K. Sah, S. D. Bhatt and R. K. Pande (eds.) *Himalaya: Environment, Resources and Development*. Shree Almora Book Depot, Almora. pp,69-73.
- Nautiyal, P., 2010.** Food chains of Ganga River ecosystems in the Himalayas. *Aquatic Ecosystem Health & Management*, 13:4, 362-373.
- Nautiyal, P., 1984.** Studies on the riverine ecology of torrential waters in the Indian uplands of Garhwal region II. Seasonal fluctuations in diatom density. *Pro. Indian Acad.Sci. (Anim.Sci.)* 93:671-674.
- Nautiyal, P., 1997.** Migratory phenomenon of the endangered Himalayan Mahseer, Tor Putitora in relation to the Ecology of the river Ganga. Final Technical Report of Research Project No. 14/ 28/ 92 submitted to the Ministry of the Environment and Forests, New Delhi under Man and Biosphere Programme. Pp. 106.
- Nautiyal, P., 2001.** Ecology of mountain streams and rivers in Garhwal Himalaya. In: A. Kumar (Ed.), *Ecology and Conservation of Lakes, Reservoirs and Rivers*. A B D Publishers,
- Nautiyal, P., Agarwal, N. K., Singh, H. R., 1991.** Certain Abiotic components of the Fluvial system and their interrelationships as evidenced by statistical evaluation. *Advances in Limnology*. 177-182.
- Nautiyal, R., Nautiyal, P., Singh, H.R. 1996.** Pennate Diatoms flora of a cold water mountain river, the Alaknanda; II, suborder Araphideae. *Phycos* 35: 57-63.
- Nautiyal, R., Nautiyal, P., Singh, H.R., 2000.** Species richness and diversity of epilithic diatom communities on different natural substrates in the coldwater river Alaknanda. *Tropical Ecology* 41(2): 255-258.
- Needham, J. G., Needham, P. R., 1978.** *A Guide to the study of fresh-water biology*. Fifth edition. Holden-Day, Inc., San Fransisco. pp108.

- Negi, M.**, 1993. Phytobenthos of the hillstream Alaknanda of Garhwal Himalaya. pp. 139-144. In: H.R. Singh (ed.) *Advances in Limnology*. Narendra Publishing House, Delhi.
- Negi, R. K., Negi, T.**, 2010a. Assemblage structure of stream fishes in the Kumaon Himalaya of Uttarakhand State, India. *Life Science Journal*, 7 (1). 9-14.
- Negi, R. K. and A. Rajput.**, 2011. Diversity of Phytoplankton in the Freshwater Streams of Kumaon Himalaya of Uttarakhand state. *The Ecoscan* 5(1&2). 15-19.
- Negi, R. K. and Negi, T.**, 2010b. Diversity of zooplanktons in the Hival freshwater stream at Shivpuri (Garhwal region), Uttarakhand. *J. Env. Bio. Sci.* 24(2): 167-169.
- Negi, R. K. Joshi, B. D., Negi, T., Prakash, C.**, 2007. A study on stream morphology of some selected hill streams of district Nainital with special reference to its biotic communities. *National Seminar on Limnology*. pp. 288-295.
- Nehring, R.B., Miller, D.D.**, 1987. "The influence of spring discharge levels on brown and rainbow trout recruitment and survival, Black Canyon of the Gunnison River, Colorado, as determined by IFIM, PHABSIM models." Proceedings Annual Conference, Western Association of Fish and Wildlife Agencies. Salt Lake City, Utah. Pp. 388-397.
- Nelson, J. S.**, 1994. *Fishes of the World*, 3rd edn. John Wiley & Sons, New York.
- Neves, I.F., Rocha, O., Roche, K.F., Pinto, A.A.**, 2003. Zooplankton community structure of two marginal lakes of the river Cuibá (Mato Grosso, Brazil) with analysis of Rotifera and Cladocera diversity. *Braz. J. Biol.*, 63:329-343.
- Newbold, J. D., Elwood, J. W., O'Neill, R. V., Sheldon, A. I.** 1983. Phosphorus dynamics in a woodland stream ecosystem; A study of nutrient spiralling. *Ecology* 64: 1249-1265.
- Newbold, J. D.**, 1992. Cycles and spirals of nutrients. In P. Calow, and G. E. Petts, eds. The rivers handbook, I. Hydrological and ecological principles. Blackwell Sci. Publis., Oxford. PP. 379-408.
- Nogués-Bravo, D., Araújo, M. B., Romdal, T., Rahbek, C.**, 2008. Scale effects and human impact on the elevational species richness gradients. *Nature* 453, 216–220.
- Norris, R. C., Charlton, J. I.**, 1962. A chemical and biological survey of Sungei Gombok. Jabatan Chetak Kerajaan, Perse Kutuan Tanah Melayu.
- NWWFCC. 2001.** Survey on water quality and status of fish in the rivers of Thimphu, Paro and Ha Dzongkhags. **Report.** *National Warm Water Fish Culture Centre, Ministry of Agriculture*, Royal Government of Bhutan. Gelephu. 35p.
- O'Brien, D.W.F.**, 1997. Fish bombing in Hong Kong – investigation and detection. In: Proceedings of the First International Symposium on Marine Conservation, October 1996, Hong Kong. Hong Kong Marine Conservation Society. pp. 68-78
- O'Malley, L.S.S.**, 1907. Bengal District Gazetteer: Darjeeling. Rept. Logos Press, New Delhi, 1985.

- O'Neill, M. P., Abraham, A. D.,** 1987. Objective identification of pools and riffles. *Water Resource Researches* 20: 921-926.
- Ohle, W.,** 1938. Teichwirtschaftliche Kalkkontrolle und die pH-SBV-Tasche (Control of liming in ponds with an outfit for pH and alkalinity determination). *Z. Fisch.* 36: 185-191.
- Ormerod, S.J., Rundle, S.D., Wilkinson, S.M., Daly, G.P., Dale, K.M., Juttner, I.,** 1994. Altitudinal trends in the diatoms, bryophytes, macro invertebrates and fish of a Nepalese river system. *Freshwater Biology.* **32**, 309–322.
- Otsuki, A., R. G. Wetzel.** 1974. Calcium and total alkalinity budgets and calcium carbonate precipitation of a small hard water lake. *Arch. Hydrobiol.* 73: 14-30.
- Ownbey, C. R., D. A. Kee.,** 1967. Chlorides in Lake Erie. *Proc. Conf. Great Lakes Res., Int. Assoc. Great Lakes Res,* 10: 382-389.
- Pace, M. L.** 1986. An empirical analysis of zooplankton community size structure across lake trophic gradients. *Limnology and Oceanography.* 31: 45-55.
- Pace, M. L., Findlay, S. E. G., Lints, D.,** 1992. Zooplankton in advective environments: The Hudson River Community and a comparative analysis. *Can. J. Fish, Aquat. Sci.* 49: 1060-1069.
- Pandey, K.K., Lal, M.S.,** 1995. Limnological Studies of Garhwal Himalayan Hill Stream Khandagad; Seasonal Fluctuation in Abiotic Profile. *J. Freshwater Biol,* **7(1)**, 7-11.
- Panwar, M. R. S., Sharma, P. D.,** 1983. Fungal colonization of *Scirpus tuberosus* Desf. *Rev. Ecol. Biol. Sol.* 20: 299–316.
- Paramasivan, M., Sreenivasan, A.,** 1981 Changes in algal flora due to pollution in Cauvery river, *Indian J. Environ. Health;* **23** : 222-238.
- Park, G.S., Marshall, H.G.,** 2000. Estuarine relationships between zooplankton community structure and trophic gradients. *J. Plankton Res.* 22(1):121-135.
- Patalas, K.,** 1990. Diversity of zooplankton communities in Canadian lakes as a function of climate. *Verh. Internat. Verein. Limnol.,* 24, 360-368.
- Pathani, S.S., Upadhyay, K.K.** 2003. An inventory on zooplankton, zoobenthos and fish fauna in the River Ramganga (W) of Uttaranchal, India. *ENVIS Bulletin Vol 14(2):Himalayan Ecology.*
- Patra, A. K., Sengupta, S., Datta, T.** 2011. Physico-chemical Properties and Ichthyofauna Diversity in Karala River, a tributary of Teesta River at Jalpaiguri district of West Bengal, India. *International Journal of Applied Biology and Pharmaceutical Technology.* 2(3):47-58.
- Patra, M.K., Acharjee, S.K. and Chakraborty, S.K.** 2005. Conservation categories of siluroid fishes in North-East Sundarbans, India. *Biodiversity and Conservation* 14: 1863–1876.

- Patralekh, L. N., 1994.** Comparative account of physico-chemical properties of three freshwater ecosystems. *J. Freshwater Biol.*6:115-119.
- Paturej E., Goździejewska, A., 2005.** Zooplankton-based assessment of the trophic state of three coastal lakes – Łebsko, Gardno, and Jamno. *The Bulletin of the Sea Fisheries Institute* 3 (166): 7 – 25.
- Peet, R. K., 1974.** The measurement of species diversity. *Annual Review of Ecology and Systematics*. 5: 285-307.
- Pennak, R.W., 1953.** *Freshwater invertebrates of United States*, 2nd ed. New York: John Wiley & Sons Ltd.
- Petr, T., 1983.** Limnology of the Purari basin. In: “*The Purari – Tropical Environment of a High Rainfall River Basin.*” (T. Petr, Ed.), pp. 141–178. Dr. W. Junk Publishers, The Hague.
- Pereira, A. C. S., 2000.** *Caracterizacao fisico-quimica e sua relacao com a distribuicao de peixes onivoros e herbivoros do lago Camaleao.* Monografia de Graduacao, UFAM. Amazonas, 32.
- Petr, T., 1999.** Coldwater fish and fisheries in Bhutan. In: *Fish and Fisheries at Higher Altitudes; Asia* (T. Petr, ed.) FAO Fisheries Technical Paper, No, 385: 6-12. FAO, Rome.
- Petrere, Jr. M., 1989.** River fisheries in Brazil: a review. *Reg. River.Res. Mgmt.* 4: 1-16.
- Petts G.E., Amoros, C., (Eds) (1996).** *Fluvial Hydrosystems.* Chapman & Hall, London.
- Philipose, M.T., 1967.** *Chlorococcales Monographs on Algae.* ICAR Publication, New Delhi, India, Pages: 365.
- Pielou, E. C., 1966.** “The measurement of diversity in different types of biological collections.” *Journal of Theoretical Biology*. 13, 131–144.
- Pimentel, D., Bailey, O., Kim, P., Mullaney, E., Calabrese, J., Walman, L., Nelson, F. and Yao, X. 1999.** Will limits of the Earth’s resources control human numbers? *Environment*, Pergamon press. 220-230pp.
- Plafkin, J. L., Barber, M. T., Potter, K. D., Gross, S. K., Hughes, R. M., 1989.** *Rapid bioassessment protocol for use in streams and rivers for benthic macro invertebrates and fish.* EPA/ 444/ 4-89/001. Office of water regulation and standards. U.S. Environmental Protection Agency, Washington DC, USA.
- Poff, N.L., Ward, J.V., 1989.** “Implications of streamflow variability and predictability for lotic community structure: A regional analysis of streamflow patterns”. *Canadian Journal of Fisheries and Aquatic Science* 46: 1805-1818.
- Pokharel, K.K., 2011.** Study on Fish Ecology of the Seti Gandaki River Pokhara: II. Spatio-Temporal Variations in Fish Communities. *Nepal Journal of Science and Technology* 12: 350-357.

- Poole, R. W., 1974.** *An Introduction to Quantitative Ecology*. McGraw-Hill series in Population Biology. New York. 532 p.
- Poudevigne, I., D. Alard, R. S. E. W. Leuven and P. H. Nienhuis, 2002.** A system approach to river restoration: a case study in the lower Seine valley, France. *River Research and Applications* 18: 239–247.
- Prasad, B.N., Khanna, P., 1987.** The Cyanophycean flora of Sikkim- I. Oscillatoriaceae. *J. Ind. bot. Soc.* 66: 253-260.
- Prasad, B.N., Misra, R., 1987.** Desmid flora of Sikkim- I. *Geophytology* 17(2): 163-173.
- Prescott, G.W. (1982).** *Algae of the west great lakes area*. W.M.C Brown Company
- Probst, E., 1950.** Teichdungungo (Pond fertilization). *Allg. Pisch. Zeit.*, 75 (8): I9I-I94; (9): 211-225.
- Purvis, A., Hector, A., 2000.** Getting the measure of biodiversity. *Nature* (London) 405:212–219.
- Quiros, R.,Cutch, S., 1990.** The fisheries and limnology of the lower Plata basin. In: Dodge DP (ed) *Proceedings of the international large rivers symposium*. *Can Spec Pub Fish Aquat Sci* 106:429–443
- Rahman, M.J., 2006.** Recent advances in the biology and management of Indian shad (*Tenulosa ilisha* Ham.).*SAARC Journal of Agriculture* 4: 76–98.
- Rai, S.K., Misra. P.K., 2010.** Freshwater cyanophyceae from east Nepal. *Bangladesh J. of Plant Taxonomy* 17(2): 121-139.
- Rai, S.K., Subba, B.R., Limbu, K.P., 2008.** Fresh water algae from running streams of Gajurmukhi VDC, Ilam, Nepal. *Our Nature* 6: 80-81.
- Raina, R. Subla, B.A., Zutshi, D.P., 1982.** Water quality and phytoplankton of Jhelum River. *Int. J. Ecol. Environ. Sci.*, 8: 11 – 17.
- Ranjit, R., 2002.** The current status of capture fishery in the upper Sunkoshi River. In. Petr, T.; Swar, D.B. (eds.), *Cold water fisheries in the trans-Himalayan countries*. p. 364. *FAO Fisheries Technical Paper*, 431. 247-256.
- Rao, C. B., 1955.** On the distribution of algae in a group of six small ponds - II, Algal periodicity. *J. Ecol.*, 43: 291 pp.
- Rashid, H.U., Pandit, A. K., 2008.** Ecology of Plankton community of River Sindh in Kashmir Himalaya. *Journal Himalayan Ecology and sustainable development*. 3:11-22.
- Rawat, M. S., Gusain, O. P., Juyal, C. P., Sharma, R. C., 1993.** First report on the limnology (abiotic profile) of a Garhwal Himalayan lake Deoria Tal. In *Advances in limnology*, ed. H. R. Singh, pp. 87-92. Narendra Publishing House, Delhi.
- Raykov, T., Marcoulides, G.A., 2008,** *An Introduction to Applied Multivariate Analysis*. Rotledge Publication, New York, USA

- Rencher, A.C.**, 2002, *Methods of Multivariate Analysis*, John Wiley and Sons Publication, New York, USA
- Resh V.H., Brown A.V., Covich A.P., Gurtz M.E., Li H.W., Minshall G.W., Reice S.R., Sheldon A.L., Wallace J.B., Wissmar R.**, 1988. The role of disturbance in stream ecology. *Journal of the North American Benthological Society*. **7**, 433–455.
- Reynolds, C. S.**, 1988. Potamoplankton: Paradigms, paradoxes and prognoses. In F.E. Round (ed) *Algae and the Aquatic Environment*. Biopress Ltd Bristol, 285-311.
- Reynolds, C. S., Descy, J. P.**, 1996. The production, biomass and structure of phytoplankton in large rivers. *Archiv für Hydrobiologie*, Supplement 113, Large Rivers 10: 161–187.
- Reynolds, C.S.**, 1984. *The ecology of freshwater phytoplankton*, Cambridge University Press, Cambridge, UK.
- Reynolds, C.S.**, 1997. Vegetation processes in the Pelagic. A Model for Ecosystem Tehory. ECI, Oldendorf, Germany.
- Ricciardi, A. & J. B. Rasmussen** 1999. Extinction rates of North American Fresh water fauna. *Conserv. Biol.* 13: 1220-1222.
- Richard, K. S. (1978)**. Simulation of flow geometry in a riffle pool stream. *Earth Surface Processes* 3: 345-354.
- Richardson, W. B.**, 1991. Seasonal dynamics, benthic habitat use, and drift of zooplankton in a small stream in southern Oklahoma, USA. *Can. J. Zool*, 69, 748-756.
- Richardson, W. B.**, 1991. Microcrustacea in flowing water; Experimental analysis of washout times and a field test. *Freshwater. Biol*, 28: 217-230.
- Ripl, W., J. Pokorný, M. Eiseltová and S. Ridgill**, 1994. A holistic approach to the structure and function of wetlands and their degradation. *International Waterfowl and Wetlands Research Bureau Publication* 32: 16–35.
- Rocha, O., Matsumura-Tundisi, T., Sampaio, E.V.**, 1997. Phytoplankton and zooplankton community structure and production as related to trophic state in some Brazilian lakes and reservoirs. *Verh. Int. Verein. Limnol.* 26: 599-604.
- Robertson, A. L., Lancaster, J., Hildrew, A. G.**, 1995. Stream hydraulics and distribution of microcrustacea; A role of refugia? *Freshwater. Biol.* 33, 469-484.
- Rodhe, W.**, 1949. The ionic composition of lake waters. *Verh. Internat. Verein. Limnol.* 10: 377-386.
- Roule, L.**, 1930. L'essai du pH dans revaluation de la productive des etangs a carpes (pH determination in the evaluation of carp ponds). *C.R. Acad. Agri. France*, 16: 1056-1060.

- Rout, J., Gour, J. P.,** 1994. Composition and dynamics of epilithic algae in a forest stream at shillong (India). *Hydrobiologia*, 291: 61-74.
- Roy, H.,** 1955. Plankton ecology of river Hoogly (West Bengal). *Ecol.* 36, 169-174.
- Rutherford, M. C., G. F. Midgley, W. J., Bond, L. W., Powrie, R., Roberts, Allosopp. J.,** 2000. Plant biodiversity. In Kiker, G., Editor, *Climate change impacts in Southern Africa*, Report to National Climate Change Committee, Department of Environmental Affairs and Tourism Pretoria, South Africa.
- Ruttner, F.,** 1953. *Fundamentals of limnology*, 2nd ed. Univ. of Toronto Press, Toronto, Canada. 295 p.
- Ryder, R. A., Presendorfer. J.,** 1989. Large rivers are more than flowing lakes; A comparative review. In D. P. Dodge, ed. Proceedings of the International Large River Symposium. *Can. Spec. Publ. Fish. Aquat. Sci.* 106: 65-85.
- Sarkar, S.K., and Chowdhury, B.,** 1999. Role of some environmental factors on the fluctuations of plankton in a lentic pond at Calcutta. *Limnological research in India*, Daya publishing house. 108-130.
- Sarkar, T., Pal, J.,** 2008. Studies on the Diversity of Fish in Different Reservoir and Rivers of Terai Region. *North Bengal University Journal of Animal Sciences*, 2(2): 83-88.
- Sarwar, S. G., Zutshi, D. P.** 1989. Studies on periphyton productivity of Himalayan Lakes. *Proc. Indian. Natu. Sci. Acad. B* 55, No.3, pp 173-176.
- Saxena, V. K., Kumar., A.,** 2009. Impct of Limno-chemical factors on the seasonal abundance of benthic organisms in upper stretches of river Beas, Himachal Pradesh. *J. Inland. Fish. Soc. India.* 41(2): 70-75.
- Scheffer, M., Rinaldi, S., Huisman J., Weissing, F. J.,** 1993. Why plankton communities have no equilibrium: solutions to the paradox. *Hydrobiologia* 491 (1-3), 9-18.
- Schindler, D. E.,** 2007. Fish Extinctions and Ecosystem functioning in tropical ecosystem. *Proc. Natl. Acad. Sci. USA*, 104: 5707-5708.
- Scrimgeour. G., Chambers, P.,** 2000. Cumulative effects of pulp mill and municipal effluents on the epilithic biomass and nutrient limitation in a large northern river ecosystem. *Can J Fish Aquat Sci.* 57, 1342–1354.
- Segnini, S., Chacón, M.M.,** 2005. Caracterización fisicoquímica del hábitat interno y ribereño de ríos Andinos en la Cordillera de Mérida, Venezuela. *Ecotropicos* 18, 38–61.
- Sehgal, K. L.,** 1971. Fisheries survey of Himachal Pradesh and some adjacent areas with special references to trout, mahseer and allied species. *Jour. Bombay Nat. Hist. Soc.*, 70 (3): 458-474.
- Sehgal, K. L.,** 1999. Coldwater fish and fisheries in the Himalayas: rivers and streams. In: *Fish and Fisheries at Higher Altitudes; Asia* (T. Petr, ed.) *FAO Fisheries Technical Paper. No. 385:* 41-63. Rome, FAO.

- Sehgal, K. L.**, 1974. Report on the researches carried out at the Coldwater Fisheries Research Centre in Himachal Pradesh and Kashmir from 1966-1973, *CIFRI Suppl. Rep.* 13pp.
- Sehgal, K. L.**, 1983. Fisheries resources and their management. In Singh, T. V. & J. Kaur (eds), *Studies in ecodevelopment: Himalayan mountain and men*. Print House, Lucknow, India.
- Sehgal, K. L.**, 1988. Ecology and fisheries of mountain streams of the north-western Himalayas. Thesis for the award of D. Sc. degree, University of Meerut, India.
- Semwal, N., Akolkar, P.**, 2006. Water quality assessment of sacred Himalayan rivers of Uttaranchal. *Curr. Sci*, 9(4), 486-496.
- Sen, D.**, 2006. River Dynamics. In: Vass, K. K., K. Mitra, V. R. Suresh, P. K. Kathia, and N. P. Srivastava (eds.). *River Fisheries in India – issues and Current status*. Inland Fisheries Society of India. Barrackpore, W. B., pp. 13-24.
- Sen, N.**, 2000. Occurrence, Distribution and Status of Diversified Fish Fauna of North-East India: pp. 31- 48. In: *Fish Diversity of North-East India* (Eds.) Ponniah, A.G. and Sarkar, U.K., pp. 228, National Bureau of Fish Genetic Resources, ICAR (Lucknow).
- Sen, P.K., Biswas, S.N.**, 2006. Development strategies of cold water fisheries in Darjeeling hill areas of West Bengal. In: Proceedings of State Level Seminar on Prospects and Potentialities of Cold Water Fisheries in West Bengal Jointly organized by Department of Fisheries, Aquaculture, Aquatic resources, and Fishing harbours, Government of West Bengal and Department of Zoology, University of North Bengal, Siliguri. pp. 24-48
- Sen, T. K.**, 1992. *Freshwater Fish*. State Fauna Series 3: Fauna of West Bengal, Part 2, Zoological Survey of India: 101-242.
- Shannon, C. E., Wiener, W.**, 1963. The mathematical theory of communication. University Illinois Press, Urbana pp36.
- Shannon, C. E.**, 1948. A mathematical theory of communication. *Bell System Technical Journal*. 27, 379-423.
- Sharma, A. P., Mishra, A.**, 2002. Present status and prospects of mahseer fishery in Garhwal Region of Central Himalaya. In: T. Petr and S.B. Swar (Eds) *Cold water fisheries in the trans-Himalayan countries*. FAO Fisheries Technical Paper, 431, 250-265.
- Sharma, B. K., Sharma, S.**, 1999a. Freshwater Rotifers (Rotifera: Eurotatoria). In: *State Fauna Series: Fauna of Meghalaya*. 4(9): 11–161. Zoological Survey of India, Calcutta.
- Sharma, B. K., Sharma, S.**, 1999b. Freshwater Cladocerans (Crustacea: Branchiopoda: Cladocera). In: *State Fauna Series: Fauna of Meghalaya* 4(9): 469 –550. Zoological Survey of India, Calcutta.
- Sharma, A., Sharma, R. C., Anthwal, A.**, 2007. Monitoring phytoplanktonic diversity in the hill stream Chandrabhaga of Garhwal Himalaya. *Life Science Journal*, 4(1). 80-84.

- Sharma, C.M., Shrestha, J.** 2001. Fish Diversity and Fishery Resources of the Tinau River, Western Nepal. *Environment and Agriculture: Biodiversity, Agriculture and Pollution in South Asia*. 78-83.
- Sharma, E.** 2007. 'Biodiversity resources of the eastern Himalaya: Challenges to climate change.' Paper presented at the Nepal stakeholder workshop on Climate Change and Vulnerability of Mountain Ecosystems in the Eastern Himalayan Region, 12-13 December 2007, Kathmandu, Nepal.
- Sharma, K. K., Chowdhary, S., 2011.** Macroinvertebrate assemblages as biological indicators of pollution in a Central Himalayan River, Tawi (J&K). *International Journal of Biodiversity and Conservation*, 3(5), pp. 167-174.
- Shastri, Y., Pendse, D. C.,** 2001. Hydrobiological study of Dahikuta reservoir. *J. Environ.biol.* 22(1), 67-70.
- Shaw, G. E., Shebbeare, E. O.,** 1937. The fishes of Northern Bengal. *Journal Royal Asiatic Society of Bengal. Science*. Volume III, Article No. 1. Pp. 137.
- Sheldon, A. L.,** 1968. Species diversity and longitudinal succession in stream fishes. *Ecology* 49: 193-198.
- Shiklomanov, L. A.,** 1993. World Fresh water Resources. In: Gleick, P. H. (ed.). *Water crisis; a guide to world's Freshwater Resources*. Oxford University Press, New York, USA.13-24.
- Shrestha, B. R.,** 1991. Report on water quality investigation of Thimphu, Paro and Ha as well as water source of National Cold Water Fish Research Centre at Ha, its present status, improvement made and improvement needed. Ministry of Agriculture, Bhutan. 3 p.
- Shrestha, T. K.,** 1998. Medium Hydropower Study Project of Dudh Koshi Hydroelectricity Project. Project Preparation & Studies Directorate, Project Preparation Department, NEA, Kathmandu.
- Shrestha, J.,** 1999. Coldwater fish and fisheries in Nepal. In: Petr, T. (ed.). *Fish and fisheries at higher altitude-Asia. FAO Fisheries Technical Paper. No. 385*: Rome, FAO. pp. 13-40.
- Shrestha, J.,** 2001. Taxonomic Revision of Fishes of Nepal. Environment and Agriculture. In: *Biodiversity, Agriculture and Pollution in South Asia* (P.K. Jha et. al., eds): 171-180. ECOS, Kathmandu.
- Shrestha, J.,** 2002. Taxonomic revision of coldwater fishes of Nepal. In. Petr, T.; Swar, D.B. (eds.), *Cold water fisheries in the trans-Himalayan countries*. p. 364. *FAO Fisheries Technical Paper, 431*. 273-288.
- Shrestha, T. K.,** 1990. Status, Ecology, Conservation and Management of Genetic Resources of Crocodiles of the Himalayan Rivers in Nepal. In N. K. Sah, S. D. Bhatt and R. K. Pande (eds.) *Himalaya: Environment, Resources and Development*. Shree Almora Book Depot, Almora. pp,332-350.

- Shivashankar, P., Venkataramana, G. V.,** 2012. Ichthyodiversity status with relation to water quality of Bhadra River, Western Ghats, Shimoga District, Karnataka. *Annals of Biological Research*, 3 (10):4893-4903
- Simpson, E. H.,** 1949. Measurement of diversity. *Nature*. 163: 688.
- Singh, A., Laura, J.S.,** 2012. An assessment of physico-chemical properties and phytoplankton density of Tilyar lake, Rohtak (Haryana). *Int. Jr.of Current Research.*, 4(05):047-051
- Singh H.R., Badola, S.P., Dobriyal, A.K.,** 1982. Ecology of the river Nayar of Garhwal Himalaya. *Uttar Pradesh Journal of Zoology* 2, pp. 72-76.
- Singh, A.K., Lakra, W.S.,** 2006. Alien fish species in India: Impact and emerging scenario. *Journal of Ecophysiology and Occupational Health* 6: 165–174.
- Singh, D., Sharma, R. C.,** 1998. Biodiversity, ecological status and conservation priority of the fish of the River Alaknanda, a parent stream of the River Ganges (India) *Aquatic conservation: Marine and Fresh water Ecosystems*, 8(6); Pp 761 – 772.
- Singh, H. R., Kumar, N.** 2003. Some aspects of ecology of hillstreams: stream morphology, zonation, characteristics and adaptive features of Ichthyofauna in Garhwal Himalaya. In Datta Munshi, J. S., J. Ojha and T. K. Ghosh (eds), *Advances in Fish Research*. Narendra Publishing House, New Delhi, India 3: 119–142.
- Singh, H. R., Kumar, N.,** 2000. Some aspects of ecology of hillstreams, stream morphology, zonation, characteristics, and adaptive features of ichthyofauna in Garhwal Himalaya. In: Datta Munshi, J. S., (Ed.), *Modern Trends in Fish Biology Research*. Narendra Publishing House, Delhi. pp. 1-18.
- Singh, H.P.,** 1990. Distribution and seasonal fluctuation of certain physico-chemical features in the Brahmaputra river. *J. Assam Sci. Soc.* **32**: 64-69.
- Singh, H.R.,** 1988. Pollution study of the Upper Ganga and its tributaries. Final Technical report of Research Project No. J- 13013/20/83 RE (EN-I) under Ganga Action Plan, Ministry of Environment and Forests New Delhi. Department of Zoology, Garhwal University, Srinagar–Garhwal India.
- Singh, H.R., Nautiyal, P., Dobriyal, A.K., Pokhriyal, R.C., Negi, M., Baduni, V., Nautiyal, R., Aggarwal, N.K., Preeti Nautiyal., Gautam, A.** 1994. Water quality of river Ganga (Garhwal Himalaya). *Acta Hydrobi-ologica*. **36**: 3-15.
- Singh, J., Agarwal, D.K., Panwar, S.,** 2008. Seasonal variation in different physico-chemical characteristics of Yamuna river water quality in proposed lakhwar hydropower project influence area. *Intl. J. Appl. Environ. Sci.* 3(1), 107-117.
- Singh, K.P., Gupta, R.K.,** 2000. A note on the algae from Apatani valley, Arunanchal Pradesh, India. *Ann. For.* **8(1)**: 38-44.
- Singh, N., Bahuguna, S. N., Bhatt, K. C.,** 1993. The profile of river ecosystem, food and feeding habits of hill-stream fishes and consequences of recent environmental degradation in Garhwal Himalaya. *Acta Ichthyologica Et Piscatoria*. XIII (1): 3-30.

- Singh, S.**, 1990. The Lotic water Fisheries of Kumaun Himalaya. In N. K. Sah, S. D. Bhatt and R. K. Pande (eds.) *Himalaya: Environment, Resources and Development*. Shree Almora Book Depot, Almora. pp.276-284.
- Singh, S., G. Maheshwari**, 1987. Swarming ecology of Chironomidae (Diptera) of high altitude Lake Chandertal (Northwest Himalaya). *Adv. Biosci.* 6: 179–186.
- Singh, T.** 2005. Emerging trends in world ornamental fish trade. *Infofish International*, 24 (3): 15 – 18.
- Sinha, R.K.**, 2006. Ecological basis for management and consideration of riverine fisheries with special reference to the Ganga river system. River Fisheries in India- Issues and Current Status. Vass, K.K., Mitra, K., Suresh, V. R., Katiha, P. K., Shrivastava, N. P. (Eds.). *Proceeding of the national seminar on Management Challenges in Fisheries of Rivers and Associated Ecosystem-Issues and Strategies*, Barrackpore, India. 83-97.
- Sinha, R.K., Simha, R.K., Sarkar, U.K., Lakra, W.S.**, 2010. First record of the southern sailfin catfish, *Pterygoplichthys anisitsi* Eigenmann and Kennedy, 1903 (Teleostei: Loricariidae), in India. *Journal of Applied Ichthyology* 26: 606–608.
- Smakhtin, V., Anputhas, M.**, 2006. *An assessment of environmental flow requirements of Indian river basins*. International Water Management Institute Research Report 107. Colombo, Sri Lanka.
- Smith, V.H.**, 1983. Low nitrogen to phosphorus ratios favor dominance by blue green algae in Lake phytoplankton. *Science* . **221**: 667-671.
- Smith, R. A., Alexander, R. B., Wolman, M. G.**, 1993. Stream water Quality in the conterminous United States – status and trends of selected indicators during the 1980's. Geological Survey, Water Supply Paper 2400, Reston, Virginia.
- Smith, B., Wilson, J.**, 1996. A consumer's guide to evenness indices. *Oikos*, 76, 70-82.
- Sommer, U.**, 1988. Phytoplankton succession in microcosm experiments under simultaneous grazing pressure and resource limitation. *Limnol. Oceanogr.* 33(5): 1037-1054. doi:10.4319/lo.1988.33.5.1037.
- Sorensen, T.**, 1948, “A method of establishing groups of equal amplitude in plant society based similarity of species content,” *K. Danske. Vidensk. Selsk.* 5: 1-34.
- Spalding, R. F., Exner, M. F.**, 1993. Occurrence of nitrate in ground water-a review. *J. Environ. Qual.* 22, 392-402.
- Spencer, C. N., Hauer., F. R.**, 1991. Phosphorus and nitrogen dynamics in streams during a wildfire. *J. N. Amer. Benthol. Soc.* 10: 24-30.
- Sreekantha, K. V., Ramachandra, T. V.**, 2005. Fish diversity in Linganamakki Reservoir, Sharavathi River. *Ecol Environ Conserv.* 11, 337–348.
- Srivastava, G.** 1998. Fishes of U.P. and Bihar. Viswhavidyalaya Prakashan. Varanasi, India. Pp. 207.

- Srivastava, G.**, 2010. Fishes of U.P. and Bihar. 13<sup>th</sup> edition. Viswhavidyalaya Prakashan. Varanasi, India. Pp. 207.
- Srivastava, S.K, Sarkar, U.K., Patiyal, R.S.**, 2002. Fishing methods in streams of the Kumaon Himalayan region of India. *Asian Fish. Sci.*, 15, 347-356
- Stanford, J.A., Ward, J.V.**, 1983. Insect species diversity as a function of environmental variability and disturbance in stream systems. In: *Stream Ecology: Application and Testing of General Ecological Theory* (eds J.R. Barnes & G.W. Minshall). Plenum Press, New York.
- Staub, R., Hofstaler., Hass, I. J.**, 1970. The effect of industrial effluents of Memphis and Shelby country on primary plankton production. *Biosciences*, 20: 905- 912.
- Stemberger, R. S., Iazorchak, J. M.**, 1994. Zooplankton assemblage responses to disturbance gradients. *Can. J. Fish. Aquat. Sci.* 51: 2435-2447.
- Steveninck, E.D., de Ruyter van, W.A. Admiraal, L. Breebaart, G.M.J. Tubbing and B.van Zanten.(1992).** Plankton in the River Rhine: structural and functional changes observed during down-stream transport. In: *Jour. Of Plankton Research*, 14(10):1351-1368.
- Subba, B.R., Pandey, M.R., Limbu, K.P., Rai., S.K.**, 2009. On Some Diatoms from Upper Mustang Trans-Himalaya Region, Nepal. *Our Nature* 7, 243-247.
- Sunder, S and B. A. Subla.** 1986. Macrobenthic Fauna of a Himalayan River. *Indian J. Ecol.*, 13(1): 127-132.
- Suresh, B., Manjappa, S., Puttaiah, E. T.**, 2009. The contents of zooplankton of the Tungabhadra river, near Harihar, Karanataka and the saprobiological analysis of water quality. *Journal of Ecology and the Natural Environment* 1(9): 196-200.
- Suseela, M. R., Toppo, K.**, 2006. Enumeration of freshwater algal flora of Gangtok, Sikkim, India. *Geobios*, 33(2). p. 225-232.
- Svobodova, Z., Lloyd, R., Machova, J., Vykusova, B.**, 1993. Water quality and fish health. *EIFAC Technical Paper*. No. 54: 1-59. Rome, FAO.
- Swain, S. K., Jena, J. K., Ayappan, S.**, 2003. Prospects of export – oriented fresh water ornamental fish culture in India. *Fishing Chimes*, 22 (10 & 11): 111 – 113.
- Swingle, H.S.**, 1967. method of analysis of waters, organic matter and pond bottom soils used in fisheries research Auburn University, *Alabama Research and Development Series* No.22 pp30.
- Talwar, P.K., Jhingran, A. G.**, 1991. Inland Fishes of India and adjacent countries. In 2 vols. Oxford & IBH Publishing House, New Delhi. Pp. xx+1158.
- Tamang, P.** 1993. Fish geography of Sikkim. *Panda* (Bi-annual Newsletter on Environment, Forest and Wildlife, Forest Department, Government of Sikkim), 1: 19-20.

- Tate, C. M.** 1990. Patterns and controls of nitrogen in tallgrass prairie streams. *Ecology* 71: 2007-2018.
- Tekriwal, K. L., Rao, A. A.,** 1999. *Ornamental Aquarium Fish of India*. Waterlooville, Kingdom Books. Pp. 144.
- Thapa Chhetry, D.,** 2006. Studies on physico-chemical parameters and macro-biota with special reference to fishes in the wetland of Koshi Tappu wildlife reserve and its surroundings, Nepal. Ph. D. Thesis. University of North Bengal.
- Thapa Chhetry, D., Pal, J.,** 2011. Physico-chemical Parameters of Koshi River at Kushaha Area of Koshi Tappu Wildlife Reserve. *Our Nature* 9: 156-167.
- Thapa, S., Yonzon, P.B., Rai, A.K.,** 2010. Life of a river in the Himalaya: An ecological study of Trisuli River system in Nepal. *Aquaculture Asia Magazine (Genetics and Biodiversity)*, Volume XV No. 1. 37- 40pp.
- Tilak, R.** 1975. On addition to the fish fauna of North Bengal. *Cheetal*. 15. 34-40.
- Tilak, R., Baloni, S. P.,** 1988. Notes on ecology of Hill-stream fishes of Tehri-Garhwal (U.P), *Indian J. Ecol.* 15 (1): 114-116.
- Tilak, R.,** 1987. *The fauna of India, pisces (Teleostomi), sub-family-Schizothoracinae*. Zoological Survey of India, Calcutta. pp. 229.
- Timm, N.H.,** 2002, *Applied Multivariate Analysis*, Springer Publication, New York, USA
- Tockner, K., Stanford, J. A.,** 2002. Riverine flood plains: Present state and future trends. *Environmental Conservation*. 29(3): 308-330.
- Townsend, C. R., Harper, J.L., Begon, M.** 2000. *Essentials of Ecology*. 3<sup>rd</sup> edition. lackwell Science Publishers, London.
- Train , R. E.,** 1979. *Quality criteria for water*, Castle House Publications, London.
- Triska, F. J., Kennedy, V. C., Avanzino, R. J., Zellweger, G. W., Bencala, K. E.,** 1990. In situ retention-transport response to nitrate loading and storm discharge in a third order stream. *J. N. Am. Benthol. Soc.* 9:229-239.
- Trivedy, R.K.,** 1988. *Ecology and Pollution in India*. Ashish Publ. House, New Delhi, 294p.
- Trivedy, R.K., Goel, P.K.,** 1984. *Chemical and Biological Methods for Water Pollution Studies*. Environmental Publications, Karad (India).
- Trivedi, R.K., Gurung, V., Das, B.K., Rout, S.K.,** 2003. Variations of plankton population of two hill streams of the Darjeeling District, West Bengal. *Environment and Ecology*. 21(SPL Pub): 50-53.
- Turcotte, P., and Harper, P.P.,** 1982. The macro-invertebrate fauna of a small Andean stream. *Freshwater Biology*, 12, 411-419.

- U.S. Environment Protection Agency.,** 1976. *Quality Criteria for Waters*. US Environment Protection Agency. Washington DC.
- U.S. Environment Protection Agency.,** 1986. *Quality Criteria for Waters 1986*. U.S. Environment Protection Agency, Office of water Regulation and Standards, EPA 440/5-86-001. Washington DC.
- UNEP/GRID-Arendal.** 2007. *Water towers of Asia – glaciers, water and population in the greater Himalayas-Hindu Kush- Tien Shan-Tibet region*. *UNEP/GRID-Arendal Maps and Graphics Library*, June 2007. <http://maps.grida.no/go/graphic/water-towers-of-asia-glaciers-water-and-population>. Accessed on 30 March 2012.
- Uniyal, D.U., Bahuguna, S.N., Kumar, A., Uniyal, M.B.,** 2002. Fishing Methods an important tool for fish conservation and management : A case study in Doon Valley, Uttaranchal. In: Abstract Proceedings, National Seminar on Aquatic Resource Management in Hills, National Research Centre on Cold Water Fisheries (ICAR), Nainital. p. 68
- Vagelli, A.A., Erdmann, M.V.,** 2002. First comprehensive ecological survey of the Banggai cardinalfish, *Pterapogon kauderni*. *Environmental Biology of Fishes*, 63: 1-8.
- Vaidya, S. R., Yadav , U. K. R.,** 2008. Ecological study on zooplankton of some fresh water bodies of kathmandu valley with reference to water quality. *J. Nat. Hist. Mus.* Vol. 23, 1-11.
- Van der Velde, G., Leuven R. S. E. W., Nagelkerken, I.,** 2004. Types of river ecosystems. 2.7.2.4. In Dooge, J. C. I. (ed.), *Fresh Surface Water, Encyclopedia of Life Support Systems (EOLSS)*. EOLSS Publishers, Oxford (available online [www.eolss.net](http://www.eolss.net)).
- Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., Cushing, C. E.,** 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 130-137.
- Vass, K.K., Raina, H.S., Zutshi, D.P., Khan, M.A.,** 1977. Hydrobiological studies on River Jhelum. *Geobios*, 4: 238 – 242.
- Venkateshraj, K., Ravikumar, P., Someshekar, R. K., Prakash, K. L.,** 2010. Physico-chemical and Bacteriological Investigation on the river Cauvery of Kollegal stretch in Karnataka. *Kathmandu Univ. Jour. Sci. Eng. and Tech.* 6(1), 50-59.
- Verma, P. K., Datta-Munshi, J. S.,** 1987. Plankton community structure of Bedur Reservoir, Bhagalpur (Bihar). *Trop. Ecol.* 28: 200-207.
- Vilela, C.G, Sanjinés A.E.S, Ghiselli Jr., R.O, Filho J.G., Neto, J.A., Barbosa, C.F.,** 2003. Search for Bioindicators of Pollution in the Guanabara Bay: Intergrations of Ecologic Patterns. *Anuário Do Intituto De Geociências* 26: 25–35.
- Vishwanath, W., Manojkumar, W., Kosygin. L.,** 1998. Biodiversity of freshwater fishes of Manipur, India. *Italian J Zool* 65:321–324.
- Vishwanath, W., Lakra, W.S., Sarkar, U.K.,** 2007. *Fishes of North East India*. National Bureau of Fish Genetic Resources, Lucknow, India.

- Walling, D.E., Webb, B.W.**, 1992. Water quality I: physical characteristics. In “*The Rivers Handbook* Vol. 1” (P. Calow and G.E. Petts, Eds), pp. 48–72. Blackwell Publishing, Oxford, UK.
- Wani, R., Subla, B.**, 1990. (eds), Proc.Symp. on recent advances in tropical ecology, Varanasi, India, pp:368-375.
- Ward, H.B., Whipple, G.C.**, 1959. *Fresh Water Biology*, 2<sup>nd</sup> Edition (Ed. Edmondson) John Willey and Sons, New York, USA.
- Ward, J. V., Robinson, C. T., Tockner, K.**, 2002. Applicability of ecological theory to riverine ecosystems. *Verhandlungen Internationale Vereinigung fu“ r Theoretische und Angewandte Limnologie* 26: 443–450
- Ward, J.V.**, 1989. The four dimensional nature of lotic ecosystems. *Journal of the North American Benthological Society*. 8: 2-8.
- WATCH**. 2010. *Ganges Brahmaputra River Basin*. Water and Global Change. Centre for Ecology and Hydrology, at Wallingford, UK.  
www.waterandclimatechange.eu/riverbasin/ganges-brahmaputra. Accessed on 30 March 2012.
- Watling, K., Bottom, G., Pembroke, A., Maurer, D.**, 1979. Seasonal variations in Delaware Bay phytoplankton community structure. *Mar. Biol.* 53, 207-215.
- Welch, P.S.**, 1952. *Limnology*, 2<sup>nd</sup> edn. New York-Toronto and London, Mc Graw Hill Book Co.
- Welcomme, R. L.**, 1985. River fisheries. *FAO Fish Tech Pap.* 262, 1–318.
- Westlake, D.F.**, 1980. Primary production in Lecren, E.D & Lowe McConnell, R.H. (Eds). The functioning of freshwater ecosystem Cambridge university press. *International biological programme*, 122:414-446.
- Wetzel, R.G.**, 2001. *Limnology; Lake and River Ecosystems*, (3<sup>rd</sup> edition). Academic Press, USA.
- Weiher, E., Keddy, P. A.**, 1999. Relative abundance and evenness patterns along diversity and biomass gradients. *Oikos* 87:355–361.
- Wilsey, B.J., Chalcraft, D.R., Bowles, C.M., Willig, M.R.**. 2005. Relationships among indices suggest that richness is an incomplete surrogate for grassland biodiversity. *Ecology* 86(5): 1178-1184.
- Wheeler, P. A., Huyer, A., Fleischbein, J., 2002.** Cold halocline, increased nutrients and higher chlorophyll off Oregon. *Geophysical Research Letters*, 3 (15), 8021, doi:10.1029/2003GL017395
- Whittaker, R. H.**, 1972. Evolution and measurement of species diversity. *Taxon*. **21**, 213–251.
- Whittaker, R.H.** 1965. Dominance and Diversity in land plant communities. *Science* 147: 250-260.

- Whitton, B. A., (Ed.).** 1975. *River ecology. Studies in ecology*, v. 2. University of California, Berkeley. x + 725 p.
- Wichert, G. A., Rapport, D. J.,** 1998. Fish community structure as a measure of degradation and rehabilitation of riparian systems in an agricultural drainage basin. *Environ Manag.* 22(3): 425–443.
- Wilson, E. O.,** 1992. *The Diversity of Life*. Penguin Books, London. Pp. 406.
- Winemiller, K. O., Agostinho, A. A., Caramaschi, É. P.,** 2008. Fish Ecology in Tropical Streams. In Dudgeon, D., (ed.), *Tropical Stream Ecology*. Academic Press is an Imprint of Elsevier. London, UK. Pp. 107-146.
- Wolter, C., Minow, J., Vilcinskas, A., Grosch, U.,** 2000. Long-term effects of human influence on fish community structure and fisheries in Berlin water: an urban water system. *Fish Manag Ecol.* 7, 97–104.
- Wunderlin, D.A., Diaz, M., Ame, M.M.V., Pesce, S.F., Hued, A.C., Bistoni, M.,** 2001. Pattern recognition techniques for the evaluation of spatial and temporal variations in water quality. A case study: Suquia river basin (Cordoba-Argentina). *Water Res.* 35 (12), 2881–2894.
- Yousuf, A. R., Balki, M. H., Qadri, M.Y.,** 1986. Limnological Features of a forest lake of Kashmir. *J. Zool. Soc. India.* 38(1/2): 29-42.
- Zale, A.V., Leslie, D. M. Jr., Fisher, W.L., Merrifield, S.G.,** 1989. The Physicochemistry, Flora, and Fauna of Intermittent Prairie Streams: A Review of the Literature. *U. S. Fish Wildl. Serv., Biol. Rep.* 89 (5).
- Zaret, T. M.,** 1980. *Predation and Freshwater Communities*. Yale University Press. 187pp.



# *Index*

# *Index*

---

## **A**

### Acid

carbonic, 13, 15, 180

deposition, 1

fulvic, 15

mineral, 17, 188, 189

nucleic, 188

sulphanilic, 49, 51

strong, 15

weak, 15

wash, 49

$\alpha$ -naphthylamine and sulphanilic acid method, 49

Algae, 21, 23

### Ammonium

ion, 19

nitrogen, 19, 49, 51, 59, 62, 63, 66, 69, 70-73, 75, 77, 79, 81-89, 99-101, 113-115, 127-129, 141-143, 157, 158, 171, 185, 188, 199, 200, 208-210, 220-222, 223

### Alkalinity

total, 12, 13, 15-18, 49, 59-61, 64, 66-68, 69, 71-73, 75, 77, 81-89, 99-101, 113-116, 127-129, 141-143, 157-159, 172-189, 193, 199, 200, 208-210, 221-223.

Allochthonous, 7, 21, 217, 222

Anthropogenic, 5, 193, 197, 207, 219

Aquatic, 4, 5, 9, 15, 19-21, 25, 26, 29, 30, 32, 185, 188, 193, 195, 213, 215, 219, 220

Argentometric method, 49

## **B**

Bacillariophyceae, 23, 24, 90, 91, 93, 104-106, 190

Benthos, 4, 27, 226

Biodiversity, 1-5, 31

Blue green algae, 23

Brucine-sulphate method, 49

## C

Calcium, 15, 17, 184, 188

Carbon dioxide, 14, 48, 49, 61, 69, 70, 76, 83-86, 99-101, 113-115, 127-129, 141-143, 157, 158, 172, 181, 188, 193, 199, 200, 205, 208-210, 221-223

Carbonate, 13, 15, 17

Catchment, 1, 9, 11, 37, 38, 40, 187

Catch per unit effort, 34, 53, 147, 150-154, 157, 160-162, 166, 169, 171, 175, 176, 214- 222, 225

Chloride, 16-18, 48-51, 59-64, 66-69, 71-73, 75, 76, 78, 81-89, 99-103, 113-116, 127-131, 141-145, 157-161, 172-176, 183-185, 188-189, 194, 199, 200, 208-210, 221-223

Chlorophyceae, 22-24, 90-93, 104-106, 190, 224

Cladocera, 27, 28, 118-120, 132, 133, 201, 206-208, 210, 224, 225

Community, 4, 21, 22, 25-28, 32, 35, 54, 56, 95, 109, 123, 137, 148, 167, 191, 195-200, 201-212, 216, 218, 219

Conductivity, 12, 13, 48, 49, 46, 59-61, 64, 67-72, 75, 76, 82-89, 103, 116, 131, 145, 161, 176, 180- 189, 194, 200, 208, 210, 221, 222

Copepoda, 27, 28, 118-120, 133, 201, 224

Correlation, 9-14, 16-19, 56-70, 73, 84, 89, 96, 103, 110, 116, 124, 131, 139, 145, 154, 161, 171, 176, 178-187, 192-197, 203-206, 214-217, 220-221, 223-225

Cyanophyceae, 23, 24, 90-93, 104-106, 190

## D

Dams, 1, 3, 226

Density

phytoplankton, 5, 6, 22-26, 51-56, 90-103, 104-117, 191-200, 224-226

zooplankton, 4-6, 27, 28, 52, 56, 118-131, 132-145, 202-210, 224-226

ichthyofauna, 6, 35, 53, 54, 149-156, 161, 168, 170-172, 176, 212, 214, 217, 218-221, 223, 226

Diatoms, 22-24, 90, 104, 190-195, 200

Diversity Indices, 24, 28, 29, 34, 54, 56, 90, 93, 95-99, 103-106, 109-113, 116-118, 120, 123-126, 132, 134, 137- 141, 145, 147- 150, 153-156, 161, 162, 164, 168-171, 176, 192, 196-198, 200-202, 206-208, 214, 218, 219, 223, 225

Dominance Index, 25,55, 92, 93-98, 101-103, 106, 108-112, 115-117, 120,121, 126, 129-131, 134-140, 143-145, 148-154, 156, 159-161, 164, 167-171, 174-176, 190,196-200, 201-203, 205-210, 212, 216- 222

## **E**

EDTA titremetric method, 49

Euglenophyceae, 23, 24, 90-93, 104-106, 190

Evenness Index, 24, 25, 29, 35, 54, 55, 88, 92-94, 95-98, 100-103,106-112,114, 116, 117, 120-122, 128-131, 134-140, 142-145,148, 150- 156, 158-161, 164, 166-171, 173-176, 195-200, 205-210, 215-222, 224, 225

## **F**

Flavour Rating Assessment, 46

Flood, 1-4, 8, 11, 22, 25, 29, 30, 38, 39, 180, 190-192, 196-197, 202-205, 210-213, 219, 220

Flow, 1, 2, 7-11, 18, 22, 24, 26-29, 31-34, 36-38, 42-43, 146, 178, 179, 192, 193, 203, 208, 213, 219,220

Food chain, 4, 5, 30

## **G**

Green algae, 23, 90, 104, 194

## **H**

Hardness, 12, 13, 16-18, 48, 49, 59, 62-64, 66-73, 75-89, 99-102, 113-116,127-131,141-145, 157-161, 172-176,180-185, 187-189, 194, 200, 208-210, 221-223

Herbivorous, 212

## **I**

Ichthyodiversity, 33, 146, 160, 162, 175, 212, 226

Ichthyofauna, 5, 6, 28, 30, 32, 34, 35, 53-55. 57, 147-151, 162, 164, 165-171, 173, 176, 211-221, 223-226

## **L**

Light, 22, 25, 190, 192, 193, 200

Limnology, 7, 8

Lotic, 1, 3, 7, 12, 14, 18, 23, 26-30, 203

## **M**

Magnesium, 12, 15,17, 184, 188, 194

## **N**

Nauplius, 119, 133

Nitrate

nitrogen, 18-20, 49-51, 59, 63, 64, 67, 69-73, 75-77, 79, 82, 85-89, 99-103, 113-116, 127-131, 141-145, 157-161, 176, 185-188, 199-200, 205, 208-210, 220-

Nitrite

nitrogen, 20, 49, 51, 59, 62, 63, 66-73, 75-77, 79-89, 99-103, 113-116, 127-131, 141-145, 157-161, 172, 176, 185-187, 193, 199,200, 208-210, 220-223

Nutrients, 12, 18, 26, 29, 51, 68, 70, 71, 83, 84, 86-88, 117, 176, 188, 189, 192, 193, 199, 200, 205, 210, 217, 221-225

## **O**

Omnivorous, 212

Oxygen

dissolved, 4, 9, 10, 13, 14, 47, 49, 59-61, 64-68, 75-89, 99-103, 113-117,127-129, 141-145, 157,158,161, 172, 176, 179,181-183, 188. 189,194, 199,200, 208-210, 221-223

## **P**

Paradox of plankton, 191

Periphyton, 4, 21, 192, 226

pH, 12-14, 15, 16, 48, 49, 59-61, 64-73, 75, 76, 80-89, 99-103, 113-116,127-131, 142- 145, 157-161,176, 180-185,188-189,193, 199-200, 208-210, 221-223

Phenate method, 49

Phenol Hypochlorite method, 49

Phosphate

phosphorous, 18, 21, 49, 51,59, 63, 64, 66-73, 75, 79, 82, 85-89, 99-103, 113-116, 127-131,141-145, 157-161, 172, 176, 187, 189, 193, 199, 200, 208-210, 220-223,

Phytoplankton, 3-6, 13, 19-26, 29, 51, 90-117, 190-200, 224-226

Pollution, 5, 16, 17, 25, 29, 194, 195, 215

Population size, 50, 53, 147, 150, 152-154, 156, 157, 160-172,175,176, 214, 222, 225

Precipitation, 11, 41, 180, 181

Principal Component Analysis, 56, 70-72, 84-87, 187, 223- 224

Productivity, 7, 21, 22, 24-26, 190-192, 198, 207, 214, 220

Protozoa, 27, 28, 118-120, 132-134, 201- 224

## **R**

Regression, 50, 57, 99-102, 113-117,124, 127-130, 141-144, 154, 157-160, 171-175, 199, 208, 209,221, 223

Relative abundance, 22, 24, 27, 90-91, 104, 105, 118, 119, 132, 133, 146, 162, 163

Richness Index, 6, 25-29, 55, 92-98, 101-103,106-112, 115-117, 120-126, 128-131, 134-140, 143-145,148-154, 156-161, 164-171, 173-176, 195-200, 201, 205-210, 215-222,224, 225

Rotifera, 27, 28, 118-120, 132, 201

Running water, 1, 7, 8

## **S**

Shannon-Wiener species diversity index, 24, 35, 54, 92-98, 100-103, 106-112, 114-117, 120-126, 128-131, 134-140, 142-145, 147-154, 156-161, 164-171, 173-176, 194-200, 203-210, 215-222, 224-225

Similarity Index, 55, 95, 98, 109, 112, 120, 123, 134, 137, 148, 150, 164, 167, 191, 202, 212, 224, 225

Stannous chloride method, 49

## **T**

Temperature

air, 9, 45, 54, 55, 62-65, 67-71, 76-78, 81-83, 99, 113, 128, 142, 158, 173, 175, 176

water, 9, 10, 13, 14,18,26, 29, 30, 45, 46, 54, 55,60-67, 70,71, 76-82, 95-97, 110-112, 124-126, 139,140, 154, 155, 169, 174-181, 185-187, 195-198, 201-207, 211, 214-217, 219

Titration method, 46

titrimetric method, 46

## **W**

Water Colour, 50, 58, 74, 177, 223

Water velocity, 11, 24-29, 32, 48,49, 59, 60, 64-69, 71-75, 80-89, 99-116, 127-131, 141-145, 157-161, 172-176, 179-180, 185, 188-192, 195-197, 199, 200, 202-205, 208-210, 214, 220-223, 225

Winkler's iodometric method, 49

## **Z**

Zooplankton, 4-6, 19, 23, 26-30, 51, 52, 118-145, 201-210, 224-226



# *Appendices*

## APPENDIX- A

### Salient Features of the River Teesta (Anonymous, 2001)

- I. **Origin:** In the Pauhungri glacier of North Sikkim at an altitude of 6200 m.
- II. **Outfall:** It outfalls into river Brahmaputra near Raniganj town of Rangpur district of Bangladesh. It belongs to the Brahmaputra system of rivers.
- III. **Length:**

a) In Sikkim	151 km.
b) Boundary between Sikkim and West Bengal	19 km.
c) Upto Sivoke	29 km.
d) Upto Indo-Bangladesh border from Sivoke	94 km.
e) In Bangladesh	121 km.
Total length	414 km.
- IV. **Width:**

a) At Chungthang (Sikkim).	30m
b) At Singtam (Sikkim).	40m
c) Within Darjeeling district	100m-900m
d) Near Jalpaiguri town	2.4 km to 4.8 km.
- V. **Average depth:** 1.8m-4.5m.
- VI. **Longitudinal slope of the river (In m/km.):**

a) From Chungtham to Singtam	34.96 to 16.5
b) From Rangpo to Teesta Bazar.	3.8
c) At Jalpaiguri	0.7
- VII. **Velocity of flow:**

a) In hilly region	high as 6 m/sec
b) In terai	2.4 m to 3m/sec.
- VIII. **Catchment area (in km<sup>2</sup>):**

a) Hilly region	8051
i) Sikkim	6930
ii) West Bengal	1121
b) In plain	4108
i) West Bengal	2104
ii) Bangladesh	2004
Total in India	10,155
Total in Bangladesh	2004
Grand total	12,159
- IX. **Mean annual sediment load:** 6.0 M. ton Or 3.16 M. cum.
- X. **The average depth of deposition or scour** 1 cm to 18 cm.
- XI. **Calculated peak discharge:**

a) At Rangpo (Sikkim border)	3, 92, 600 cusec or 11,100 cumec
b) At Teesta Bazar	5, 79, 300 cusec or 16, 400 cumec.
c) At Coronation bridge	6, 16, 900 cusec or 17, 450 cumec.
d) At Jalpaiguri	7, 12, 870 cusec or 20,190 cumec.
e) At Bangladesh border	7, 61, 130 cusec or 21, 550 cumec.

## APPENDIX- B

### **Salient Features of the hill- stream Relli:**

- I. Origin:** Algarah-Labha ridge in Khampang reserve forest of Kalimpong sub-division at an altitude of about 1800 m.
- II. Outfall:** It outfalls into the river Teesta near Teesta Low Dam Project, stage III (TLDP-III), 7 km downstream of Teesta Bazaar at an altitude of about 212 m.
- III. Total length:** 30.64 km.
- IV. Width:** 90- 150 m.
- V. Depth:** 0.5-1.5 m.
- VI. Longitudinal slope of the river (m/km.):** 11
- VII. The slope of the river bank:**  $20^{\circ}$  to  $90^{\circ}$ .
- VIII. Total catchment area:**  $165 \text{ km}^2$

## APPENDIX- C

### List of Fish, Distribution, Relative Abundance, Conservation and Other Status of Fish Fauna from the Teesta River in Darjeeling Himalaya.

Name of the Species/ Length in cm. / English (E), Nepali (N) and Bengali (B) Name.	2007-2008				2008-2009			
	TR-I	TR-II	TR-III	TR-IV	TR-I	TR-II	TR-III	TR-IV
<b>Order – Cypriniformes</b>	<b>96.2</b>	<b>96.4</b>	<b>88.5</b>	<b>87.7</b>	<b>96.8</b>	<b>92.5</b>	<b>94.6</b>	<b>84.0</b>
<b>Family – Cyprinidae</b>	<b>74.1</b>	<b>71.5</b>	<b>60.9</b>	<b>58.6</b>	<b>75.6</b>	<b>69.0</b>	<b>65.6</b>	<b>63.2</b>
<b>Sub-family - Rasborinae</b>	33.3	33.9	29.3	33.6	31.0	30.5	31.6	29.6
1. <i>Barilius barna</i> (Ham.)L=10; Barna baril (E), Fakatar or Pothi (N),Boroli or Ghol (B). <b>LR- nt, FF/OR.</b>	++	++	++	+++	++	+++	+++	++
2. <i>Barilius barila</i> (Ham.)L=6; Barred baril (E), Barali, Koksa (B). <b>Vu, FF/OR.</b>	-	-	-	+	-	-	-	+
3. <i>Barilius bendelisis</i> (Ham.)L=12; Hamilton's baril (E), Gurdere or Khabati (N);Joia (B). <b>LR-nt, FF/OR.</b>	+++	+++	+++	+++	+++	+++	+++	++
4. <i>Barilius shacra</i> (Ham.) L=13; Shacra baril (E), Faketa (N); Koksa (B). <b>LR-nt, FF/OR.</b>	+	+	+	-	+	-	-	-
5. <i>Barilius tileo</i> (Ham.) L=14; Tileo baril (E), Faketa or Khamare (N), Koksa (B). <b>LR-nt, FF/OR.</b>	-	-	+	+	-	+	+	+
6. <i>Barilius vagra</i> (Ham.)L=11; Vagra baril (E), Chahale or Lam faketa (N), Koksa (B). <b>Vu, FF/OR.</b>	+	+	+	-	+	+	-	+
7. <i>Aspidoparia morar</i> (Ham.)L=12; Carplet (E), Murari, Boroli (B). <b>LR-nt, FF/OR.</b>	-	-	+	+	-	-	+	+
8. <i>Raiamas bola</i> (Ham.)L=24; Indian trout (E), Bola or Goha (N), Bhola or Ghol (B). <b>Vu, FF</b>	-	-	+	+	-	+	-	-
9. <i>Devario devario</i> (Ham.)L=7; Sind danio(E), Chitharipothi (N), Bans pata (B). <b>LR-nt, FF/OR.</b>	-	-	-	+	-	-	-	+
10. <i>Devario aequipinnatus</i> (Mc Clelland)L=13; Giant danio (E), Vitti (N),Chhebli (B). <b>LR-nt, FF/OR.</b>	++	+	-	+	+	+	-	+
<b>Sub-family - Cultrinae</b>	-	-	-	3.9	-	0.9	0.9	2.5
11. <i>Salmophusia bacaila</i> (Ham.)L=13; Large razor belly minnow (E), Chilwa (N), Chela (B). <b>LR-ic, FF/OR.</b>	-	-	-	+	-	+	+	+
<b>Sub-family - Garrinae</b>	14.7	10.5	7.9	5.9	10.0	12.0	10.5	9.0
12. <i>Garra annandalei</i> (Hora) L=12; Annandale Garra(E), Buduna (N), Patharchata (B). <b>NE, FF/OR.</b>	+	+	+	-	-	+	-	-
13. <i>Garra gotyla gotyla</i> (Gray)L=13; Sucker head (E), Buduna (N), Patharchata or Ghorpoia (B). <b>Vu, FF/OR.</b>	++	++	++	+	++	++	++	++
14. <i>Garra lamta</i> (Mc Clelland)L=12; Lamta Garra (E), Buduna (N), Siltokra (B). <b>NE, FF/OR.</b>	-	+	-	-	-	-	-	-
15. <i>Crossocheilus latius</i> (Ham.)L=13; Gangetic latia(E), Mate Buduna (N),Kala-bata (B). <b>DD, FF/OR.</b>	+	-	-	+	+	+	+	+
<b>Sub-family - Schizothoracinae</b>	12.4	16.3	10.2	2.2	19.0	12.7	6.9	4.7
16. <i>Schizothorax progastus</i> (Mc Clelland)L=40; Point nosed snow trout (E), Chuche Asala(N). <b>LR-nt, FF/SF</b>	+	+	-	-	+	+	-	-
17. <i>Schizothorax richardsonii</i> (Gray) L=22; Blunt nosed snow trout (E), Buche Asala (N). <b>Vu,FF/SF.</b>	+++	+++	+++	+	+++	+++	++	+

(Continued).

Name of the Species/ Length in cm. /Name	TR-I	TR-II	TR-III	TR-IV	TR-I	TR-II	TR-III	TR-IV
<b>Sub-family - Cyprininae</b>	13.7	10.8	13.5	12.9	15.6	12.9	15.6	17.4
18. <i>Chagunius chagunio</i> (Ham.)L=30; Chaguni(E), Rewa or Chaguni (N),Pithkati or Darangi (B). <b>NE, FF/OR.</b>	-	-	-	+	-	+	+	+
19. <i>Cyprinion semiplotum</i> (Mc Clelland) L=20; Assamese kingfish (E), Chepti or Khurpe (N), Badangi (B). <b>Vu, FF/OR.</b>	+	-	+	-	+	-	-	+
20. <i>Labeo boga</i> (Ham.) L=18; Boga labeo (E), Boga, Bhangan, Tikauli (B). <b>LR-nt, FF/OR.</b>	+	+	+	-	+	+	+	-
21. <i>Labeo dero</i> (Ham.) L=25; Kalabans(E), Gerdi (N), Kathalkushi or Ghorea (B). <b>Vu, FF/OR.</b>	+	+	+	-	+	+	+	+
22. <i>Labeo dyocheilus</i> (Mc Clelland)L=35; Brahmaputra labeo(E), Gardi (N), Degra or Silghorea (B). <b>Vu, FF.</b>	-	-	+	-	-	+	-	+
23. <i>Labeo pungusia</i> (Ham.)L=40; Pangasia labeo(E), Kalaacha or Ther (N), Utta,Boitka or Darangi (B). <b>LR-nt, FF.</b>	-	-	-	+	-	+	-	+
24. <i>Neolissocheilus hexagonolepis</i> (Mc Clelland) L=50; Copper mahseer (E), Katli or Katlae (N), Bhuluk (B). <b>NE, FF/SF.</b>	++	++	++	++	+++	++	++	++
25. <i>Neolissocheilus hexastichus</i> (Mc Clelland) L=18; Mc clelland's boker (E), Katli or Katlae (N), Bhuluk (B). <b>Vu, FF/SF</b>	+	-	+	-	+	-	-	-
26. <i>Tor putitora</i> (Ham.)L=88; Golden mahseer (E), Pahale Sahar(N), Mahseer or Mahasol (B). <b>EN, FF/SF.</b>	+	-	-	+	+	-	+	+
27. <i>Tor tor</i> (Hamilton-Buchanan) L=76; Turia mahseer (E), Falame Sahar(N), Mahseer or Mahasol (B). <b>EN, FF/SF</b>	-	-	+	-	+	-	-	-
28. <i>Puntius conchoni</i> (Ham.) L=9; Rosy barb (E), Kanchan puti (B), Sidre (N). <b>Vu, FF/OR.</b>	-	-	-	+	-	-	-	+
29. <i>Puntius gelius</i> (Ham.) L=4; Golden dwarf barb (E), Sidre (N), Gili Punti (B). <b>NE, FF/OR.</b>	-	-	-	+	-	-	+	-
30. <i>Puntius ticto</i> (Ham.)L=8; Ticto barb (E), Titae Pothi (N),Titpunti (B). <b>LR-nt, FF/OR.</b>	-	-	-	-	-	-	-	+
<b>Family – Psilorhynchidae</b>	<b>0.3</b>	<b>1.8</b>	<b>1.2</b>	<b>-</b>	<b>-</b>	<b>0.9</b>	<b>1.7</b>	<b>1.7</b>
31. <i>Psilorhynchus balitora</i> (Ham.) L=9; Balitora minnow (E), Pathar Chati (N),Balichura (B). <b>NE, FF/OR.</b>	-	+	-	-	-	+	+	-
32. <i>Psilorhynchus sucatio</i> (Ham.) L=6; River stone carp (E), Titae (N), Titari (B). <b>EN, OR.</b>	-	+	+	-	-	-	-	+
33. <i>Psilorhynchus homaloptera</i> (Ham.) L=8.5; Torrent stone carp (E), Patharchati (N). <b>Vu, OR.</b>	+	-	-	-	-	-	+	-
<b>Family – Cobitidae</b>	<b>-</b>	<b>1.5</b>	<b>0.6</b>	<b>3.9</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>3.9</b>
<b>Sub-family - Cobitinae</b>	<b>-</b>	<b>1.5</b>	<b>0.6</b>	<b>3.9</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>3.2</b>
34. <i>Lepidocephalichthyes guntea</i> (Ham.)L=8; Guntea loach (E), Lata or Gethu (N), Gunte Poia or Gutum (B). <b>NE, FF/OR.</b>	-	-	-	+	-	-	-	+
35. <i>Pangio pangia</i> (Ham.) L=5; Coolie loach (E), Pangya or Daria (B). <b>Vu, OR.</b>	-	-	-	+	-	-	-	-
36. <i>Canthophrys gongota</i> (Ham.)L=10; Jaguar loach (E), Latai (N),Ghor-poia (B). <b>LR-nt, FF/OR.</b>	-	+	+	+	-	-	-	+
<b>Sub-family - Botiinae</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>0.7</b>
37. <i>Botia lohachata</i> (Choudhuri)L=11; Y-loach (E), Baghi (N), Rani mach, Boumach (B). <b>EN, FF/OR.</b>	-	-	-	-	-	-	-	+

Continued

Name of the Species/ Length in cm. / Name	TR-I	TR-II	TR-III	TR-IV	TR-I	TR-II	TR-III	TR-IV
<b>Family – Balitoridae</b>	<b>21.8</b>	<b>21.6</b>	<b>25.8</b>	<b>21.3</b>	<b>21.2</b>	<b>22.6</b>	<b>27.3</b>	<b>15.2</b>
<b>Sub-family - Balitorinae</b>	-	-	-	1.1	-	0.7	0.9	-
38. <i>Balitora brucei</i> (Gray) L=7; Gray's stone loach (E), Tita Kabre (N). <b>LR-nt, OR.</b>	-	-	-	+	-	+	+	-
<b>Sub-family - Nemacheilinae</b>	<b>21.8</b>	<b>21.6</b>	<b>25.8</b>	<b>20.2</b>	<b>21.2</b>	<b>21.9</b>	<b>26.3</b>	<b>15.2</b>
39. <i>Aborichthyes elongatus</i> (Hora) L=8; Wedge tail loach (E), Bami Gadela (N). <b>EN, OR.</b>	-	-	-	-	+	+	-	-
40. <i>Acanthocobitis botia</i> (Ham.) L=8; Leopard loach (E), Gadela (N); Bilchuri, Khorkey bata (B). <b>LR-nt, FF/OR.</b>	-	-	+	+	-	-	-	-
41. <i>Schistura beavani</i> (Gunther) L=4; Creek loach (E), Gadela (N), Poia, Bibhan- khorkey (B). <b>NE, OR.</b>	+	-	+	-	-	-	-	-
42. <i>Schistura rupicola</i> (Mc Clelland) L=7; Banded loach (E), Gadela (N), Rupali-khorkey (B). <b>LR-nt, OR.</b>	+	-	+	-	+	-	-	-
43. <i>Schistura scaturigina</i> (Mc Clelland) L= 6; Victory loach (E), Gadela (N), Dari, Poia, khorkey (B). <b>Vu, OR.</b>	+	+	++	++	+	++	++	+
44. <i>Nemacheilus devdevi</i> (Hora) L=3; Olivaceous loach (E), Gadela (N), Poia, Khorkey (B). <b>EN, OR.</b>	+++	+++	++	++	++	++	+++	++
45. <i>Nemacheilus multifasciatus</i> (Day) L=9.8; Many banded loach (E), Gadela (N), Poia, Kharika (B). <b>EN, OR.</b>	+	+	+	+	+	+	++	+
46. <i>Nemacheilus botia aureus</i> (Day, 1878) L=6 ; Mottled loach(E), Gadela (N); Poia (B). <b>NE, FF/OR.</b>	-	+	-	-	-	-	+	+
<b>Order – Siluriformes</b>	<b>3.7</b>	<b>2.9</b>	<b>10.4</b>	<b>15.2</b>	<b>3.1</b>	<b>7.2</b>	<b>4.8</b>	<b>15.1</b>
<b>Family – Bagridae</b>	-	-	<b>0.8</b>	<b>1.8</b>	-	-	-	<b>2.0</b>
47. <i>Batasio batasio</i> (Ham.) L=6; Tista batasio (E), Batasio (N), Batasi or Bajori (B). <b>NE, FF/OR.</b>	-	-	+	+	-	-	-	+
<b>Family – Schilbeidae</b>	<b>0.9</b>	-	<b>1.8</b>	<b>2.4</b>	<b>0.5</b>	-	<b>0.7</b>	-
<b>Sub-family - Schilbeinae</b>	0.9	-	0.9		0.5	-	0.7	-
48. <i>Clupisoma garua</i> (Ham.) L=36; Garua bacha (E), Jalkapoor (N), Ghaura (B). <b>Vu, FF.</b>	+	-	+	-	+	-	-	-
49. <i>Clupisoma montana</i> (Hora) L=21; Kocha garua (E), Jalkapoor (N), Ghaura (B). <b>NE, FF.</b>	+	-	-	-	-	-	+	-
<b>Sub-family- Ailiinae</b>	-	-	0.9	2.4	-	-	-	-
50. <i>Ailia coila</i> (Mc Clelland) L=14; Gangetic ailia (E), Patsi (N), Kajri, Kajoli (B). <b>Vu, FF/OR.</b>	-	-	+	+	-	-	-	-
<b>Family – Sisoridae</b>	<b>2.8</b>	<b>2.9</b>	<b>7.7</b>	<b>9.7</b>	<b>2.6</b>	<b>7.2</b>	<b>4.1</b>	<b>10.7</b>
51. <i>Bagarius bagarius</i> (Ham.) L=68; Giant river catfish or Goonch (E), Goonch (N), Bagha Air (B). <b>Vu, FF/SF</b>	+	-	-	-	+	+	-	-
52. <i>Parachilognanis hodgarti</i> (Hora) L=6; Torrent catfish (E), Til-Kabri (N). <b>EN, OR.</b>	-	-	-	-	-	+	-	-
53. <i>Gagata cenia</i> (Ham.) L=8; Clown catfish (E), Ganfak (N), Gong tengra, Ketakata (B). <b>NE, FF/OR.</b>	-	-	+	-	-	+	-	+
54. <i>Glyptothorax telchitta</i> (Ham.) L=7; Copper catfish (E), Telcapre, Telchitta (N), Dhal Magur (B). <b>LR-nt, FF/OR.</b>	-	-	+	-	-	+	+	+

Continued

Name of the Species/ Length in cm. / Name	TR-I	TR-II	TR-III	TR-IV	TR-I	TR-II	TR-III	TR-IV
55. <i>Glyptothorax cavia</i> (Ham.) L=16; Banded torrent catfish (E), Capre (N), Kani tengra (B). <b>EN, FF/OR.</b>	+	-	-	-	+	+	+	-
56. <i>Glyptothorax conirostris</i> (Steindachner) L=12; Torrent catfish (E), Capre (N), Kani tengra (B). <b>NE, FF/OR.</b>	-	-	+	+	-	-	-	-
57. <i>Glyptothorax pectinopterus</i> (Talwar) L=11; River cat (E), Capre, Karray(N), Kani tengra (B). <b>LR-nt, FF/OR.</b>	-	-	-	+	-	-	-	+
58. <i>Gogangra viridescens</i> (Ham.) L=8; Huddah nangra (E), Ganfak (N), Gong tengra (B). <b>LR-nt, FF/OR.</b>	-	-	+	-	-	-	+	+
59. <i>Nangra nangra</i> (Ham.) L=4.5; Kosi nangra (E), Befuni (N), Gong tengra (B). <b>Vu, FF/OR.</b>	-	-	+	+	-	+	-	+
60. <i>Pseudecheneis sulcata</i> (Mc Clelland) L=15; Sucker throat catfish (E), Gotel or Kabre (N). <b>Vu, FF/OR.</b>	+	+	-	-	+	-	+	-
61. <i>Pseudolaguvia shawi</i> (Hora) L=3; Cheetah catfish (E), Kani tengra (B). <b>EN, OR.</b>	-	+	+	+	-	-	-	-
62. <i>Sisor rhabdophorus</i> (Ham. 1822) L=16; Whiptail catfish (E), Bistuiya (N), Chenua, sisor (B). <b>EN, OR.</b>	-	-	-	-	-	+	+	+
<b>Family – Amblycepsidae</b>	-	-	-	<b>1.3</b>	-	-	-	<b>1.7</b>
63. <i>Amblyceps mangois</i> (Ham.) L=7; Scissor tail catfish (E), Baljung (N), Bot-singhi (B). <b>LR-nt, FF/OR.</b>	-	-	-	+	-	-	-	+
<b>Family – Olyridae</b>	-	-	-	-	-	-	-	<b>0.7</b>
64. <i>Olyra longicauda</i> (Mc Clelland) L=8; Himalayan olyra (E), Bot-singhi (B). <b>NE, FF/OR.</b>	-	-	-	-	-	-	-	+
<b>Order – Synbranchiformes</b>	-	<b>0.5</b>	<b>1.2</b>	<b>0.9</b>	-	-	<b>0.5</b>	<b>0.7</b>
<b>Suborder-Mastacembeloidei</b>	-	<b>0.5</b>	<b>1.2</b>	<b>0.9</b>	-	-	<b>0.5</b>	<b>0.7</b>
<b>Family – Mastacembelidae</b>	-	0.5	1.2	0.9	-	-	0.5	0.7
65. <i>Mastacembelus armatus</i> (Lacepede) L=25; Tyre track eel (E), Chusi-bam (N), Bhaim (B). <b>NE, FF/OR.</b>	-	+	+	+	-	-	+	+

\*\*Absent (-), < 5% (+), <10% (++) , above 10% (+++).EN- Endangered, Vu-Vulnerable, LR-nt-Low risk near threatened, LR-lc- Low risk least concern, DD-Data deficient, NE-Not evaluated. FF-Food fish, OR-Ornamental, SF-Sport fish.

## APPENDIX- D

### List of Fish, Distribution, Relative Abundance, Conservation and Other Status of Fish Fauna from the Hill-Stream Relli in Darjeeling Himalaya.

Name of the Species/ Length (L) in cm. / English (E), Nepali (N), Bengali (B) Name.	RR-I	RR-II	RR-III	General & Conservation Status.
<b>Order – Cypriniformes</b>				
<b>Family – Cyprinidae</b>				
<b>Sub-family - Rasborinae</b>				
1. <i>Barilius barna</i> (Hamilton, 1822) L=10; Khoksa, Boroli, Ghol (B); Fakatar, Titer kani faketa (N); Barna baril, Hill trout (E).	++	++	++	FF,OR/LR-nt
2. <i>Barilius bendelisis</i> (Hamilton, 1807) L=12; Joia, Baril (B); Fageta, Guder, Khabati (N); Hamilton's baril(E).	+++	+++	+++	FF, OR/NE
3. <i>Barilius shacra</i> (Hamilton, 1822) L=13; Koksa (B); Faketa, Khabati (N); Shacra baril (E).	-	+	+	FF,OR/LR-nt
4. <i>Barilius vagra</i> (Hamilton, 1822) L=11; Koksa, korang (B); Lam faketa (N) Vagra baril (E).	+	+	+	FF,OR/Vu
5. <i>Devario aequipinnatus</i> (McClelland, 1839) L=13; Chebli (B); Bhitti (N); Giant danio (E).	-	-	+	FF,OR/LR-nt
<b>Sub-family - Garrinae</b>				
6. <i>Crossocheilus latius</i> (Hamilton, 1822) L=15; Kalabata (B); Mate buduna (N); Gangetic latia (E).	-	-	+	FF,OR/NE
7. <i>Garra annandalei</i> (Hora, 1921) L=13; Ghor poia (B); Chucho buduna (N); Annandale Garra (E).	+	+	+	FF,OR/NE
8. <i>Garra gotyla gotyla</i> (Gray, 1830) L=13; Patharchata, Ghor poia (B); Buduna (N); Sucker head, stone roller, Gotyla (E).	+++	+++	+++	FF,OR/Vu
9. <i>Garra lamta</i> (Hamilton, 1822) L=12; Siltokra (B); Buduna (N); Lamta Garra (E).	-	+	+	FF,OR/Vu
<b>Sub-family - Schizothoracinae</b>				
10. <i>Schizothorax progastus</i> (McClelland, 1839) L=40; Chuchhe asala (N), Point nosed snow trout, Dinnawah snowtrout (E)	+	+	-	FF, SF/LR-nt
11. <i>Schizothorax richardsonii</i> (Gray, 1832) L=22; Buche Asala, Dhumke asala (N); Blunt nosed snowtrout, Snowtrout (E),	++	+++	+++	FF, SF/ LR-nt
<b>Sub-family - Cyprininae</b>				
12. <i>Cyprinion semiplotum</i> (McClelland, 1839) L=20; Chepti, Khurpe (N); Bedangi (B); Assamese kingfish (E).	-	-	+	FF, OR/Vu
13. <i>Neolissochilus hexagonolepis</i> (McClelland, 1839) L=29; Bhuluk, Bhorkul (B); Katle (N); Copper or chocolate mahseer (E).	+++	+++	+++	FF, CI/NE
14. <i>Neolissochilus hexastichus</i> (McClelland,	++	+	+	FF, CI/NE

1839) L=50; Bhuluk (B); Katle (N); McClelland's Boker (E).				
<b>Family-Psilorhynchidae</b>				
15. <i>Psilorhynchus sucatio</i> (Hamilton, 1822) L=7; Titari (B); Titae (N); Sucatio minnow or River stone carp (E).	-	-	+	OR/EN
<b>Family-Balitoridae</b>				
<b>Sub-family - Nemacheilinae</b>				
16. <i>Aborichthys elongatus</i> (Hora, 1921) L=8; Bami gadela (N); Wedge tail minnow (E)	++	+	+	OR/EN
17. <i>Acanthocobitis botia</i> (Hamilton, 1822) L=8; Mottled loach, Leopard loach (E); Bilturi, Poia(B); Gadela (N)	-	-	+	OR/LR-nt
18. <i>Nemacheilus devdevi</i> (Hora, 1935) L=3; Olivaceous loach (E); Gadela (N); Poia(B).	++	++	+++	OR/EN
19. <i>Schistura rupecula</i> (McClelland, 1838) L=4; Banded loach(E); Gadela (N); Poia (B).	+	+	+	OR/ LR-nt
20. <i>Schistura multifasciata</i> (Day, 1878) L=7; Many banded loach (E); Gadela (N); Poia (B).	+	+	+	OR/EN
21. <i>Schistura scaturigina</i> (McClelland, 1839) L=6 ; Victory Loach (E); Gadela (N); Dari, Poia (B).	++	++	++	OR/Vu
<b>Family – Cobitidae</b>				
<b>Sub-family - Cobitinae</b>				
22. <i>Canthophrys gongota</i> (Hamilton, 1822) L=8; Gongota loach, Jaguar loach (E); Poia (B); Latai (N).	-	-	+	FF,OR/LR-nt
<b>Order- Siluriformes</b>				
<b>Family – Sisoridae</b>				
23. <i>Parachiloganis hodgarti</i> (Hora, 1923) L=6; Torrent catfish (E); Til- kabri(N).	-	-	+	OR/Vu
24. <i>Glyptothorax cavia</i> (Hamilton, 1822) L=18; Banded torrent catfish (E); Kani tengra (B); Capre (N).	-	-	+	FF, OR/EN
25. <i>Pseudecheneis sulcata</i> (McClelland, 1842) L=16; Sucker throat catfish (E); Gotel, Kabre (N).	+	+	+	FF, OR/Vu

\*FF-Food fish, CI-Commercially important, OR-Ornamental, SF-Sport fish, EN- Endangered, Vu-Vulnerable, LR-nt-Low risk near threatened, NE-Not evaluated. \*\*Absent (-), < 5% (+), <10% (++) , above 10% (+++).

## APPENDIX- E

**Pearson's Correlation Coefficients Matrix for Density and Diversity Indices of Phytoplankton, Zooplankton and Ichthyofana in the Hill-Stream Relli at the three Sites.**

	PDENS	PNOG	PSDI	PEVEN	PRICH	PDOMI	ZDENS	ZNOG	ZSDI	ZEVEN	ZRICH	ZDOMI	FDENS	FPOP	FNOS	FSDI	FEVEN	FRICH	FDOMI
PDENS	1	0.89**	0.77	-0.18	0.73	-0.72	0.91	0.85	0.81	0.19	0.61	-0.75	-0.15	-0.1	-0.1	-0.09	-0.04	-0.06	0.09
PNOG	**	1	0.95	0.07	0.95	-0.92	0.85	0.85	0.87	0.3	0.68	-0.85	-0.02	0	0.04	0.04	-0.07	0.06	-0.03
PSDI	**	**	1	0.32	0.95	-0.98	0.76	0.81	0.86	0.34	0.68	-0.85	0.02	0.01	0.11	0.1	-0.06	0.13	-0.08
PEVEN	x	x	**	1	0.23	-0.4	-0.07	0.04	0.11	0.17	0.18	-0.16	0.08	-0.01	0.14	0.11	0	0.12	-0.08
PRICH	**	**	**	*	1	-0.94	0.73	0.77	0.82	0.33	0.64	-0.82	0.04	0.06	0.14	0.12	-0.08	0.15	-0.1
PDOMI	**	**	**	**	**	1	-0.7	-0.76	-0.82	-0.35	-0.64	0.84	-0.05	-0.03	-0.15	-0.14	0.07	-0.16	0.11
ZDENS	**	**	**	x	**	**	1	0.92	0.86	0.19	0.69	-0.79	-0.07	-0.06	-0.11	-0.12	-0.04	-0.12	0.13
ZNOG	**	**	**	x	**	**	**	1	0.96	0.41	0.77	-0.89	-0.07	-0.06	-0.03	-0.03	-0.01	-0.01	0.04
ZSDI	**	**	**	x	**	**	**	**	1	0.54	0.76	-0.97	-0.01	-0.01	0.04	0.04	0	0.05	-0.03
ZEVEN	x	**	**	x	**	**	x	**	**	1	0.33	-0.62	-0.04	-0.06	0.08	0.09	0.13	0.13	-0.1
ZRICH	**	**	**	x	**	**	**	**	**	**	1	-0.72	0	-0.08	-0.12	-0.13	-0.03	-0.15	0.12
ZDOMI	**	**	**	x	**	**	**	**	**	**	**	1	-0.03	-0.01	-0.08	-0.09	-0.03	-0.09	0.08
FDENS	x	x	x	x	x	x	x	x	x	x	x	x	1	0.86	0.69	0.65	-0.18	0.44	-0.6
FPOP	x	x	x	x	x	x	x	x	x	x	x	x	**	1	0.64	0.62	-0.2	0.43	-0.59
FNOS	x	x	x	x	x	x	x	x	x	x	x	x	**	**	1	0.97	-0.16	0.94	-0.9
FSDI	x	x	x	x	x	x	x	x	x	x	x	x	**	**	**	1	0	0.93	-0.97
FEVEN	x	x	x	x	x	x	x	x	x	x	x	x	x	*	x	x	1	-0.12	-0.11
FRICH	x	x	x	x	x	x	x	x	x	x	x	x	**	**	**	**	x	1	-0.88
FDOMI	x	x	x	x	x	x	x	x	x	x	x	x	**	**	**	**	x x	**	1

## APPENDIX- F

**Pearson's Correlation Coefficients Matrix for Density and Diversity Indices of Phytoplankton, Zooplankton and Ichthyofana in the River Teesta .**

	DENSP	NOGP	SDIP	EVENP	RICHP	DOMIP	DENSZ	NOGZ	SDIZ	EVENZ	RICHZ	DOMIZ	DENSF	POPF	NOSF	SDIF	EVENF	RICHF	DOMIF
DENSP	1	0.81	0.64	-0.42	0.6	-0.64	0.85	0.77	0.72	0.03	0.58	-0.65	-0.09	-0.09	0.34	0.41	0.18	0.41	-0.41
NOGP	**	1	0.93	-0.1	0.95	-0.87	0.78	0.8	0.76	0.02	0.67	-0.72	-0.08	-0.04	0.47	0.5	0.06	0.56	-0.46
SDIP	**	**	1	0.18	0.94	-0.95	0.7	0.75	0.75	0.09	0.66	-0.73	-0.05	0	0.51	0.53	0.03	0.6	-0.47
EVENP	**	x	x	1	0.07	-0.2	-0.28	-0.22	-0.18	0.13	-0.12	0.11	-0.02	0.03	0.05	0	-0.08	0.07	0.04
RICHP	**	**	**	x	1	-0.88	0.63	0.69	0.67	0.02	0.62	-0.65	-0.07	-0.02	0.48	0.49	0	0.57	-0.43
DOMIP	**	**	**	*	**	1	-0.67	-0.74	-0.76	-0.19	-0.66	0.78	0.01	-0.03	-0.52	-0.55	-0.05	-0.59	0.51
DENSZ	**	**	**	**	**	**	1	0.86	0.79	0.04	0.62	-0.72	-0.07	-0.04	0.39	0.43	0.11	0.45	-0.4
NOGZ	**	**	**	*	**	**	**	1	0.96	0.2	0.92	-0.88	0.01	0	0.44	0.48	0.1	0.48	-0.45
SDIZ	**	**	**	x	**	**	**	**	1	0.34	0.92	-0.95	0.04	0.04	0.45	0.5	0.06	0.49	-0.47
EVENZ	x	x	x	x	x	x	x	*	**	1	0.32	-0.5	0.17	0.15	0.21	0.22	-0.06	0.19	-0.22
RICHZ	**	**	**	x	**	**	**	**	**	**	1	-0.86	0.05	0.03	0.39	0.43	0.06	0.43	-0.4
DOMIZ	**	**	**	x	**	**	**	**	**	**	**	1	-0.07	-0.08	-0.47	-0.53	-0.06	-0.5	0.51
DENSF	x	x	x	x	x	x	x	x	x	x	x	x	1	0.88	0.59	0.44	-0.24	0.35	-0.33
POPF	x	x	x	x	x	x	x	x	x	x	x	x	**	1	0.53	0.37	-0.3	0.32	-0.26
NOSF	**	**	**	x	**	**	**	**	**	x	**	**	**	**	1	0.94	0.15	0.94	-0.82
SDIF	**	**	**	x	**	**	**	**	**	x	**	**	**	**	**	1	0.4	0.93	-0.95
EVENF	x	x	x	x	x	x	x	x	x	x	x	x	x	**	x	**	1	0.23	-0.56
RICHF	**	**	**	x	**	**	**	**	**	x	**	**	**	**	**	**	*	1	-0.82
DOMIF	**	**	**	x	**	**	**	**	**	x	**	**	**	**	**	**	**	**	1



## Impact of fishing methods on conservation of ichthyofauna of river Relli in Darjeeling Himalaya of West Bengal

Manik L. Acharjee<sup>1</sup> and Sudip Barat\*<sup>2</sup>

<sup>1</sup>Department of Zoology, Kalimpong College, Darjeeling - 734 301, India

<sup>2</sup>Aquaculture and Limnology Laboratory, Department of Zoology, University of North Bengal, Darjeeling, Siliguri - 734 013, India

(Received: October 30, 2008; Revised received: February 10, 2009; Accepted: March 02, 2009)

**Abstract:** Impact of fishing methods and gears used on fish faunal diversity in spring-fed torrential river Relli in Darjeeling hill area of West Bengal was investigated in the present study. The fish species available in the river provide nutrition and recreation (rarely income generating) for a large number of people residing along the river bank and nearby villages and towns. The fishing methods observed therein have been categorized as, i) Scientific fishing methods, that is, collection of required number and size of fish so that sufficient population of fish remains balanced in the nature. ii) Unscientific fishing methods, that is, indiscriminate killing of large number of fish which adversely affect the water quality of rivers. Ten types of fishing methods are practiced in this area, for example, diversion of river channel, cast netting, scoop netting, angling, fish spearing, rock striking or hammering, dynamiting, electric fishing, river poisoning and traps utilized. Over the years uncontrolled and often indiscriminate fishing in the unmanaged hill-stream has resulted in a sharp decline in fish resources. The study gives a clear picture on the anthropogenic pressure on the river Relli and provides baseline data which may be helpful for conservation and management of the fish species and also formulating new fishery policy.

**Key words:** Fishing methods, Fish conservation, Hill-stream, Darjeeling Himalaya  
PDF of full length paper is available online

### Introduction

Darjeeling Himalaya is the hilly and Himalayan part of the northernmost Darjeeling district of West Bengal. The hill streams of Darjeeling Himalayan river system are known for their rich ichthyofaunal diversity and richness. There are more than 125 species of fishes in the Darjeeling district (Dash, 1947). Barat *et al.* (2005) mentioned only 21 species of fishes in Darjeeling Himalaya but, according to Rao (2006) there are more than 60 species of fishes. The ichthyodiversity of this region is unique from the zoogeographical point of view. The fish fauna represents mostly the Chinese, Malayan and Indian elements of fishes of the Oriental realm (Sen and Biswas, 2006). But, this region with rich biodiversity is under immediate threat of species extinction and habitat destruction due to tremendous pressure from demotechnic growth and natural environmental changes. All the rivers are more or less impacted because of high population growth, construction of highways, roads, bridges, dams, destruction of riparian vegetation and watershed forest cover, denudation causing high siltation, boulder and sand lifting, landslides, disposal of untreated sewages, indiscriminate use of pesticides and fertilizer in agricultural practices, altered land use pattern, rampant fishing and so on. Several workers like, Jhingran and Sehgal (1978), Uniyal *et al.* (2002) and Srivastava *et al.* (2002), have mentioned that illegal fishing methods used in the Himalayan rivers cause a decline in the fish population. In Darjeeling Himalaya, Mukherjee *et al.* (2002) and Sen and Biswas (2006), have pointed out that unfair practices used to catch fishes in this region cause wanton destruction of fish diversity.

There is no detailed study of the fishing method and implements used in Darjeeling Himalayan river system. This investigation was therefore undertaken in the Relli river, a spring-fed torrential left hand tributary of mighty river Teesta, to provide information on the anthropogenic pressure on the river, and useful baseline data for ichthyofaunal conservation, management and fishery policy formulation.

### Materials and Methods

**Study area:** The river Relli has its origin in the Algarah-Lava ridge of Kalimpong subdivision (Lat. 26°51' to 27° 12' N and Long. 88° 28' to 88°53' E). in the Khampang reserve forest at an altitude of about 1800 m. The total length of the river Relli is about 32 km and joined to the river Teesta at an altitude of about 212 m. The point of joining is situated at 7 km. down from Teesta bazar. The average width of the river varies from 90-150 m. The longitudinal slope of the river is 11 m km<sup>-1</sup>. The slope of the river bank varies from 20 to 90°. During the monsoon the river is quite swift but in dry season it dries down into a small stream. The catchment area of the river is hilly spreading to 165 km<sup>2</sup> and well managed. The soil of catchments is acidic (pH 5 to 6) and carbon content ranges from 0.5 to 1.5%. The soil ranges from sandy loam to clayey loam in texture.

Information on fishing methods and gears were collected through intensive field survey and interaction with local fishermen of this region during the period of 2006-2008. Diversion of river channel, netting, angling, spearing, rock striking and hammering, dynamiting, electro-fishing, river poisoning, *Kur thunnu* traps are some of the methods used in this area (Table 1).

\* Corresponding author: [sudipbarat@rediffmail.com](mailto:sudipbarat@rediffmail.com)

**Table - 1:** Summary on information of fishing methods in river Relli of Darjeeling Himalaya

Fishing method	Description of method	Major species encountered by method	Impact of ichthyofaunal conservation
Division of river channel ( <i>Dealipara</i> or <i>Duwalo thumre</i> )	Here stretches of river or side channel is made dry deflecting the flow of water to the side channel from the main channel or from other side channel by constructing a rough dam, using stones, logs, sand, clay and so on. At the distal end of diverted channel a bamboo-made fish trap ( <i>Dhadiya</i> ) is set to catch the fish escaping from the channel. Sometimes, lime, herbal or chemical poisons are used to paralyze fishes	Small sized bottom-dwelling fishes like, Budhuna ( <i>Garra</i> spp.), Gadela ( <i>Nemacheilus</i> spp.), Fageta ( <i>Barilius</i> spp.), <i>Aborichthyes elongatus</i> and juvenile of Katli ( <i>Neolissocheilus hexagonolepis</i> ), Tor spp. and so on	This method causes wanton destruction of fish fauna of all ages and other aquatic organisms
Cast netting	Cast net is a stringed, bell-shaped, cotton or nylon net. It is thrown in the river to catch fishes. One of the most commonly used cast net in this region is <i>Bhurel/jal</i> which is small in size having a mesh ranging from 0.5 to 1.5 cm and covers an area of about 4.5 m <sup>2</sup> when thrown in the water	Fageta ( <i>Barilius</i> spp.), Gadela ( <i>Nemacheilus</i> spp.), Katli ( <i>Neolissocheilus hexagonolepis</i> ), Asala ( <i>Schizothorax</i> spp.), Budhuna ( <i>Garra</i> spp.), <i>Danio</i> spp., <i>Cyprinion semiptotum</i> , <i>Euchiloglanis hodgarti</i>	Cast netting is generally not a destructive method but netting during breeding season with small mesh sized net causes loss of brood fishes
Scoop netting	Scoop net consists of a rectangular, triangular, round or ellipsoid wooden, metallic or bamboo frame which is supported by a short handle of wood or bamboo. The frame carries an oval mosquito net. Scoop net is generally used in muddy water or in diverted channel of river or during river poisoning, dynamiting, electro-fishing or even angling	Fageta ( <i>Barilius</i> spp.), Budhuna ( <i>Garra</i> spp.), Gadela ( <i>Nemacheilus</i> spp.), <i>Schizothorax richardsonii</i> , <i>Danio</i> spp., <i>Cyprinion semiptotum</i> , Katli ( <i>Neolissocheilus hexagonolepis</i> )	Scoop netting is not itself a destructive method of fishing but, when it is used with other destructive methods, namely, dynamiting, electro-fishing and river diversion it causes wanton killing
Angling	Angling is a popular sport fishing method to harvest cold water fishes with fishing rod. The rod is long, slender and has a slightly curved tip. Fine nylon or cotton thread (line) is tied to the curved tip or rod or sometimes a wheel and a hook is attached at the distal end of the line. Just above the hook there is a sinker made up of lead or stone. Bait usually consists of earthworms, small fishes, insect larvae, grasshopper, fleas and so on	<i>Schizothorax richardsonii</i> , <i>Schizothoracichthyes progastus</i> , Katli ( <i>Neolissocheilus hexagonolepis</i> ), Tor spp.	The method is not considered destructive
Spearing	A spear fixed at the tip of a bamboo or wooden handle is operated mostly by children at the crevices of stones and rocks when water level becomes low	<i>Aborichthyes elongatus</i> , Gadela ( <i>Nemacheilus</i> spp.), Budhuna ( <i>Garra</i> spp.), Kabre ( <i>Pseudecheneis sulcatus</i> )	The method is not considered destructive
Rock-striking or Hammering	Large and flat rocks are selected in the shallow waters on which a weighty iron hammer is struck with full force. The intensive vibration and sound thus produced impairs the acoustico-lateralis system of the fish and results in both large and small fishes to float on the water surface. These paralyzed fishes are thus caught with bare hands or scoop nets	Juvenile fishes of mainly Gadela ( <i>Nemacheilus</i> spp.), Budhuna ( <i>Garra</i> spp.), Asala ( <i>Schizothorax</i> spp.), Fageta ( <i>Barilius</i> spp.), Tor spp. and Katli ( <i>Neolissocheilus hexagonolepis</i> )	Destructive method causing indiscriminate killing of fishes of all ages hiding under the rocks
Electro-fishing	Fishes are caught by passing an electric current via electrodes (anode and cathode) from generator or 12V battery to the river water. Stunned fishes become disoriented and are easily captured by hand or scoop net	Fageta ( <i>Barilius</i> spp.), Budhuna ( <i>Garra</i> spp.), Gadela ( <i>Nemacheilus</i> spp.), juvenile Katli ( <i>Neolissocheilus hexagonolepis</i> ) and juvenile Asala ( <i>Schizothorax</i> spp.)	Mass killing of fishes of all ages

River poisoning	A stretch of river is poisoned by using toxic plant extracts like Khirro ( <i>Sapium</i> spp.), fruits of Maidai plant ( <i>Erythrina arborescens</i> ), bark of Kafal ( <i>Myrica esculanta</i> ), stem of Arare creepers ( <i>Acacia</i> sp.), stem of Siudi ( <i>Euphorbia</i> spp.), Powdered seed of <i>Xanthoxylon</i> sp., Derris root powder - rotenone being the active ingredient, and leaf extract of Tipati ( <i>Artemesia</i> sp.)	Nearly all types of fishes and other aquatic organisms	Causes wanton destruction of aquatic life and pollutes the water
Kurthunnu	A big rock is selected at the side of river channel where water flows slowly. The rock is closed on all sides by making a rough dam with stones, sand, clay and plant materials leaving a small outlet in which <i>Dhadiya</i> is placed. The fishes are now caught by hammering the rock or using ichthyotoxic plant extracts	All major types of fishes are caught	A destructive method causing wanton destruction of fish fauna hiding under the rocks
Tip (a trap)	This is a large sized trap made up of bamboo splits, the mouth of which is broad and flat. The distal narrow end is covered with fine mosquito netting a bag-like appearance in which fishes are harvested. The length of the trap is about 3 to 3.5 m with an opening of diameter 2 to 2.5 m. The conical trap is placed in a suitable place in the river channel and all the water is forced to flow through the trap by constructing a rough dam, using stones, logs and sand. Fishes are mostly trapped at night	Fishes like Fageta ( <i>Barilius</i> spp.), Budhuna ( <i>Garra</i> spp.), Gadeia ( <i>Nemacheilus</i> spp.), Kati ( <i>Neolissocheilus hexagonolepis</i> ), Asala ( <i>Schizothorax</i> spp.), Kabre ( <i>Pseudecheneis sulcatus</i> ), Chepti ( <i>Semiplotus semiplotus</i> ) and others	A destructive method causing wanton destruction of fish fauna
Thokre (a trap)	A relatively small sized trap fabricated from splits of a single piece of bamboo having a node and internodes and splits are tied together giving a cone-shaped appearance. Several traps are placed side by side following the same principal as in the case of Tip. Several such rows of <i>Thokre</i> are placed in the river channel at about 50-100 m intervals	Fishes like Fageta ( <i>Barilius</i> spp.), Budhuna ( <i>Garra</i> spp.), Gadeia ( <i>Nemacheilus</i> spp.), Kati ( <i>Neolissocheilus hexagonolepis</i> ), Asala ( <i>Schizothorax</i> spp.), Kabre ( <i>Pseudecheneis sulcatus</i> ), Chepti ( <i>Semiplotus semiplotus</i> ) and others	The method causes wanton destruction of fishes
Thali (a trap)	A big metallic bowl or rice plate is covered with a thin cloth and tied. A small hole is made at the centre of the cloth. Some rice or flour is kept in the bowl or plate and the trap is placed in the river water. Fishes enter into the trap to eat rice or flour. After sometime the trap is taken out of water and trapped small fishes are collected	Fageta ( <i>Barilius</i> spp.), Gadeia ( <i>Nemacheilus</i> spp.) and juvenile forms of other fishes namely, Kati ( <i>Neolissocheilus hexagonolepis</i> ), Asala ( <i>Schizothorax</i> spp.) and so on	A destructive method causing wanton destruction of fishes

## Results and Discussion

The above observations based on critical study of different fishing methods used in the river Relli and their impacts revealed, that the observed fishing methods can be classified into two categories, namely, (a) Scientific fishing method, that is, collection of required number and size of fish so that sufficient population of fish remain balanced in the nature, examples being, cast netting and angling (Table 1) (b) Unscientific fishing method, involves indiscriminate killing of large number of fish (juvenile, as well as, brood fish) which adversely affects the water quality of rivers, for example, (1) Dynamiting, (2) Electro-fishing, (3) Hammering, (4) River poisoning and (5) Diversion of river channel (Table 1).

The different fishing methods used in river Relli in different seasons show the patterns of fish migration. Upward spawning migration of some cold water brood fish like, Katli (*Neolissocheilus hexagonolepis*), commences from the last week of February and continues through the months of March, April and May. The spawning and breeding season lasts from June to September (Barat *et al.*, 2005). The monsoon begins to recede from September and most of the fishes begin their downward migration to return to their winter habitat in the deep pools of either river Relli or Teesta. This downward migration of juveniles and adults continues through the month of September to first week of November. During the winter months namely, November, December and January most of the fishes lie in the deep pools (Sen and Biswas, 2006).

Cast net is used almost throughout the year but the catch is maximum (10-12 fishes/effort) during rainy season, when the river bed is flooded and fishes show horizontal migration to breeding sites. Fishing with small nets in torrential hill-stream is a laborious process with very poor catches. During upward and downward migration and also during monsoon, angling is mostly done by the people as a sport fishery (Sen and Biswas, 2006). Traps, like Tip and Thokre, are used during downward migration of fishes (September to November) thus, most of the juvenile and adult fishes are killed. Hammering, dynamiting, river channel diverting, river poisoning, and electro-fishing are used mainly during winter months in the pools of the river causing indiscriminate killing of fishes. Electro-fishing and dynamiting are adopted mainly by picnickers (Sen and Biswas, 2006).

The use of dynamites and poisoning of water by toxic plants have been considered else-where, too, to be very destructive methods of catching fish. Bombs consisting of a detonator, match-head and safety fuse inserted in an explosive (usually Amatol) tied up in a polythene bag with rock are made into a package and then used for fish bombing in Hong Kong (O'Brien, 1997).

Use of five local fish plants have been listed as fish poisons in China and Taiwan (Ho, 1981). The fish poison is derived from rotenone, an active ingredient, of the Derris root that affects the ability of the fish to take up oxygen, causing them to become narcotized and easy to collect (UNEP, 1994).

Over the years uncontrolled and often indiscriminate fishing in the largely unmanaged Relli river has resulted in a sharp decline in catches of the important sport and subsistence fish.

It may be concluded, that gene pool of unique ichthyofauna in Darjeeling Himalaya is a valuable endowment of nature. The aquatic resources and fish germplasm are our national wealth which has co-evolved during the course of evolution. Any species getting extinct would upset the ecological balance resulting in dangerous imbalance of the system. Thus, the use of destructive methods of fishing calls for formation of task force, strict vigilance, stopping illegal fishing and effective enforcement of legislative measures such as, closed season, mesh size regulation and awareness of the local people residing along the river bank. The involvement of voluntary organizations, local clubs, self-help groups, is urgently needed in an effort to maintain fish stocks at a healthy level. Cornish and McKellar (1998) opined, educating the local communities on the destructive effects of the practices and making them more vigilant and responsible for controlling them would be more effective. The stocks should be enhanced through regular release of hatchery produced fingerling.

## References

- Barat, S., P. Jha and R.F. Lepcha: Bionomics and cultural prospects of Katli, *Neolissocheilus hexagonolepis* (McClelland) in Darjeeling district of West Bengal. *In: Coldwater fisheries research and development in north-east region of India* (Eds.: B. Tyagi, Shyam Sunder and M. Mohun). NRCCWF, Bhimtal. Vikrant Computers, Haldwani. pp. 66-69 (2005).
- Cornish, A.S. and D. McKellar: A history of fishing with explosives and poisons in Hong Kong waters. *Naga, the Iclarm Quarterly*, 21, 4-9 (1998).
- Dash, A.J.: Darjeeling District Gazetteer. West Bengal Government Publication. Calcutta (1947).
- Ho, M.H.: Hong Kong poisonous plants. Urban Council, Hong Kong (1981).
- Jhingran, V.G. and K.L. Sehgal: Coldwater Fisheries of India. Inland Fisheries Society of India, Barrackpore, West Bengal, India (1978).
- Mukherjee, M., R.F. Lepcha and A. Biswas: Aquatic Biodiversity Restoration Programme in Terai region of West Bengal through induced breeding and proper extension methods. *In: Abstract Proceedings, National Seminar on Aquatic Resource Management in Hills, National Research Centre on Cold Water Fisheries (ICAR), Nainital*. p. 17 (2002).
- O'Brien, D.W.F.: Fish bombing in Hong Kong – investigation and detection. *In: Proceedings of the First International Symposium on Marine Conservation, October 1996, Hong Kong*. Hong Kong Marine Conservation Society. pp. 68-78 (1997).
- Rao, A.A.: Indigenous cold water fish potential for ornamental fish exports. *In: Proceedings of State Level Seminar on Prospects and Potentialities of Cold Water Fisheries in West Bengal* jointly organized by Department of Fisheries, Aquaculture, Aquatic resources and Fishing harbours, Government of West Bengal and Department of Zoology, University of North Bengal, Siliguri. pp. 50-54 (2006).
- Sen, P.K. and S.N. Biswas: Development strategies of cold water fisheries in Darjeeling hill areas of West Bengal. *In: Proceedings of State Level Seminar on Prospects and Potentialities of Cold Water Fisheries in West Bengal* jointly organized by Department of Fisheries, Aquaculture, Aquatic resources, and Fishing harbours, Government of West Bengal and Department of Zoology, University of North Bengal, Siliguri. pp. 24-48 (2006).
- Srivastava, S.K, U.K. Sarkar and R.S. Patiyal: Fishing methods in streams of the Kumaon Himalayan region of India. *Asian Fish. Sci.*, 15, 347-356 (2002).
- UNEP: United Nations Environment Programme. *In: Staff training materials for the management of marine protected areas* (Eds.: R. Kenchington and K.L. Ch'ng). RCU/EAS Technical Reports Series No. 4. pp. 216-220 (1994).
- Uniyal, D.U., S.N. Bahuguna, A. Kumar and M.B. Uniyal: Fishing Methods- an important tool for fish conservation and management : A case study in Doon Valley, Uttaranchal. *In: Abstract Proceedings, National Seminar on Aquatic Resource Management in Hills, National Research Centre on Cold Water Fisheries (ICAR), Nainital*. p. 68 (2002).



## DIVERSITY OF LOACH AND CATFISH IN A DARJEELING HIMALAYAN HILL-STREAM – THEIR PROSPECTS AS ORNAMENTAL FISH AND CONSTRAINTS

Manik Lal Acharjee<sup>1\*</sup> and Sudip Barat<sup>2</sup>

<sup>1</sup>Department of Zoology, Kalimpong College, Darjeeling-734301, West Bengal, INDIA.

<sup>2</sup>Aquaculture & Limnology Research Unit, Department of Zoology, University of North Bengal, District-Darjeeling-734013, West Bengal, INDIA.

Received: August 30, 2012

Accepted: December 6, 2012

### ABSTRACT:

Fishes belonging to the families Balitoridae and Cobitidae are “Loaches” and siluroid fishes belonging to order Siluriformes are called “catfishes” in popular parlance. The loaches and catfishes form two important groups having good potential as aquarium fish due to their colouration, bright bands, blotches, shapes, nature, hardiness, compatibility, and small body size for which they can be reared in aquarium. Streams of Darjeeling Himalayan upland form a very rich and dynamic resource of high altitude fisheries, where cold water fishes abound. The present study was carried out in the Darjeeling Himalayan hill-stream Relli, in order to examine the diversity of loach and catfish, their prospects as ornamental fish and constraints in respect to conservation. There are 7 loach species belonging to 5 genera and 3 catfish species under 3 genera. Some species are already popular among the traders and hobbyists both locally and globally by specific trade name. The highly priced native ornamental fish resources especially loaches provide the region an ample scope for foreign exchange earnings through long term planning, conservation and judicious use of the germplasm.

**Key words:** Darjeeling Himalaya, Hill-stream, Loaches, catfish, Ornamental fish, Ichthyodiversity.

### INTRODUCTION

Small fishes having aesthetic value are known as ornamental fish. The most important characteristic feature of these fishes is their body coloration and body pigmentation. Dey (1996) defined ornamental fish as attractive and colourful fish of peaceful nature that can be kept as pets in confined spaces of an aquarium or a garden pool with the purpose of enjoying their beauty for fun and fancy. The soothing effect of aquariums in helping to relieve some of the pressures of modern urban life have helped, in part, to make ornamental fish keeping a popular pastime and an important commercial activity. Fish keeping is today the world’s most popular hobby after photography and ornamental fish are the most popular pets in the world (Singh, 2005). As such, production of ornamental fish for the aquarium hobbyist trade is rapidly increasing. Fishes belong

to the families Balitoridae and Cobitidae are popularly called “Loaches” which form an important group having good potential as a classified aquarium fish due to their small size, bright bands, blotches, colouration, peaceful nature, hardiness, compatibility, and which can be reared in aquarium throughout their life span. Siluroid fishes belong to order Siluriformes are called “catfishes” in popular parlance. Small sized catfishes with beautiful colouration, blotches, shapes, and hardiness also have immense potential as ornamental aquarium fish. Some species like Scissor tail catfish (*Amblyceps mangois*), Torrent catfish (*Parachiloglanis hodgarti*), Copper catfish (*Glyptothorax telchitta*), Long fighting catfish (*Olyra longicauda*) etc. are already popular among the traders and hobbyists both locally and globally by specific trade name.

---

\*Author for correspondence: Manik Lal Acharjee (manik\_kpg@rediffmail.com)

Darjeeling Himalaya, as it popularly known, is the hilly Himalayan part of the northern most Darjeeling district of Indian state of West Bengal. The district lies between 27°13' 05" and 26°17' 10" North latitude and between 88° 53' 00" and 87° 59' 30" East longitude. Like other parts of Himalaya, rivers and streams of Darjeeling Himalayan upland forming a very rich and dynamic resource of high altitude fisheries, where cold water fishes abound. Being the integral part of the eastern Himalaya the region is regarded as freshwater biodiversity hotspot (Kottelat and Whitten, 1996). The ichthyodiversity of this region is unique from the zoogeographical point of view. The fish fauna represents mostly the Chinese, Malayan and Indian elements of fishes of the Oriental realm (Hora and Gupta, 1940). The important contributors on North Bengal fresh water fish fauna are Shaw and Shebbeare (1937), Hora (1945, 1947), Hora and Gupta (1940), Sen (1992), Jha *et al.* (2005) and Sarkar and Pal (2008), Chakraborty and Bhattacharjee (2008), Patra (2011). The present study was carried out in the Darjeeling Himalayan hill-stream Relli, a spring-fed, sub-tropical, torrential and relatively undisturbed left hand tributary of the river in order to examine the

diversity of loach and catfish, their prospects as ornamental fish and constraints.

#### MATERIALS AND METHODS:

**Study area:** The hill stream Relli has its origin in the Algarah-Lava ridge of Kalimpong subdivision (Lat. 26° 51' to 27° 12' N and Long. 88° 28' to 88° 53' E) of Darjeeling district in the Khampang reserve forest at an altitude of about 1800 meter. The total length of the stream Relli is about 32 km and joined to the river Teesta at an altitude of about 212 m. The point of joining is situated at 7 km. down from Teesta bazaar (Fig.1). The average width of the stream bed varies from 90-150m. The longitudinal slope of the stream is 11m.km<sup>-1</sup>. The slope of the stream bank varies from 20 to 90°. During the monsoon the stream is quite swift but in dry season it dries down into a small stream. The catchment area of the stream is 165 km<sup>2</sup> and the catchment is hilly and well managed. In the present investigation, three sampling stations (RR-I, RR-II and RR-III) were selected for the collection of water samples and fishes. Physical characteristics and channel morphology and descriptions of sampling sites are depicted in Table I.

**Table I:** Physical characteristics and channel morphology in the sampling sites of River Relli

Sampling sites	Channel width (m).	Stream depth (m).	Habitat	Substrate	Longitude/ Latitude	Altitude (m)	Riparian vegetation
RR-I	7.81	0.52	Shallow pool, Riffles, Runs, Side channel.	Sand, Gravels, Boulders and bedrocks	88°34'34"E /27°05'43" N	704	Trees, shrubs, Grasses
RR-II	9.79	0.43	Shallow pool, Riffles, Runs, Side channel.	Sand, Gravels, Boulders and bedrocks	88°31'44"E /27°02'40" N	566	Trees, shrubs, Moderate encroachment
RR-III	13.12	0.61	Shallow pool, Riffles, Runs, Side channel.	Sand, Gravels, Boulders and bedrocks	88°29'25"E /27°01'39" N	340	Trees, shrubs, Grasses



**Figure 1.** Map showing study area and sampling sites (Courtesy- Google Earth).

**RR-I:** The site is located at a distance of 10 km from the origin, and near the confluence with *Payong khola*. The site is almost out of any kind of disturbance except fishing. **RR-II:** The site is located at a distance of 6 km from RR-1, and near the confluence with *Pala khola*. Several activities like extraction of building materials, fishing and car washing had been practiced here. It is a famous picnic spot. **RR-III:** The site is located at a distance of 8 km from RR-2, and near the confluence with *Khoni khola*. This is also a least disturbed site with little fishing activities.

#### **Fish sampling:**

Monthly sampling was carried out for two

years (from March 2007 to February 2009) in the stream at all sampling sites with the help of fishermen or local people who used to catch fish in this region. Cast net (*Bhureli jal*) which is small in size ( $r = 1.2\text{m}$ ; weigh about 5kg) having a mesh ranging from 0.5 to 1.5 cm with an average 1.0 cm and covers an area of about 4.5 m<sup>2</sup> and rock-striking method were mainly used to catch fish. Other gears and methods like scoop net, hook and line, various traps (*Dhadiya, tip, thokre and thali trap*), electro-fishing, water diversion, was also followed as and when available. The fishes caught were examined for their morphological features, colour bands or spots present on the body and these were recorded in the field along with their length and weight. Photographs

were taken by digital compact camera (Nikon, coolpix L10). Two specimens of each species were taken for identification and their species were ascertained on the basis of their morphometric characters and meristic counts following the criteria given by Shaw and Shebbeare (1937), Jhingran and Sehgal (1978), Tilak (1987), Menon (1987), Talwar and Jhingran (1991), Menon (1992), Sen (1992), Tekriwal and Rao (1999), Nath and Dey (2000), Daniels (2002), Jayaram (2009), and Srivastava (2010).

## RESULTS AND DISCUSSION

10 species of loach and catfish were recorded from the hill-stream and these belong to 3 families and 8 genera (Table II). Maximum number of species recorded were of family Balitoridae (6 species), followed by family Sisoridae (3 species), and Cobitidae (1 species). 6 species were found at all sites (Table II). Species like *Acanthocobitis botia*, *Canthophrys gongota*, *Parachilognan hodgarti* and *Glyptothorax cavia*, which are mostly found in river Teesta were recorded only in site RR- III. Bisht *et al.* (2009) reported similar overlapping of fish habitat in Dangchaura (Takoli) Gad upto the distance of 15 km from its confluence with Alaknanda in Garhwal Himalaya. Two species such as *Nemacheilus devdevi* (9.8%) and *Schistura scaturigina* (5.8%) were dominant (>5%) loach and endemic to India (Molur and Walker, 1998). Other loaches and catfishes have very low abundance (<5%). Of the 10 species all are considered as ornamental fish, 3 species are as food fish. References to conservation status categories within this paper are based on IUCN classification as per report of CAMP workshops (Molur and Walker, 1998). Thus, out of recorded species, 3 endangered (EN), 4 vulnerable (Vu), and 3 are as Low Risk near threatened (LR-nt). This categorization may be useful for planning conservation strategies for genetic resources of ichthyofauna.

It is evident from the present investigation that the ichthyofaunal composition of 14 km stretch (altitudinal variations 704 to 340 m asl) was

represented mostly by rheophilic, cold water hill stream species and has sufficient similarity with cold water species of Nepal, Sikkim, Bhutan, Assam and other parts of Indian Himalaya. Fast flowing stream, Relli calls for a special modification of the fish fauna. The individual modification is chiefly manifested in being small sized and development of structure of adhesion. Winemiller *et al.* (2008) has also discussed similar adaptation of fish of high altitude streams. He also mentioned another ecomorphological syndrome observed in fishes inhabiting high elevation streams is body elongation and fossorial behaviour. This syndrome is observed in loaches *eg.* *Canthophrys gongota*, *Aborichthys elongatus*, *Acanthocobitis botia* etc. 6 species of loaches belonging to the subfamily Nemacheilinae (Cylindrical Loaches) were found among the stones and pebbles at the bottom of the shallow, clear and swift stream Relli. Environmental conditions tend to produce similar characters and it is probable that the great resemblance between the various species of nemacheilids is due to a similarity in their environment (Rao, 2006). The family Cobitidae is popularly known as 'Spined Loaches'. They are bottom dwellers, mostly of small sizes and are found mainly in streams, rivers and lakes of hilly areas (Tekriwal and Rao, 1999). One species of 'Blunt Faced Loaches' which belong to the subfamily Cobitinae were found in this region. *Canthophrys gongota* (Jaguar or Moose Faced Loach) is very odd-looking fish which inhabit in sandy or muddy bottom of streams. In the present study 3 species of Sisorid Catfishes belong to the exclusively Asian family Sisoridae were recorded. Which are bottom dwelling with more or less thickened leathery skins, adhesive organs (labial or thoracic) with which they cling to the substrate of high gradient mountain streams (Rao, 2006). Thus, loaches and catfishes of the hill stream forms three major groups: a) fish sheltering among pebbles and shingles in shallows, with special attachment devices: the loaches, *Nemacheilus devdevi*, *Schistura spp*, *Canthophrys gongota*, *Aborichthys elongatus*, *Acanthocobitis botia*; b) fish which cling to exposed surface of bare rocks in slower current, with

**Table II:** Occurrence, distribution, relative abundance, local name and other status of loaches and catfish species at the sampling sites of Relli River during the study period.

Name of the Species/ Length (L) in cm. / English (E), Nepali (N), Bengali (B) Name.	RR-I	RR-II	RR-III	General & Conservation Status.
Order – Cypriniformes				
Family – Balitoridae				
Sub-family - Nemacheilinae				
1. <i>Aborichthys elongatus</i> (Hora, 1921) L=8; Bami gadela (N); Wedge tail minnow (E)	++	+	+	OR/EN
2. <i>Acanthocobitis botia</i> (Hamilton, 1822) L=8; Mottled loach, Leopard loach (E); Bilturi, Poia(B); Gadela (N)	-	-	+	OR/LR-nt
3. <i>Nemacheilus devdevi</i> (Hora, 1935) L=3; Olivaceous loach (E); Gadela (N); Poia(B).	++	++	+++	OR/EN
4. <i>Schistura rupecula</i> (McClelland, 1838) L=4; Banded loach(E); Gadela (N); Poia (B).	+	+	+	OR/ LR-nt
5. <i>Schistura multifasciata</i> (Day, 1878) L=7; Many banded loach (E); Gadela (N); Poia (B).	+	+	+	OR/VU
6. <i>Schistura scaturigina</i> (McClelland, 1839) L=6 ; Loach (E); Gadela (N); Dari, Poia (B).	++	++	++	OR/VU
Family – Cobitidae				
Sub-family - Cobitinae				
7. <i>Canthophrys gongota</i> (Hamilton, 1822) L=8; Gongota loach, Jaguar loach (E); Poia (B); Latai (N).	-	-	+	FF,OR/LR-nt
Order- Siluriformes				
Family – Sisoridae				
8. <i>Parachilognis hodgarti</i> (Hora, 1923) L=6; Torrent catfish (E); Til- kabri(N).	-	-	+	OR/VU
9. <i>Glyptothorax cavia</i> (Hamilton, 1822) L=18; Banded torrent catfish (E); Kani tengra (B); Capre (N).	-	-	+	FF, OR/EN
10. <i>Pseudecheneis sulcata</i> (McClelland, 1842) L=16; Sucker throat catfish (E); Gotel, Kabre (N).	+	+	+	FF, OR/VU

adhesive organs on their ventral surface for attachment to rocks: *Glyptothorax cavia*, *Pseudecheneis sulcata*; and c) fish which cling to

the exposed surfaces of bare rocks in fast current, with limpet shaped bodies and mouth, gills and fins highly modified to suit the habitat: *Parachilognis*

*hodgarti*. The stream has pool-run-riffle geomorphology, high substrate diversity (Bedrock, cobble, gravel, sand and terrestrial litter), and the stream is subjected to seasonal discharge variation, including periodic spates and flash-floods during the wet season. The present study revealed that Small fish and fry of fish species such as *Nemacheilus devdevi*, and *Schistura spp* etc. were found in side pools. *Nemacheilus devdevi*, *Schistura spp*, *Aborichthyes elongatus* were generally abundant in riffle type microhabitat and found below stones.

The people of this region generally do not consider loaches and small catfishes as food fish so are neglected but these fishes fetch good price in the ornamental fish market. Ornamental fishes, popularly known as 'aquarium fish', or 'live jewel', are exported to 27 countries, which amounted to 2568 Mt (0.86 per cent of the total marine export) in terms of quantity and US\$14 million (0.50 per cent of total marine export) in terms of value (MPEDA, 2007). Though in terms of percentage share to total quantity and value these figures are small, the growth potential of this sector is quite encouraging. During 2005-06, the export of aquarium fish recorded an increase of 14 per cent in quantity and 22 per cent in value, as compared to those in the preceding year. The entire supply of Indian ornamental fish is primarily dependent on wild catch (85 per cent) and a few artificially bred varieties (15 per cent) of exotic fish (Swaine *et al.* 2003; Mukherjee 2004). Among the wild catch fishes exported from the country, West Bengal and the North-Eastern states are the major contributors (Mahapatra *et al.* 2006). Capture based export is not sustainable in ornamental fish trade because species are being harvested at greater volumes and fetching higher rates, threatening the viability or sustainability of this fishery across various parts of the world (Vagelli and Erdmann, 2002; Cato and Brown, 2003; Lunn and Moreau, 2004). Moreover, the fishes are collected from the wild habitat by local fishermen and the marketed by traders who actually control the activities. The most prevailing marketing channel of ornamental fish marketing was: collectors – unregistered small traders – wholesalers –

exporters at various ports. Estimation showed that exporter enjoyed the lion's share of profit (45 per cent), followed by wholesaler (30 per cent), unorganized trader (20 per cent), and a meagre share of 5 per cent was realized by the collectors (Mahapatra *et al.* 2006). This pattern of profit-sharing indicated that the benefit of this industry was distributed unequally, depriving the farmers or collectors heavily. This could be improved by providing pertinent training to the interested farmers on captive breeding and rearing of ornamental fishes and providing incentives and assistance to them to create basic infrastructure for a fishery unit (Mandal *et al.* 2007). Breeding and farming of ornamental fish requires very little space, the same can be done even in the backyard of houses. This would enable even women to look after the culture and involve them in this business.

## CONCLUSION

The region with rich *ichthyodiversity* is under immediate threat of species extinction and habitat destruction due to tremendous pressure from demotechnic growth and natural environmental changes. All the rivers, streams and other water bodies are more or less impacted because of high population growth, construction of highways, roads, bridges, dams, destruction of riparian vegetation and watershed forest cover, denudation causing high siltation, boulder and sand lifting, landslides, disposal of untreated sewages, indiscriminate use of pesticides and fertilizer in agricultural practices, altered land use pattern, rampant fishing and so on. Several workers like, Jhingran and Sehgal (1978), Acharjee and Barat (2010) have mentioned that illegal fishing methods used in the Himalayan rivers cause a decline in the fish population.

It may be concluded, that gene pool of unique ichthyofauna in Darjeeling Himalaya and adjoining areas is a valuable endowment of nature. The aquatic resources and fish germplasm are our national wealth which has co-evolved during the course of evolution. Any species getting extinct would upset the ecological balance resulting in dangerous imbalance of the system (Das and

Chakrabarty 2007). Thus, the use of destructive methods of fishing calls for formation of task force, strict vigilance, stopping illegal fishing and effective enforcement of legislative measures such as, closed season, mesh size regulation and awareness of the local people residing along the river bank. The involvement of voluntary organizations, local clubs, self-help groups, is urgently needed in an effort to maintain fish stocks at a healthy level. Cornish and McKellar (1998) opined, educating the local communities on the destructive effects of the

practices and making them more vigilant and responsible for controlling them would be more effective. The stocks should be enhanced through regular release of hatchery produced fingerling especially of fishes with ornamental value and having endangered and vulnerable status. Thus, through long term planning, conservation and judicious use of the germplasm, the highly priced native ornamental fish resources especially loaches and catfishes may provide the region an ample scope for foreign exchange earnings.

## REFERENCES

- Acharjee, M. L. & Barat, S.** 2010. Impact of fishing methods on conservation of ichthyofauna of river Relli in Darjeeling Himalaya of West Bengal. *J. of Env. Biol.* 31(4): 431-434.
- Bisht, B., Badoni, A. K. & Bahuguna, S. N.** 2009. Seasonal distribution and relative abundance of fish fauna of a small hill-stream Dangchaura (Takoli) Gad, along the river Alaknanda. *Our Nature* 7: 182-186.
- Cato, J.C. & Brown, C.L.** 2003. Marine Ornamental Species: Collection, Culture, and Conservation. Ames, IA: Iowa State Press.
- Chakraborty, T. & Bhattacharjee, S.** 2008. The Ichthyofaunal Diversity in the Freshwater Rivers of South Dinajpur District of West Bengal, India. *J. Bombay Nat. Hist. Soc.* 105(3): 292-298.
- Cornish, A.S. & McKellar, D.** 1998. A history of fishing with explosives and poisons in Hong Kong waters. *Naga, ICLARM Quart.* 21: 4-9.
- Daniels, R. J. R.** 2002. Freshwater Fishes of Peninsular India. Universities Press (India) Private Limited. pp. 288.
- Das, S. K., & Chakrabarty, D.** 2007. The use of fish community structure as a measure of ecological degradation: a case study in two rivers of India. *Bio. Syst.* 90:188-196.
- Dey, V. K.** 1996. *Ornamental Fishes: Handbook of Aquafarming*. In The Marine Products Export Development Authority, eds. R. Froese and D. Pauly, Kochi, *FishBase*. World Wide Web electronic publication. www.fishbase.org, version (08/2012).
- Hora, S. L. & Gupta, J. C.** 1940. On a Collection of Fish from Kalimpong Duars and Siliguri Terai, Northern Bengal. *J. Royal Asiatic Soc. Bengal (Science)* VI(8): 77-83.
- Hora, S. L.** 1945. Fishes of Bengal. *Ind. Fmg. Delhi*, 6: 163-167.
- Hora, S. L.** 1947. Tista dam and its effect on the fisheries of the river. *J. Cent. Bd. Irri., Shimla*, 4:337-341.
- Jayaram. K. C.** 2009. Catfishes of India. Narendra Publishing House. Delhi (India). pp. 383.
- Jha, P., Mandal, A. & Barat, S.** 2005. Ichthyofauna and Socio-economic profile of fishery in the Mahananda reservoir, West Bengal. *Fishing Chimes* 25:10-13.
- Jhingran, V. G. & Sehgal, K. L.** 1978. Cold water Fisheries of India. 1<sup>st</sup> edition. Inland Fisheries Society of India, Barrackpore, West Bengal, India. Pp. ix+239.
- Kottelat, M. and Whitten, T.** 1996. Freshwater Biodiversity in Asia with special reference to Fish: World Bank Tech. Paper No. 343. The World Bank, Washington, DC. Pp. 17-22.
- Lunn, K.E. & Moreau, M.A.** 2004. Unmonitored trade in marine ornamental fishes: The case of Indonesia's Banggai cardinal fish (*Pterapogon kauderni*), *Coral Reefs* 23: 344-351.
- Mahapatra, B.K., Vinod, K., Mandal, B.K. & Bujarbaruah K.M.** 2006. Ornamental Fisheries in North Eastern India, Research Bulletin No. 49, ICAR Research Complex for NEH Region, Umroi Road, Umiam, Meghalaya.
- Mandal, S., Mahapatra, B. K., Tripathi, A. K., Verma, M. R., Datta, K. K. & Ngachan, S. V.** 2007. Agribusiness Opportunities of Ornamental

- Fisheries in North-Eastern Region of India. Agricultural Economics Research Review Vol. 20 (Conference Issue). pp 471-488.
- Menon, A. G. K.** 1987. Fauna of India and Adjacent Countries. Pisces Vol. IV. Teleostei-Cobitoidea, Pt. I, Homalopteridae. ZSI Calcutta. pp. X+259, plates. 1-XV.
- Menon, A. G. K.** 1992. Fauna of India and Adjacent Countries. Pisces Vol. IV. Teleostei-Cobitoidea, Pt. 2, Cobitidae. ZSI Calcutta. pp. 113, Plate 1-10.
- Molur, S. & Walker, S. (eds.).** 1998. Report of the Workshop "Conservation Assessment and Management Plan (CAMP) for Freshwater Fishes of India". Report # 18. Zoo Outreach Organisation/ Conservation Breeding Specialist Group, India, Coimbatore, India, and NBFGR, Lucknow, India.
- MPEDA.** 2007. MPEDA statistics review, Kochi, Kerala, India, pp. 131-132.
- Mukherjee, M.** 2004. The present status of ornamental fish exporters and business groups in West Bengal. In *Prospects of Ornamental Fish Breeding and Culture in Eastern and North eastern India*, ed. R. C. Das, A. Sinha, S. Datta and S. Ghosh, pp.79-92. Central Institute of Fisheries Education, Kolkata.
- Nath, P & Dey, S. C.** 2000. Fish and Fisheries of Northeastern India (Arunachal Pradesh). Narendra Publishing House. Delhi (India). Pp. xviii +217.
- Patra, A. K., Sengupta, S., and Datta, T.** 2011. Physico-chemical Properties and Ichthyofauna Diversity in Karala River, a tributary of Teesta River at Jalpaiguri district of West Bengal, India. *Int. J. Appl. Biol. Pharmaceut. Technol.* 2(3):47-58.
- Rao, A.A.** 2006. Indigenous cold water fish potential for ornamental fish exports. In: Proceedings of State Level Seminar on *Prospects and Potentialities of Cold Water Fisheries in West Bengal*. Jointly organized by Department of Fisheries, Aquaculture, Aquatic resources and Fishing harbours, Government of West Bengal and Department of Zoology, University of North Bengal, Siliguri. pp. 50-54.
- Sarkar, T & Pal, J.** 2008. Studies on the Diversity of Fish in Different Reservoirs and Rivers of Terai Region. *NBU J. Anim. Sc.* 2 (2): 83-88.
- Sen, T. K.** 1992. Freshwater Fish. State Fauna Series 3: Fauna of West Bengal, Part 2, Zoological Survey of India: 101-242.
- Shaw, G.E. & Shebbeare, E. O.** 1937. The fishes of Northern Bengal. *J. Royal Asiatic Soc. Bengal. (Science)*. III(I): pp.137.
- Singh, T.** 2005 Emerging trends in world ornamental fish trade. *Infofish International* 24 (3): 15 – 18.
- Srivastava, G.** 2010. Fishes of U.P. and Bihar. 13<sup>th</sup> edition. Viswavidyalaya Prakashan. Varanasi, India. pp. 207.
- Swain, S. K., Jena, J. K. & Ayappan, S.** 2003. Prospects of export – oriented fresh water ornamental fish culture in India. *Fishing Chimes* 22 (10 & 11): 111 – 113.
- Talwar, P.K. & Jhingran, A. G.** 1991. Inland Fishes of India and adjacent countries. Vol-1 & Vol-2. Oxford & IBH Publishing House, New Delhi. Pp. xx+1158.
- Tekriwal, K. L. & Rao, A. A.** 1999. Ornamental Aquarium Fish of India. Waterloo, Kingdom Books. Pp. 144.
- Tilak, R.,** 1987. The fauna of India, pisces (Teleostomi), sub-family-Schizothoracinae. Zoological Survey of India, Calcutta. pp. 229.
- Vagelli, A.A. & Erdmann, M.V.** 2002. First comprehensive ecological survey of the Banggai cardinalfish, *Pterapogon kauderni*. *Env. Biol. Fishes* 63: 1-8.
- Winemiller, K. O., Agostinho, A. A. & Caramaschi, É. P.** 2008. Fish Ecology in Tropical Streams. In *Tropical Stream Ecology*, ed. D. Dudgeon, Academic Press Elsevier. London, UK. pp. 107-146.



## Ichthyofaunal Diversity of Teesta River in Darjeeling Himalaya of West Bengal, India.

M. L. Acharjee<sup>1\*</sup> and S. Barat<sup>2</sup>

<sup>1</sup>Department of Zoology, Kalimpong College, Darjeeling, West Bengal, 734301, India.

<sup>2</sup>Aquaculture & Limnology Research Unit, Department of Zoology, University of North Bengal, District- Darjeeling, West Bengal, 734013, India.

Received 25-11-2012

Revised 14-12-2012

Accepted 08-01-2013

### ABSTRACT

*Large, torrential, glacier-fed river Teesta in Darjeeling Himalaya of West Bengal, India was studied from March 2007 to February 2009 for assessing distribution, abundance and diversity of fish population through space and time. The study revealed that the river stretch sustained about 65 rheophilic, cold water fish species from 39 genera and 10 families with ornamental, food and sport value of which 11 species were ubiquitously found. Fishes of family Cyprinidae were found to be dominant followed by Sisoridae and Balitoridae. 5 species of fish were abundant (62.9%) as such the stretch of river designated as 'Barilius- Mahseer- Snow trout stream'. Most of the fish species were found very rare in the river; which may be due to various anthropogenic factors. Catch per unit effort (CPUE) ranged from 21 to 64 individual / 100 m<sup>2</sup> and number of species (S) varied from 05 to 26. Both CPUE and S showed strong seasonal variations but altitudinal gradient of fish assemblage was interrupted may be due to anthropogenic disturbances. 36 species (55%) were included in the threaten category and 10 species found to be endemic to India. The study provides baseline data which may be helpful for conservation and management of the fish species and also formulating new fishery policy.*

**Key words:** Darjeeling Himalaya, Ichthyodiversity, Teesta River, Species diversity Index.

### INTRODUCTION

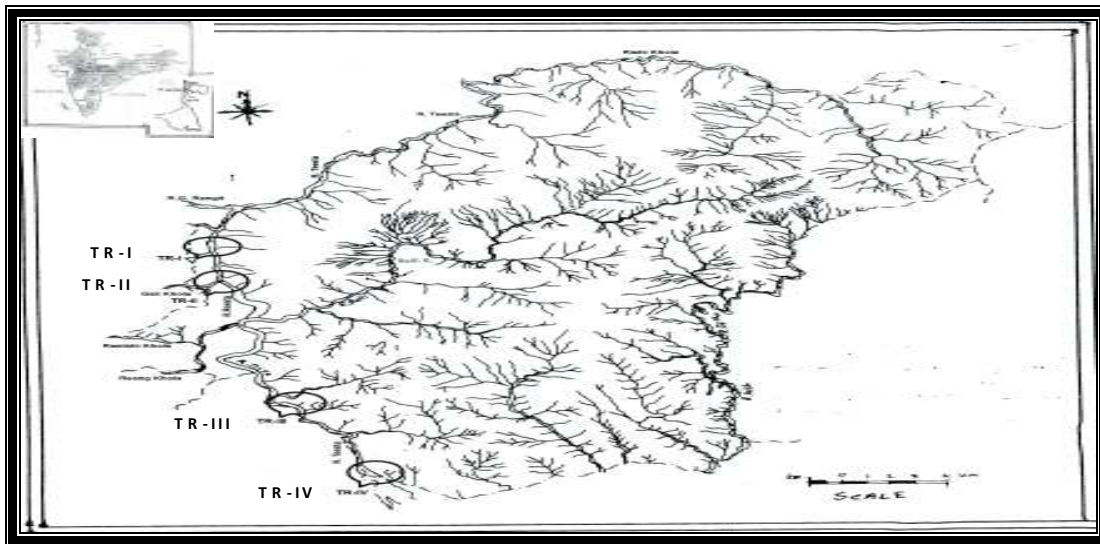
India is one of the mega biodiversity countries in the world and occupies the ninth position in terms of freshwater mega biodiversity [1]. 218 species of fishes has been listed in whole Himalayas [2]. The eastern Himalaya drained by the Brahmaputra has greater diversity of cold water fish than western Himalayan drainage [3]. Darjeeling Himalaya, as it popularly known, is the hilly Himalayan part of the northern most Darjeeling district of Indian state of West Bengal. The region has a pronounced seasonal climate and lies north of the tropical belt (The district lies between 27°13' 05" and 26°17'10" North latitudes and between 88° 53' 00" and 87° 59' 30" East longitudes). Being the integral part of the eastern Himalaya the region is regarded as freshwater biodiversity hotspot [4]. The ichthyodiversity of this region is unique from the zoogeographical point of view. The fish fauna represents mostly the Chinese, Malayan and Indian elements of fishes of the Oriental realm [5]. The region with rich biodiversity and high level of endemism is under immediate threat of species extinction and habitat destruction mainly due to tremendous pressure from demotechnic growth and natural environmental changes. Running waters are perhaps the most impacted ecosystem of the region as they are heavily exploited for water supplies, irrigation, electricity generation, waste disposal, rampant fishing etc. The important contributors on North Bengal fresh water fish fauna are [5-12]. 21 species and 125 species were mentioned respectively by [13] and [14] from Darjeeling Himalayan upland. Many workers collected fish from the Darjeeling Himalaya for taxonomic work but almost no work has been done on the distribution, abundance and diversity of ichthyofauna in the river Teesta.

The present study was thus carried out in order to examine the distribution, abundance and diversity of ichthyofauna in different reaches of the river Teesta in the hilly track just before debouching into the plains. Data on the diversity and distribution of ichthyofauna in the glacier fed river may provide important insights into the lotic ecosystem in a connecting zone between hilly and flood plain stretches, which may be helpful for conservation and management of the fish species and also formulating new fishery policy.

**MATERIALS AND METHODS**

**Study area:**

The 'Teesta' or 'Tista' is the biggest and by far most turbulent glacier fed river of Darjeeling district (Surrounded by Bhutan, Sikkim, Nepal, Jalpaiguri district and Bangladesh). The river takes its rise as 'Chumbu chu' (the upper most Teesta) in the North-East edges of North Sikkim from Pouhunri (Pouhungri) glacier (29°59' N and 88°48' E) at an altitude about 6200 m a.s.l. Teesta is 414 km long and outfalls into the river Brahmaputra in Bangladesh. It belongs to the Brahmaputra system of rivers. Tracing its course in the hilly catchment, which lies in the Sikkim state, the river gets its name Teesta below the confluence of two rivers, Lachung chhu from the north-eastern direction and Lachen chhu from north-western direction. The combined flow of the Lachung chhu and Lachen chhu, after emerging from, Chungthang (27°39' N and 88°39' E) goes by the name of Teesta River. The Teesta forms the boundary of the Darjeeling district from the point where it is joined by the Rangpo chhu to its junction with the great Rangit. From the latter point it flows entirely within the Darjeeling district through a gorge known as Sivok-Gola pass until it leaves it at Sivok. Length of the river Teesta within Darjeeling district is 48 km of which 19 km forms the boundary between Sikkim and West Bengal (**Fig.1**). According to [15] range of river width (varies from 100 m. to 900 m), average depths (varies from 1.8m to 4.5m respectively, longitudinal slope (varies from 35 to 3.8 m km<sup>-1</sup>) and Peak discharge (varies from 16400 cumec at Teesta bazaar to 17450 cumec at Coronation Bridge). Velocity of water is about 6 m sec<sup>-1</sup>. Mean annual suspended sediment load is 6.0 m ton. Total catchment area of river Teesta in hilly region is 8051 km<sup>2</sup> of which 1121 km<sup>2</sup> lies in Darjeeling district.



**Figure 1.** Map of the study area showing the sampling sites, River Teesta, Darjeeling Himalaya, India.  
**Sampling Sites:**

Four sampling sites were selected (TR-I, TR-II, TR-III, and TR-IV) in the river Teesta (**Table-1**).

**TR-I** is located at Teesta bazaar near Teesta Bridge. Several activities like extraction of building materials, fishing, car washing, river rafting has been done here. **TR-II** is located at the confluence with a small stream Geil khola, and 3 km down from the TR-1. Activities like extraction of building materials, waste disposal, fishing and river rafting were observed at this site. Teesta Low Dam Project-III (TLDP-III) is being constructed by NHPC about 3 km down from TR-II. **TR-III** is located in between the confluence with the Sweti jhora and Kalijhora where Teesta Low Dam Project-IV (TLDP-IV) is being constructed by NHPC and 12 km down from the TR-II. The site was a nice picnic spot, fishing activities practiced here. **TR-IV** is located near the Sevoke Rail Bridge, and 9 km down from the TR-III. The river flowed here in two channels. This is a famous picnic spot. Several activities like extraction of building materials, fishing were regularly exercised.

**Table I. Physical characteristics, location, and channel morphology in the sampling sites of the river Teesta**

Sampling sites	Latitudes (North)	Longitudes (East)	Altitudes, at river bed.(m asl)	Distance from the Great Rangit (Km)	River Width (m)	Channel width (m)	Depth (m)	Substrate
TR-I	27 <sup>0</sup> 03'05"	88 <sup>0</sup> 25'36"	224	4.4	125	93	3.4	Sand, gravel, cobbles, boulders and bedrocks
TR-II	27 <sup>0</sup> 01'47"	88 <sup>0</sup> 25'43"	216	7.4	128	60	3.9	Sand, gravel, cobbles, boulders and bedrocks
TR-III	26 <sup>0</sup> 56'30"	88 <sup>0</sup> 27'13"	168	19.4	162	88	3.7	Sand, gravel, cobbles, boulders and bedrocks
TR-IV	26 <sup>0</sup> 52'55"	88 <sup>0</sup> 28'37"	147	28.4	414	30/96	1.2/ 2.7	Silt, Sand, gravel, cobbles, boulders and bedrocks

### Fish sampling

Monthly sampling was carried out (from March 2007 to February 2009) in the stream at four sampling sites following fishermen or local people who used to catch fish in this region. Using cast net (*Bhureli jal*) which is small in size ( $r = 1.2$  m; weigh about 5 kg) having a mesh ranging from 0.5 to 1.5 cm with an average 1.0 cm and covers an area of about 4.5 m<sup>2</sup>, three separate and sequential efforts were made. Effort (one person, casting nets 25 times) was kept constant. Catch per unit effort (CPUE) was expressed (Average value of three efforts) as number of fish caught per 100 m<sup>2</sup> of sampling area. Other gears and methods like gill-net, scoop net, hook and line, various traps (*Dhadiya*, *tip*, *thokre* and *thali trap*), electro-fishing, rock striking, water diversion, were also followed as and when available. Here only those fish species were taken into accounts which were not found in the catches of cast net. The fishes caught were examined for their morphological features, colour bands or spots present on the body and these were recorded in the field along with their length and weight. Photographs were taken by digital compact camera (Nikon, coolpix L10). Gut content of fishes were collected for the analyses of food habit. Two specimens of each species were taken for identification and their species were ascertained on the basis of their morphometric characters and meristic counts following the criteria given by [6-7,16-18]. Valid scientific names were taken from *Fish Base* [19].

### RESULTS AND DISCUSSION

65 species of fishes were recorded from the River Teesta and these belong to 3 orders, 10 families and 39 genera (**Table-II**). Maximum number of species (30) recorded were of family Cyprinidae followed by families Sisoridae (12 species), family Balitoridae (9 species), Cobitidae (4 species), Psilorhynchidae and Shilbeidae (3 species each) and Bagridae, Olyridae, Amblycepsidae and Mastacembelidae (one species each). Similar greatest diversity in Cypriniformes and Siluriformes in the freshwater habitats were reported from other parts of Himalaya [20], [21]. 11 species were found at all four sites (**Table-II**). Most of the fish species were found very rare in the river, which may be due to various anthropogenic factors. 10 Species like *Barilius barila*, *Devatio devatio*, *Puntius conchoniis*, *Puntius ticto*, *Lepidocephalichthys guntea*, *Pangio pangia*, *Botia lohachata*, *Glyptothorax pectinopterus*, *Olyra longicauda* and *Amblyceps mangois* were found only at TR-IV. Five species of fishes were abundantly (62.9%) found in the river Teesta which were *Barilius bendelisis* (14.8%), *Schizothorax richardsonii* (12.8%), *Nemacheilus devdevi* (12.5%), *Barilius barna* (11.9%), *Neolissocheilus hexagonolepis* (10.9%). Thus, the stretch of the river can be designated as 'Barilius-Mahseer-Snow trout Stream'. Similar zonation of stream on the basis of the dominant fish species has been identified by Shrestha (1999). Gut content analyses revealed that all dominant species are omnivorous except *Schizothorax richardsonii* (herbivorous). Similar findings were reported from Yangtze River basin of China [22] and two tropical river of India [23]. Based on the study of trophic level of fishes it appears that omnivores are often the most tolerant of degradation or ecosystem dysfunction because they are able to consume food from a wide variety of sources in a changing ecosystem [24] and this may be useful to assess quality of the fish habitat. Some authors attributed dominance of Himalayan fishes to complex physico-hydrological characteristics as well as in part to zoogeographical factors regarding the dispersal and dominance from the oriental realm, and Central Asia, after the early Tertiary upheavals that created these mountains and during interglacial periods of the Pleistocene respectively [25], [26]. It is evident from the present investigation that the ichthyofaunal composition of 29 km stretch (altitudinal variations 224 to 147 m asl) was represented mostly by rheophilic, cold water hill stream species and has sufficient similarity with cold water species of Nepal, Sikkim, Bhutan, Assam and other parts of Indian Himalaya. Some species like *Crossocheilus latius*, *Psilorhynchus sucatio*, *Psilorhynchus homaloptera*, *Aborichthys elongatus*, *Acanthocobitis botia*, *Schistura rupicola*, *Schistura scaturigina*, *Nemacheilus devdevi*, *Bagarius bagarius* and *Pseudolaguvia shawi* are endemic to India [27]. Present study also revealed that out of 65 species recorded 41 species considered as food fish with ornamental value, 7 species of food fish with sport value, 5 species of food fish and 12 species with ornamental value (**Table II**).

**Table II: List of fish, Distribution, Relative abundance, Conservation and other status of fish fauna from the Teesta River in Darjeeling Himalaya.**

Name of the Species/ Length in cm. / English (E), Nepali (N) and Bengali (B) Name.	2007-2008				2008-2009			
	TR-I TR-IV	TR-II	TR-III	TR-III	TR-I TR-IV	TR-II	TR-III	TR-III
<b>Order – Cypriniformes</b>	<b>96.2</b>	<b>96.4</b>	<b>88.5</b>	<b>87.7</b>	<b>96.8</b>	<b>92.5</b>	<b>94.6</b>	<b>84.0</b>
<b>Family – Cyprinidae</b>	<b>74.1</b>	<b>71.5</b>	<b>60.9</b>	<b>58.6</b>	<b>75.6</b>	<b>69.0</b>	<b>65.6</b>	<b>63.2</b>
<b>Sub-family - Rasborinae</b>	33.3	33.9	29.3	33.6	31.0	30.5	31.6	29.6
1. <i>Barilius barna</i> (Ham.)L=10; Barna baril (E), Fakatar or Pothi (N),Boroli or Ghol (B). <b>LR-nt, FF/OR.</b>	++	++	++	+++	++	+++	+++	++
2. <i>Barilius barila</i> (Ham.)L=6; Barred baril (E), Barali, Koksa (B). <b>Vu, FF/OR.</b>	-	-	-	+	-	-	-	+
3. <i>Barilius bendelisis</i> (Ham.)L=12; Hamilton’s baril (E), Gurdere or Khabati (N);Joia (B). <b>LR-nt, FF/OR.</b>	+++	+++	+++	+++	+++	+++	+++	++
4. <i>Barilius shacra</i> (Ham.) L=13; Shacra baril (E), Faketa (N); Koksa (B). <b>LR-nt, FF/OR.</b>	+	+	+	-	+	-	-	-
5. <i>Barilius tileo</i> (Ham.) L=14; Tileo baril (E), Faketa or Khamare (N), Koksa (B). <b>LR-nt, FF/OR.</b>	-	-	+	+	-	+	+	+
6. <i>Barilius vagra</i> (Ham.)L=11; Vagra baril (E), Chahale or Lam faketa (N), Koksa (B). <b>Vu, FF/OR.</b>	+	+	+	-	+	+	-	+
7. <i>Aspidoparia morar</i> (Ham.)L=12; Carplet (E), Murari, Boroli (B). <b>LR-nt, FF/OR.</b>	-	-	+	+	-	-	+	+
8. <i>Raiamas bola</i> (Ham.)L=24; Indian trout (E), Bola or Goha (N), Bhola or Ghol (B). <b>Vu, FF</b>	-	-	+	+	-	+	-	-
9. <i>Devario devario</i> (Ham.)L=7; Sind danio(E), Chitharipothi (N), Bans pata (B). <b>LR-nt, FF/OR.</b>	-	-	-	+	-	-	-	+
10. <i>Devario aequipinnatus</i> (Mc Clelland)L=13; Giant danio (E), Vitti (N),Chhebli (B). <b>LR-nt, FF/OR.</b>	++	+	-	+	+	+	-	+
<b>Sub-family - Cultrinae</b>	-	-	-	3.9	-	0.9	0.9	2.5
11. <i>Salmophusia bacaila</i> (Ham.)L=13; Large razor belly minnow (E), Chilwa (N), Chela (B). <b>LR-ic, FF/OR.</b>	-	-	-	+	-	+	+	+
<b>Sub-family - Garrinae</b>	14.7	10.5	7.9	5.9	10.0	12.0	10.5	9.0
12. <i>Garra annandalei</i> (Hora) L=12; Annandale Garra(E), Buduna (N), Patharchata (B). <b>NE, FF/OR.</b>	+	+	+	-	-	+	-	-
13. <i>Garra gotyla gotyla</i> (Gray)L=13; Sucker head (E), Buduna (N), Patharchata or Ghorpoia (B). <b>Vu, FF/OR.</b>	++	++	++	+	++	++	++	++
14. <i>Garra lamta</i> (Mc Clelland)L=12; Lamta Garra (E), Buduna (N), Siltokra (B). <b>NE, FF/OR.</b>	-	+	-	-	-	-	-	-
15. <i>Crossocheilus latius</i> (Ham.)L=13; Gangetic latia(E), Mate Buduna (N),Kala-bata (B). <b>DD, FF/OR.</b>	+	-	-	+	+	+	+	+

<b>Sub-family - Schizothoracinae</b>	12.4	16.3	10.2	2.2	19.0	12.7	6.9	4.7
1. <i>Schizothorax progastus</i> (Mc Clelland)L=40; Point nosed snow trout (E), Chuche Asala(N). <b>LR-nt, FF/SF</b>	+	+	-	-	+	+	-	-
2. <i>Schizothorax richardsonii</i> (Gray) L=22; Blunt nosed snow trout (E), Buche Asala (N). <b>Vu,FF/SF.</b>	+++	+++	+++	+	+++	+++	++	+
<b>Name of the Species/ Length in cm. /Name</b>	TR-I TR-IV	TR-II	TR-III		TR-I	TR-II	TR-III	TR-IV
<b>Sub-family - Cyprininae</b>	13.7	10.8	13.5	12.9	15.6	12.9	15.6	17.4
18. <i>Chagunius chagunio</i> (Ham.)L=30; Chaguni(E), Rewa or Chaguni (N),Pithkati or Darangi (B). <b>NE, FF/OR.</b>	-	-	-	+	-	+	+	+
19. <i>Cyprinion semiplotum</i> (Mc Clelland) L=20; Assamese kingfish (E), Chepti or Khurpe (N), Badangi (B). <b>Vu, FF/OR.</b>	+	-	+	-	+	-	-	+
20. <i>Labeo boga</i> (Ham.) L=18; Boga labeo (E), Boga, Bhangon, Tikauli (B). <b>LR-nt, FF/OR.</b>	+	+	+	-	+	+	+	-
21. <i>Labeo dero</i> (Ham.) L=25; Kalabans(E), Gerdi (N), Kathalkushi or Ghorea (B). <b>Vu, FF/OR.</b>	+	+	+	-	+	+	+	+
22. <i>Labeo dyocheilus</i> (Mc Clelland)L=35; Brahmaputra labeo(E), Gardi (N), Degra or Silghorea (B). <b>Vu, FF.</b>	-	-	+	-	-	+	-	+
23. <i>Labeo pungusia</i> (Ham.)L=40; Pangasia labeo(E), Kalaacha or Ther (N), Utta,Boitka or Darangi (B). <b>LR-nt, FF.</b>	-	-	-	+	-	+	-	+
24. <i>Neolissocheilus hexagonolepis</i> (Mc Clelland) L=50; Copper mahseer (E), Katli or Katlae (N), Bhuluk (B). <b>NE, FF/SF.</b>	++	++	++	++	+++	++	++	++
25. <i>Neolissocheilus hexastichus</i> (Mc Clelland) L=18; Mc clelland's boker (E), Katli or Katlae (N), Bhuluk (B). <b>Vu, FF/SF</b>	+	-	+	-	+	-	-	-
26. <i>Tor putitora</i> (Ham.)L=88; Golden mahseer (E), Pahale Sahar(N), Mahseer or Mahasol (B). <b>EN, FF/SF.</b>	+	-	-	+	+	-	+	+
27. <i>Tor tor</i> (Hamilton-Buchanan) L=76; Turia mahseer (E), Falame Sahar(N), Mahseer or Mahasol (B). <b>EN, FF/SF</b>	-	-	+	-	+	-	-	-
28. <i>Puntius conchoni</i> (Ham.) L=9; Rosy barb (E), Kanchan puti (B), Sidre (N). <b>Vu, FF/OR.</b>	-	-	-	+	-	-	-	+
29. <i>Puntius gelius</i> (Ham.) L=4; Golden dwarf barb (E), Sidre (N), Gili Punti (B). <b>NE, FF/OR.</b>	-	-	-	+	-	-	+	-
30. <i>Puntius ticto</i> (Ham.)L=8; Ticto barb (E), Titae Pothi (N),Titpunti (B). <b>LR-nt, FF/OR.</b>	-	-	-	-	-	-	-	+
<b>Family – Psilorhynchidae</b>	<b>0.3</b>	<b>1.8</b>	<b>1.2</b>	<b>-</b>	<b>-</b>	<b>0.9</b>	<b>1.7</b>	<b>1.7</b>
31. <i>Psilorhynchus balitora</i> (Ham.) L=9; Balitora minnow (E), Pathar Chati (N),Balichura (B). <b>NE, FF/OR.</b>	-	+	-	-	-	+	+	-
32. <i>Psilorhynchus sucatio</i> (Ham.) L=6; River stone carp (E), Titae (N), Titari (B). <b>EN, OR.</b>	-	+	+	-	-	-	-	+

33. <i>Psilorhynchus homaloptera</i> (Ham.) L=8.5; Torrent stone carp (E), Patharchati (N). <b>Vu, OR.</b>	+	-	-	-	-	-	+	-
<b>Family – Cobitidae</b>	-	<b>1.5</b>	<b>0.6</b>	<b>3.9</b>	-	-	-	<b>3.9</b>
<b>Sub-family - Cobitinae</b>	-	1.5	0.6	3.9	-	-	-	3.2
34. <i>Lepidocephalichthyes guntea</i> (Ham.)L=8; Guntea loach (E), Lata or Gethu (N), Gunte Poia or Gutum (B). <b>NE, FF/OR.</b>	-	-	-	+	-	-	-	+
35. <i>Pangio pangia</i> (Ham.) L=5; Coolie loach (E), Pangya or Daria (B). <b>Vu, OR.</b>	-	-	-	+	-	-	-	-
36. <i>Canthophrys gongota</i> (Ham.)L=10; Jaguar loach (E), Latai (N),Ghor-poia (B). <b>LR-nt, FF/OR.</b>	-	+	+	+	-	-	-	+
<b>Sub-family - Botiinae</b>	-	-	-	-	-	-	-	0.7
37. <i>Botia lohachata</i> (Choudhuri)L=11; Y-loach (E), Baghi (N), Rani mach, Boumach (B). <b>EN, FF/OR.</b>	-	-	-	-	-	-	-	+
<b>Name of the Species/ Length in cm. / Name</b>	<b>TR-I</b>	<b>TR-II</b>	<b>TR-III</b>	<b>TR-IV</b>	<b>TR-I</b>	<b>TR-II</b>	<b>TR-III</b>	<b>TR-IV</b>
<b>Family – Balitoridae</b>	<b>21.8</b>	<b>21.6</b>	<b>25.8</b>	<b>21.3</b>	<b>21.2</b>	<b>22.6</b>	<b>27.3</b>	<b>15.2</b>
<b>Sub-family - Balitorinae</b>	-	-	-	1.1	-	0.7	0.9	-
38. <i>Balitora brucei</i> (Gray) L=7; Gray’s stone loach (E), Tita Kabre (N). <b>LR-nt, OR.</b>	-	-	-	+	-	+	+	-
<b>Sub-family - Nemacheilinae</b>	21.8	21.6	25.8	20.2	21.2	21.9	26.3	15.2
39. <i>Aborichthyes elongatus</i> (Hora) L=8; Wedge tail loach (E), Bami Gadela (N). <b>EN, OR.</b>	-	-	-	-	+	+	-	-
40. <i>Acanthocobitis botia</i> (Ham.) L=8; Leopard loach (E), Gadela (N);Bilchuri, Khorkey bata (B). <b>LR-nt, FF/OR.</b>	-	-	+	+	-	-	-	-
41. <i>Schistura beavani</i> (Gunther) L=4; Creek loach (E),Gadela (N), Poia, Bibhan- khorkey (B). <b>NE, OR.</b>	+	-	+	-	-	-	-	-
42. <i>Schistura rupicola</i> (Mc Clelland) L=7; Banded loach (E), Gadela (N), Rupali-khorkey (B). <b>LR-nt, OR.</b>	+	-	+	-	+	-	-	-
43. <i>Schistura scaturigina</i> (Mc Clelland)L= 6; Victory loach (E), Gadela (N), Dari, Poia, khorkey (B). <b>Vu, OR.</b>	+	+	++	++	+	++	++	+
44. <i>Nemacheilus devdevi</i> (Hora) L=3; Olivaceous loach (E), Gadela (N),Poia, Khorkey (B). <b>EN, OR.</b>	+++	+++	++	++	++	++	+++	++
45. <i>Nemacheilus multifasciatus</i> (Day) L=9.8; Many banded loach (E), Gadela (N),Poia, Kharika (B). <b>EN, OR.</b>	+	+	+	+	+	+	++	+
46. <i>Nemacheilus botia aureus</i> (Day, 1878) L=6 ; Mottled loach(E), Gadela (N);Poia (B). <b>NE, FF/OR.</b>	-	+	-	-	-	-	+	+
<b>Order – Siluriformes</b>	<b>3.7</b>	<b>2.9</b>	<b>10.4</b>	<b>15.2</b>	<b>3.1</b>	<b>7.2</b>	<b>4.8</b>	<b>15.1</b>
<b>Family – Bagridae</b>	-	-	<b>0.8</b>	<b>1.8</b>	-	-	-	<b>2.0</b>
47. <i>Batasio batasio</i> (Ham.) L=6; Tista batasio (E), Batasio (N),Batasi or Bajori (B). <b>NE, FF/OR.</b>	-	-	+	+	-	-	-	+

<b>Family – Schilbeidae</b>	<b>0.9</b>	<b>-</b>	<b>1.8</b>	<b>2.4</b>	<b>0.5</b>	<b>-</b>	<b>0.7</b>	<b>-</b>
<b>Sub-family - Schilbeinae</b>	0.9	-	0.9		0.5	-	0.7	-
48. <i>Clupisoma garua</i> (Ham.) L=36; Garua bacha (E), Jalkapoor (N), Ghaura (B). <b>Vu, FF.</b>	+	-	+	-	+	-	-	-
49. <i>Clupisoma montana</i> (Hora) L=21; Kocha garua (E), Jalkapoor (N), Ghaura (B). <b>NE, FF.</b>	+	-	-	-	-	-	+	-
<b>Sub-family- Ailiinae</b>	-	-	0.9	2.4	-	-	-	-
50. <i>Ailia coila</i> (Mc Clelland) L=14; Gangetic ailia (E), Patsi (N), Kajri, Kajoli (B). <b>Vu, FF/OR.</b>	-	-	+	+	-	-	-	-
<b>Family – Sisoridae</b>	<b>2.8</b>	<b>2.9</b>	<b>7.7</b>	<b>9.7</b>	<b>2.6</b>	<b>7.2</b>	<b>4.1</b>	<b>10.7</b>
51. <i>Bagarius bagarius</i> (Ham.) L=68; Giant river catfish or Goonch (E), Goonch (N), Bagha Air (B). <b>Vu, FF/SF</b>	+	-	-	-	+	+	-	-
52. <i>Parachiloganis hodgarti</i> (Hora) L=6; Torrent catfish (E), Til-Kabri (N). <b>EN, OR.</b>	-	-	-	-	-	+	-	-
53. <i>Gagata cenia</i> (Ham.) L=8; Clown catfish (E), Ganfak (N), Gong tengra, Ketakata (B). <b>NE, FF/OR.</b>	-	-	+	-	-	+	-	+
54. <i>Glyptothorax telchitta</i> (Ham.) L=7; Copper catfish (E), Telcapre, Telchitta (N), Dhal Magur (B). <b>LR-nt, FF/OR.</b>	-	-	+	-	-	+	+	+
<b>Name of the Species/ Length in cm. / Name</b>	<b>TR-I</b>	<b>TR-II</b>	<b>TR-III</b>	<b>TR-IV</b>	<b>TR-I</b>	<b>TR-II</b>	<b>TR-III</b>	<b>TR-IV</b>
55. <i>Glyptothorax cavia</i> (Ham.) L=16; Banded torrent catfish (E), Capre (N), Kani tengra (B). <b>EN, FF/OR.</b>	+	-	-	-	+	+	+	-
56. <i>Glyptothorax conirostris</i> (Steindachner)L=12; Torrent catfish (E), Capre (N), Kani tengra (B). <b>NE, FF/OR.</b>	-	-	+	+	-	-	-	-
57. <i>Glyptothorax pectinopterus</i> (Talwar) L=11; River cat (E), Capre, Karray(N), Kani tengra (B). <b>LR-nt, FF/OR.</b>	-	-	-	+	-	-	-	+
58. <i>Gogangra viridescens</i> (Ham.) L=8; Huddah nangra (E), Ganfak (N), Gong tengra (B). <b>LR-nt, FF/OR.</b>	-	-	+	-	-	-	+	+
59. <i>Nangra nangra</i> (Ham.) L=4.5; Kosi nangra (E), Befuni (N), Gong tengra (B). <b>Vu, FF/OR.</b>	-	-	+	+	-	+	-	+
60. <i>Pseudecheneis sulcata</i> (Mc Clelland) L=15; Sucker throat catfish (E), Gotel or Kabre (N). <b>Vu, FF/OR.</b>	+	+	-	-	+	-	+	-
61. <i>Pseudolaguvia shawi</i> (Hora) L=3; Cheetah catfish (E), Kani tengra (B). <b>EN, OR.</b>	-	+	+	+	-	-	-	-
62. <i>Sisor rhabdophorus</i> (Ham. 1822) L=16; Whiptail catfish (E), Bistuiya (N), Chenua, sisor (B). <b>EN, OR.</b>	-	-	-	-	-	+	+	+
<b>Family – Amblycepsidae</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>1.3</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>1.7</b>
63. <i>Amblyceps mangois</i> (Ham.) L=7; Scissor tail catfish (E), Baljung (N), Bot-singhi (B). <b>LR-nt, FF/OR.</b>	-	-	-	+	-	-	-	+

<b>Family – Olyridae</b>	-	-	-	-	-	-	-	<b>0.7</b>
64. <i>Olyra longicauda</i> (Mc Clelland) L=8; Himalayan olyra (E), Bot-singhi (B). <b>NE, FF/OR.</b>	-	-	-	-	-	-	-	+
<b>Order – Synbranchiformes</b>	-	<b>0.5</b>	<b>1.2</b>	<b>0.9</b>	-	-	<b>0.5</b>	<b>0.7</b>
<b>Suborder-Mastacembeloidei</b>	-	<b>0.5</b>	<b>1.2</b>	<b>0.9</b>	-	-	<b>0.5</b>	<b>0.7</b>
<b>Family – Mastacembelidae</b>	-	0.5	1.2	0.9	-	-	0.5	0.7
65. <i>Mastacembelus armatus</i> (Lacepede) L=25; Tyre track eel (E), Chusi-bam (N), Bhaim (B). <b>NE, FF/OR.</b>	-	+	+	+	-	-	+	+

\*\*Absent (-), < 5% (+), <10% (++) , above 10% (+++).EN- Endangered, Vu-Vulnerable, LR-nt-Low risk near threatened, LR-lc- Low risk least concern, DD-Data deficient, NE-Not evaluated. FF-Food fish, OR-Ornamental, SF-Sport fish

Almost all the species in the collection are represented mostly by young specimens. The array of juveniles and sub adults in this work suggests the river and its tributary streams in this area may be used as a breeding ground and nursery ground. Findings of [5] and [28] supported the view and they opined that Teesta provides a highway for the migration of fishes. However, the absence of adults among other factors may be due to pressure exerted from selective overfishing by local fisherman or from migration of the fish or both. Similar observation has been made by [29] in the rivers of Nigeria. [30] reported unscientific overfishing in this area.

Fast flowing river Teesta calls for a special modification of the fish fauna. The individual modification is chiefly manifested in being small sized and development of structure of adhesion. Fish species found in the present study may be categorised into six major groups on the basis of morphological characteristics in relation to distributional pattern which enable them to inhabit the torrential streams. These are, i) fish dwelling in shallow, clear cold waters in the foothills without any striking modifications to current: Barilius spp; ii) fish inhabiting the bottom water layers in deep fast current, with powerful muscular cylindrical bodies: Schizothorax spp, Tor spp, Neolissocheilus spp; etc. iii) fish sheltering among pebbles and stones to ward off the strong current: Crossocheilus latius; iv) fish sheltering among pebbles and shingles in shallows, with special attachment devices: the loaches, Nemacheilus spp, Schistura spp, Canthophrys gongota, Aborichthys elongatus, Acanthocobitis botia; v) fish which cling to exposed surface of bare rocks in slower current, with adhesive organs on their ventral surface for attachment to rocks: Garra spp, Glyptothorax spp, Pseudecheneis sulcata; and vi) fish which cling to the exposed surfaces of bare rocks in fast current, with limpet shaped bodies and mouth, gills and fins highly modified to suit the habitat: Parachilognis hodgarti. Similar six major groups have been recognised by [25] in Himalayan fish.

Summary catch per unit effort (CPUE) and number of fish species recorded (showing the Range and Mean ± Standard Deviation) of River Teesta (n=12) in three sampling sites during the study period is presented in the Table III. The CPUE ranged from 21 individual/100m<sup>2</sup> to 64 individual/100m<sup>2</sup> with a mean value 36.9 individual/100m<sup>2</sup> (±10.3). Lowest value was recorded in May 2007 (TR-II) and highest in September 2007 at TR-III. The number of species (S) ranged from 05 to 26 with a mean value 13.6 (±3.9). Lowest number of species was recorded in July 2007 (TR-II) and highest number found in September 2007 at TR-III. The low CPUE of fish in this stretch may have resulted from the passage of the river through deep and narrow gorges, and the presence of cold glacier and snow-melt water, which may not be conducive for much fish density. [31] have reported similar low (Ranged from 246.95/0.1 ha to 510.70/0.1 ha) CPUE in Seti Gandaki river of Nepal. Analyses of monthly data obtained during the study period (March' 2007 – February'2009) in the selected stretch of the sub-Himalayan river Teesta indicated that catch per unit effort (CPUE) and number of species (S) increased slightly in the month of May and again increased sharply in September (Fig. 2).

**Table III: Summary catch per unit effort (CPUE) and number of fish species recorded (showing the Range and Mean ± Standard Deviation) of River Teesta (n=12) in three sampling sites during the study period.**

Period of study	March 2007 – February 2008				March 2008-February 2009			
	TR-I	TR-II	TR-III	TR-IV	TR-I	TR-II	TR-III	TR-IV
Density and number of fish species.								
1. Fish CPUE (Individual/100m <sup>2</sup> ).	31-61 45.08±10.1	21-54 31.67±10.2	31-64 43.25±11.6	22-56 37.92±10.5	24-51 34.67±8.6	33-57 34.67±10.4	24-51 34.83± 8.4	26-46 33.5± 6.4
3. Number of fish species (S).	07-19 13.5± 3.8	05-14 11.1 ± 2.6	09-26 17 ± 4.1	09-19 14.1± 3.9	06-15 11 ± 2.5	06-19 12.7± 3.5	09-18 13± 2.5	13-25 16.8± 3.3

When data on CPUE and Number of Species were pooled together into seasonal values, the highest value of both was found in post monsoon months at all sites. Post monsoon increment may be due to downward march of migratory brood fishes along with year old young from upstream or from tributary streams. But the lowest value of CPUE was recorded in winter (TR-I, III and IV) and in pre monsoon at TR-II where as that of S recorded in monsoon months at all sites. During monsoon months fish yields decline due to the elevated water level [32], highly turbid water and spawning migration. Two factors, more downward migration to winter habitat and indiscriminate fishing may be responsible for low CPUE during winter months. Average value of CPUE was found to be TR-II (33.2 individual/100m<sup>2</sup>) < TR-IV (35.7 individual/100m<sup>2</sup>) < TR-III (39.0 individual/100m<sup>2</sup>) < TR-I (39.9 individual/100m<sup>2</sup>) and that of number of species were TR-II (11.9) < TR-I (12.3) < TR-III (15.0) < TR-IV (15.5). Thus, the current pattern of fish distribution along the elevational gradients contrasts sharply with the typical pattern i.e., a decrease in species diversity as altitude increases [33]. The pattern found in this river suggests cumulative temporal and spatial effects of habitat loss or environmental degradation [34], [35].



**Figure 2. Monthly mean variations of observed data of Catch Per Unit Effort (CPUE) and Number of Species (S) of fish in the studied stretch of Teesta River during the study period.**

References to conservation status (Table II) categories within this paper are based on IUCN classification as per CAMP-NBFGR [27]. Thus, out of recorded species, 11 (17%) endangered (EN), 18 (28%) vulnerable (Vu), 19 (29%) low risk near threatened (LR-nt), 1 (1%) low risk least concern (LC-lc), 1 (2%) data deficient (DD) and rest 15 (23%) were not evaluated (NE). But recent revise by NBFGR [36] included species like *Chagunius chagunio*, *Crossocheilus latius*, *Nangra nangra* and *Amblyceps mangois* under endangered (EN) category and *Garra lamta*, *Labeo pungusia*, *Glyptothorax telchitta* and *Olyra longicauda* under vulnerable (Vu) category. Thus, about 55% fish species of the river Teesta are threatened.

**CONCLUSION**

The present study provides an informative data and helps to understand the ichthyofaunal density, abundance and diversity in a section of glacier-fed torrential, largest river in the Darjeeling Himalaya. Results show that the 65 species

of rheophilic, coldwater, hill stream fish with special modifications to inhabit the torrential river. On the basis of dominant fish species the stretch of river may be designated as 'Barilius-Mahseer-Snow trout stream'. Most of the species are omnivorous in their feeding habit and 36 species (55%) of important fish with threatened status. In the present study, it was observed that the anthropogenic activity altering the fine tune of the river ecosystem and established as a major cause of habitat alteration and fish stock depletion and thus most of the species were rare. Fish assemblages along the elevational gradient of the river might be interrupted due to anthropogenic disturbances. The gene pool of unique ichthyofauna in Darjeeling Himalaya is a valuable endowment of nature. Thus, some steps and awareness programme is needed to educate people about the importance of the river, its biodiversity and fish productivity.

#### ACKNOWLEDGEMENTS

The authors are grateful to the time to time Head, Department of Zoology, University of North Bengal; Principal, Kalimpong College for providing necessary laboratory facilities for the present work. We are very much thankful to Dr. Mrinal Mukherjee, of CIFRI, Barrackpore and Prof. D. N. Das, Rajiv Gandhi University, Arunachal Pradesh for their valuable suggestion, identification of some fish species and encouragements during the course of the study. We are also grateful to Mr. S. Rai, K. Monger, N. Gupta, G. Chhetri, K. Pradhan, Shanti Rai, B. B. Chhetri, S. Sherpa and P. B. Rai for their help and assistance during sampling.

#### REFERENCES

- [1] Mittermeier, R.A. and Mittermeier, C.G. (1997). Megadiversity: Earth's Biologically Wealthiest Nation. In: McAllister, D. E., Hamilton, A. L. and Harvery B. (Eds.). *Global Freshwater Biodiversity*. Sea Wind, Cemex, Mexico City, 11: 1-140.
- [2] Menon, A. G. K. (1962). A distributional list of fishes of the Himalayas. *Journal of Zoological Society, India* 14 (1 & 2): 23-32.
- [3] Sehgal, K. L. (1999). Coldwater fish and fisheries in the Himalayas: rivers and streams. In: Petr, T. (ed.). *Fish and fisheries at higher altitude-Asia*. FAO Fisheries Technical Paper. No. 385: Rome, FAO. Pp. 41-63.
- [4] Kottelat, M. and Whitten, T. (1996). Freshwater biodiversity in Asia with special reference to fish. World Bank, Washington, D. C, pp 17-22.
- [5] Hora, S. L. and Gupta, J. C. (1940). On a Collection of Fish from Kalimpong Duars and Siliguri Terai, Northern Bengal. *Journal Royal Asiatic Society of Bengal. Science*. VI (8): 77-83.
- [6] Shaw, G. E. and Shebbeare, E. O. (1937). The fishes of Northern Bengal. *Journal Royal Asiatic Society of Bengal. Science*. Volume III, Article No. 1. Pp. 137.
- [7] Sen, T. K. (1992). Fresh water Fish. State Fauna Series 3: Fauna of West Bengal, Part 2, *Zoological Survey of India*: 101-242.
- [8] Jha, P., Mandal, A. and Barat, S. (2004). Mahananda Reservoir, W. B.: Its Ichthyofauna, Fishery and Socio-economic Profile of Fish Production. *Fishing Chimes* 24(6), pp.14-17.
- [9] Sarkar, T. and Pal, J. (2008). Studies on the Diversity of Fish in Different Reservoir and Rivers of Terai Region. North Bengal University *Journal of Animal Sciences*. 2(2): 83-88.
- [10] Chakraborty, T. and Bhattacharjee, S. (2008). The Ichthyofaunal Diversity in the Freshwater Rivers of South Dinajpur District of West Bengal, India. *Journal of Bombay Natural History Society*, 105(3): 292-298.
- [11] Mukherjee, M., Lepcha, R. F. and Chakraborty, C. (2011). Fish and Fisheries of Himalayan and Terai Region of West Bengal with Ornamental touch. Daya publishing House, Delhi, pp. 342.
- [12] Patra, A. K., Sengupta, S. and Datta, T. (2011). Physico-Chemical properties and Ichthyofauna Diversity in Karala river, A tributary of Teesta river at Jalpaiguri district of West Bengal, India. *International Journal of Applied Biology and Pharmaceutical Technology* 2 (3): 47-58.
- [13] Barat, S., Jha, P. and Lepcha, R.F. (2005). Bionomics and Cultural prospects of Katli, *Neolissocheilus hexagonolepis* (Mc Clelland) in Darjeeling district of West Bengal. In: Tyagi, B., Shyam Sunder and Mohan, M. (Eds). *Coldwater Fisheries Research and Development in North East Region of India*. NRCCWF, Bhimtal. Vikrant Computers, Haldwani: 66-69
- [14] Mukherjee, M. and Sarkar, G. (2005). *Endangered Fishes of West Bengal, with a special reference to North Bengal on Research, restoration, and Future plan of action*. Published by Department of Fisheries, Aquaculture, Aquatic Resources and Fishing Harbour.
- [15] Anonymous. (2001). Preparation of Master Plan for Flood Management and Erosion Control in North Bengal, Phase-I, Draft final Report, Volume-I and II. Uttarbanga Unnayan Parshad. Office of the Commissioners. Jalpaiguri Division, By Water and power Consultancy Services (India) Limited. New Delhi, pp. 9.6 (I) and 7.5 (II).
- [16] Talwar, P.K. and Jhingran, A. G. (1991). *Inland Fishes of India and adjacent countries*. In 2 vols. Oxford & IBH Publishing House, New Delhi. pp. xx+1158.
- [17] Tekriwal, K. L. and Rao, A. A. (1999). *Ornamental Aquarium Fish of India*. Waterlooville, Kingdom Books. pp. 144.
- [18] Jayaram, K. C. (2009). *Catfishes of India*. Narendra Publishing House. Delhi (India). pp. 383.
- [19] Froese, R. and Pauly, D. (Eds.) (2012). *FishBase*. World Wide Web electronic publication. www.fishbase.org, version (08/2012).
- [20] Johal, M. S. and Rawal, Y. K. (2005). Key to the management of the western Himalayan Hill streams in relation to fish species richness and diversity. *Hydrobiologia*. 532: 225-232.
- [21] Shrestha, J. (1999). Coldwater fish and fisheries in Nepal. In: Petr, T. (ed.). *Fish and fisheries at higher altitude-Asia*. FAO Fisheries Technical Paper. No. 385: Rome, FAO. pp. 13-40.
- [22] Fu, C., Wu, J., Chen, J., Wu, Q. and Lei, G. (2003). Fresh water fish biodiversity in the Yangtze River basin of China: patterns, threats and conservation. *Biodivers Conserv*. 12: 1649-1685.
- [23] Das, S. K. and Chakraborty, D. (2007). The use of fish community structure as a measure of ecological degradation: a case study in two rivers of India. *Bio Syst*. 90: 188-196.
- [24] Wichert, G. A. and Rapport, D. J. (1998). Fish community structure as a measure of degradation and rehabilitation of riparian systems in an agricultural drainage basin. *Environ Manag*. 22(3): 425-443.
- [25] Menon, A. G. K. (1954). Fish geography of the Himalayas. *Proceedings of the National Institute of Science of India*. 20: 467-493.

- [26] Edds, D. R. (1993). Fish Assemblage Structure and Environmental Correlates in Nepal's Gandaki River. *Copeia* (1): 48-60.
- [27] Molur, S. and Walker, S. (eds.) (1998). Report of the Workshop "Conservation Assessment and Management Plan (CAMP) for Freshwater Fishes of India". Report # 18. Zoo Outreach Organisation/Conservation Breeding Specialist Group, India, Coimbatore, India and NBFGR, Lucknow, India.
- [28] Hora, S. L. and Nair, K. K. (1944). Pollution of Streams and conservation of fisheries; Effluent of the quinine factory at Mongpo, District Darjeeling, Bengal. *Current Science*. X(1): 147-164.
- [29] Emmanuel, L. O. and Modupe, O. O. (2010). Fish Diversity in Three Tributaries of River Ore, South West, Nigeria. *World Journal of Fish and Marine Sciences*. 2 (6): 524-531.
- [30] Acharjee, M. L. and Barat, S. (2010). Impact of fishing methods on conservation of ichthyofauna of river Relli in Darjeeling Himalaya of West Bengal. *Journal of Environmental Biology* 31: 431-434.
- [31] Pokharel, K.K. (2011). Study on Fish Ecology of the Seti Gandaki River Pokhara: II. Spatio-Temporal Variations in Fish Communities. *Nepal Journal of Science and Technology* 12: 350-357.
- [32] Begossi, A., Silvano, R.A.M., Amaral, B.D. and Oyakawa, O.T. (1999). Use of local resources by fishers and hunters in an extractive reserve (Upper Jurua, Acre, Brazil). *Environ. Dev. Sust.* 1: 73-93.
- [33] Lomolino, M. V. (2001). Elevation gradients of species-density: historical and prospective views. *Global Ecology & Biogeography* 10: 3-13. doi: 10.1046/j.1466-822x.2001.00229.x.
- [34] Scrimgeour, G. and Chambers, P. (2000). Cumulative effects of pulp mill and municipal effluents on the epilithic biomass and nutrient limitation in a large northern river ecosystem. *Can J Fish Aquat Sci.* 57, 1342-1354.
- [35] Wolter, C., Minow, J., Vilcinskas, A. and Grosch, U. (2000). Long-term effects of human influence on fish community structure and fisheries in Berlin water: an urban water system. *Fish Manag Ecol.* 7, 97-104.
- [36] Lakra, W. S., Sarkar, U. K., Gopalkrishnan, A. and Kathirvelpandian, A. (2010). Threatened Freshwater Fishes of India. National Bureau of Fish Genetic Resources, Lucknow. pp, 1-20.

**Corresponding Author: Dr. M. L. Acharjee** (Assistant Professor), Department of Zoology  
Kalimpong College, Darjeeling, West Bengal, 734301, India. Email : manik\_kpg@rediffmail.com