CHAPTER I
INTRODUCTION

1.0 Prelude

Rivers are a much-esteemed aspect of the nature. They carry out numerous important functions in both societal and ecosystem terms, together with personal water utilization, health and sanitation requirements, agricultural, navigational, and industrial uses, and various artistic, cultural, religious, and recreational associations. In various parts of the world, human-induced degradation has overwhelmingly altered the natural functioning of river systems. Continual mistreatment has resulted in significant apprehension for river health, defined as the ability of a river and its associated ecosystem to act upon its natural function. River health is a measure of catchment health, which in order provides a signal of environmental and societal health.

Rivers display amazing variety of landforms. Every river shows assemblage of distinctive landforms and its own behavioral system. Some rivers have considerable competence to regulate their shape whilst others have a comparatively uncomplicated geomorphic structure and inadequate ability to adjust. This inconsistency in geomorphic structure and capacity to adjust, which reflects the assortment of landscape settings in which these rivers are found (Gary J. Brierley and Kirstie A. Fryirs, 2006). A system is a compilation of linked objects and the processes that link those objects collectively. Inside fluvial systems, objects for instance hillslopes, the channel set-up and floodplains are coupled collectively by the processes that move water and sediment between them. In general by means of other systems, the fluvial system is hierarchical, in that there are incorporated sub-systems working within it.

The fundamental unit of the fluvial system is the drainage basin. Fluvial systems are open systems, which means that energy and materials are exchanged with the adjacent environment. The foremost inputs to the system are water and sediment resulting from the breakdown of the underlying rocks. Supplementary inputs incorporate biological material and solutes derived from atmospheric inputs, rock weathering and the breakdown of organic material. Water and sediment be in motion through the system to the drainage basin passage, where material is discharged to the ocean or lake. Landforms such as channels, hillslopes and floodplains form a morphological system, also referred to as a form system. The form of each component of a morphological system is related to the form of the other components in the system. The components of the morphological system are linked by a cascading system, which refers to the flow of water and sediment through the morphological system. Cascading systems are also called process systems or flow systems. These flows follow interconnected pathways from hillslopes to channels and through the channel network. The two systems interact as a process–response system. This describes the adjustments between the processes of the cascading system and the forms of the morphological system. There is a two-way feedback between process and form. In other words, processes shape forms and forms influence the way in which processes operate (Fundamentals of Fluvial Geomorphology, Ro Charlton, 2006). The influence of the external basin controls on the fluvial system is represented schematically (Figure 1.0)

SIMPLIFIED REPRESENTATION OF THE FLUVIAL SYSTEM

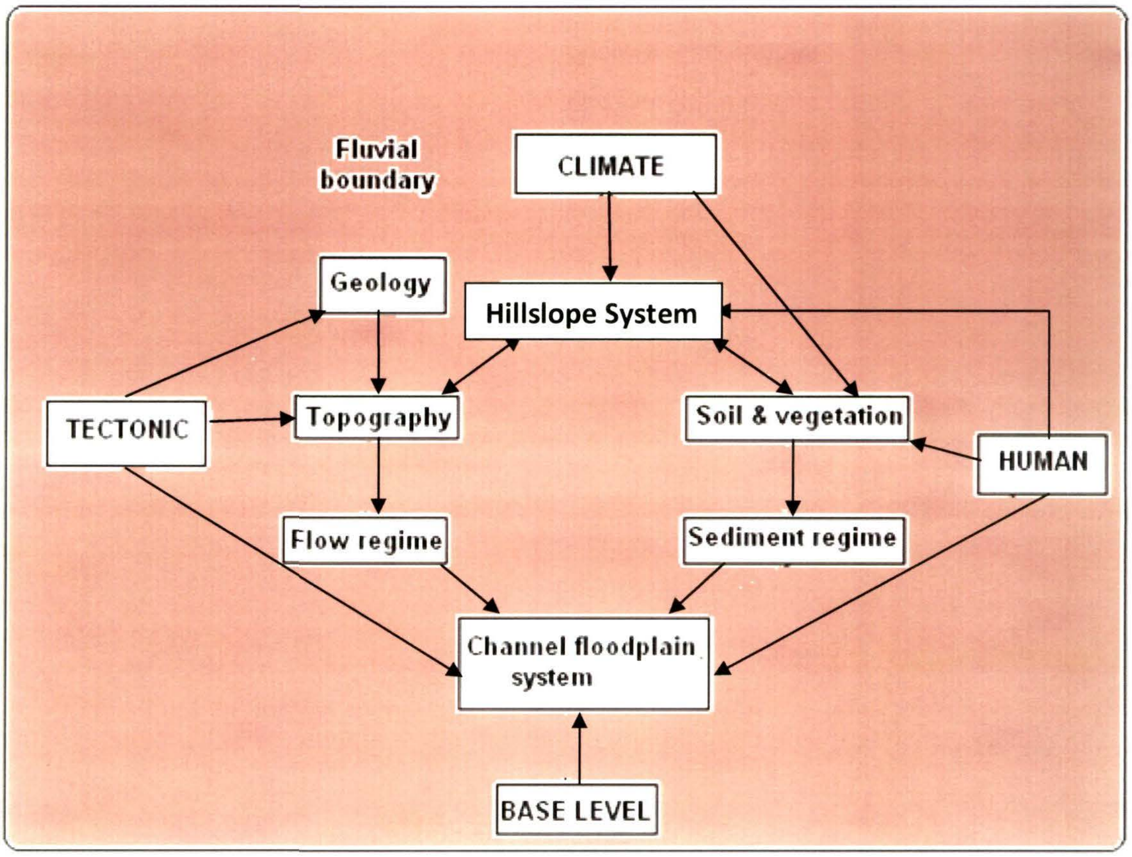

Figure 1.0 Simplified representation of the fluvial system.

Source: Fundamentals of Fluvial Geomorphology, Ro Charlton.

The response of the fluvial system to alteration is habitually multifaceted for the reason that of the many interrelationships that subsist between the diverse components of the system. Variables are quantities whose values change throughout time. They incorporate such things as drainage density, hillslope angle, soil type, flow discharge, sediment yield, and channel pattern and channel depth. Comprehending the nature and characteristics of the river, one should know concerning the origin of the earth and the configuration of mountains and river systems. For the appropriate management of the drainage basin it is indispensable to recognize well regarding the fluvio-geomorphic characteristics of the drainage basin. River management is now multidisciplinary, relating experts from a number of different fields, including geomorphology, ecology, engineering and economics. Geomorphologists have an important role to play in assessing the condition of rivers and their catchments, their compassion and future rejoinder to alteration.

1.1 The study area

The mountain stream Rayeng is a right bank tributary of Tista River. The Basin of Rayeng River is a 6^{th} order sub-drainage basin of Tista River. The shape of the basin is more or less circular or pear shaped and drained by Rayeng River and its tributaries. The most considerable tributary of Rayeng River is the Rambi River. The basin positioned in the Darjeeling hill area in West Bengal.

The Rayeng Basin covers an area of about 145.50 sq. km. The basin falls in the areas of three C.D Blocks of Darjeeling District i.e. Rangli-Rangliot, Kurseong, and Kalimpong -I respectively. The northern, western, and northwestern tracts of the basin positioned in the Rangli-Rangliot Block. Southern tract of the basin encompass the northern part of the Kurseong Block. At the confluence of Rayeng and Tista the basin comprises some part of western tract of Kalimpong Block-I. The Rayeng Basin lies between the latitudes 26°54′41′′ N to 27°02′11′′ N and longitudes 88°18′20′′ E to 88°27′33′′ E (Figure 1.1). The Rayeng River is of length 17.50 km from its source to confluence. Rambi River is almost 14.28 km long from its source to its confluence with Rayeng. There are 431 1^{st} order, 95 2^{nd} order, 23 3^{rd} order, 4 4^{th} order, 2 5^{ih} order, and 1 6^{th} order streams in the basin. Total length including the entire order of streams of this basin is about 280 km. The confluence of Rayeng River with Tista River is at Rambi village and just about at the intersection of 27°02′08′′ N latitude and 88°27′ E longitude.

The main tributary Rambi mingled with Rayeng River in northeastern part of Rangli-Rangliot C.D Block at the intersection of 88°25′21′′ E longitude and 27°00′33′′ N latitude. At the source region of Rambi and Kali rivers Takdah reserve forest is situated covers Pubong Khasmahal of Rangli Rangliot C.D Block. Senchal forest area covers Labda Khasmahal of Rangli Rangliot C.D Block. Cinchona plantations found mostly in catchment area of Rambi River comprise Pubong and Mongpu villages of Rangli Rangliot C.D Block. Agricultural land use furthermore found in the middle part of the basin of both Kurseong and Rangli-Rangliot C.D Blocks. Tea garden is at Rangli Rangliot village of Rangli Rangliot C.D Block (Figure 1.2).

LOCATION MAP OF THE STIDY AREA

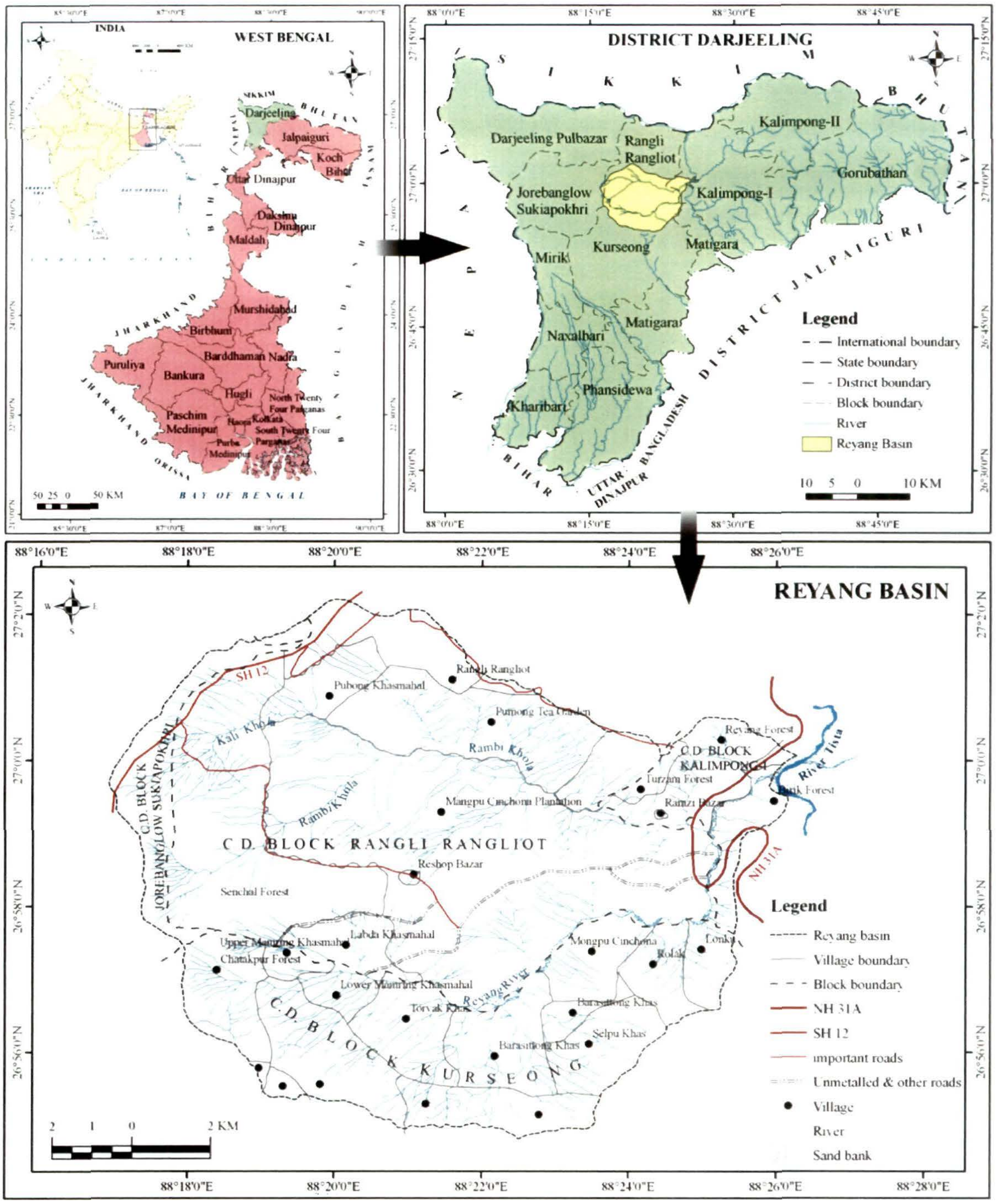

Figure 1.1 Location of the study area.

ADMINISTRATIVE AREA OF RAYENG BASIN

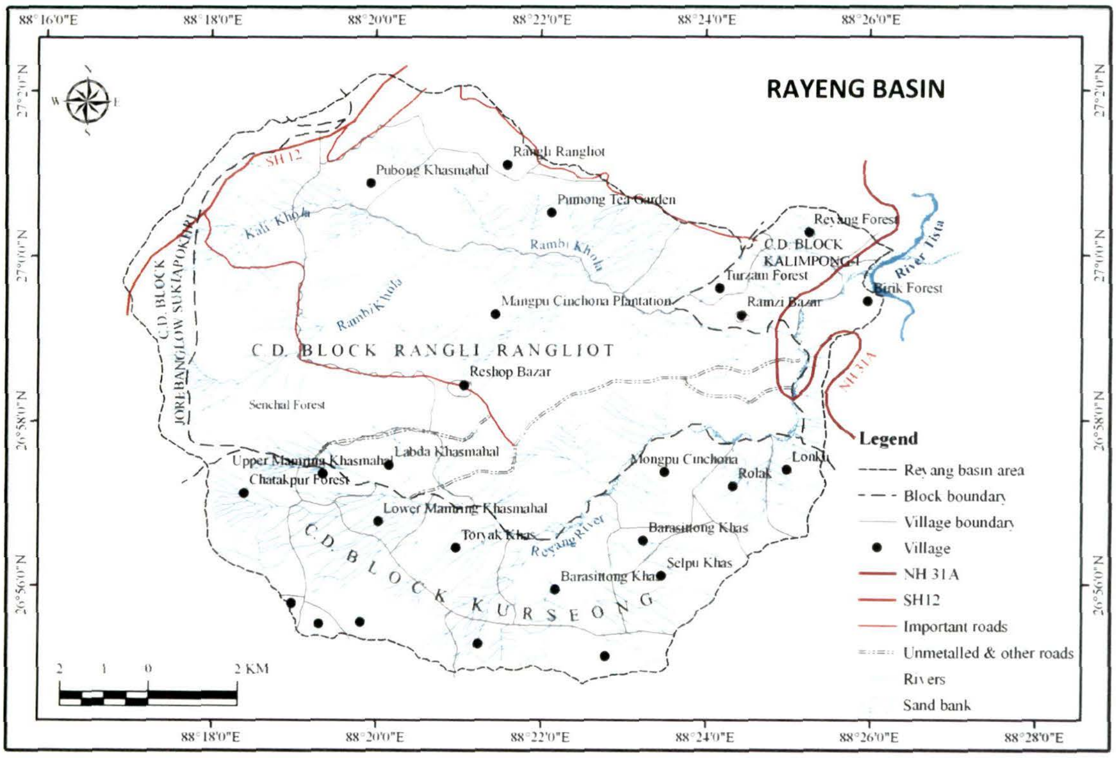

Figure 1.2 Administrative units under the area of Rayeng Basin.

The Rayeng and Rambi are flowing from southwest and northwest to northeast respectively in the course of deep and narrow channels. Both the rivers and their tributaries have shaped a number of erosional features. Near the confluence sands, gravels and boulders deposits are spectacular. Constructional works introduced by the man at the confluence of Rayeng River with the Tista River caused an interruption in the natural channel behaviour. Near the confluence, the channel of Rayeng River has been bifurcated in a number of channels by the mid-channel bar. Settlements have been built-up on the mid-channel bar. Due to heavy rainfall, the amount of discharge in the Rayeng and Rambi River increases drastically in the monsoon season. In contrast, amount of discharge in the above mentioned rivers decrease outstandingly owing to be deficient in water during the off-monsoon period. Therefore, the amount of discharge in this basin is characterised by seasonal changeability.

The basin has complex geological layout. Different geological formations observed in this basin area namely Darjeeling gneiss, Kanchenjungha Augen gneiss, Damuda formation, Paro sub-group, lingtse granite, feldspathic greywacke marble, Rayeng formation, and Gorubathan formation (after Ray, 1989, GSI, 2000). Because of a variety of geological formation, the morphological features in the basin area differ in magnitude and dimension.

The study area is unique from environmental eco-perception. The basin has momentous variation in altitude in respect to relief. These rivers have their sources at an altitude of more than 2300m, which declines to 200m near the confluence of Rayeng River. The relief of the basin is marked with sharp change i.e., breaks in slope denote rugged topography. The upper reaches of the basin are vulnerable to landslides. However, the middle and lower parts of the basin are not as vulnerable. The study area has wonderful natural scenic beauty but at the confluence, the natural character of the basin disrupted by the human intervention. Thus, to restore the environmental quality of the study area scientific management is indispensable.

1.2 Scope of the study

Geomorphology incorporated the study of landforms with their genesis. One of the significant branches of geomorphology is fluvial geomorphology. Cotton, (1948) stated "the fluvial geomorphic system is so widespread and effective that it has been commonly regarded as the normal process of landscape evolution on the earth". One of the excellent examples of a fluvial geomorphological system is drainage basin. The drainage is a fundamental geomorphic unit as it has direct functional significance for fluvial processes. Drainage basin considered as a basic areal unit within which topographic attributes measured, organized, and analyzed. According to Schumm (1977), "the application of fluvial geomorphology to geology mainly involves evaluation of existing condition and post diction". For the understanding and solving the problems raised by the interaction of man with geomorphic and environmental system application of geomorphic knowledge is highly appreciated. H.Th. Verstappen (1983) has stated that the scope of geomorphic study includes the followings:

1. Topographic and thematic mapping of natural resources.
2. Survey of natural hazards, landslides, avalanches, earthquake, volcanism, land subsidence, flooding, draughts, and natural hazards reduction.
3. Rural development and planning emphasizing land utilization, controls of man induced soil erosion, channel manipulation, and river basin movement.
4. Urbanization, mining and construction.
5. Engineering design.

The present study on the subject of the geomorphorphic characteristics of Rayeng Basin has the following scope:

1. **Perception of topography of the drainage basin**

The study would be helpful for better perception of topographic characteristics of drainage basin. The sensitivity of topographic characteristics of drainage basin by the eminent scholars as follows (Table 1.0 & 1.1):

Table 1.0 Topographic perception of scholars.

Scholars	**Topographic characteristics**
A.R.E. Horton (1945)	Form factor, compactness, mean elevation, general slope, mean slope, drainage density, stream number, average fall, and slope of streams, direction, and length of overland flow
B.W.B. Langbein (1947)	Area, stream density, area-distance distribution, length of the basin, slope, channel area-altitude distribution (basin hypsometry), area of water surface
C.D. Johnstone and W.P Cross (1949)	Area, overland slope, channel slope, size of channel, stream pattern, stream density
D.A.N. Stahler (1965)	Linear aspects of channel system, areal aspects of drainage basin, relief (gradient) aspects of drainage basin and channel networks
E.D.M. Gray (1965)	Drainage area, size and shape, density and distribution of water courses, overland slope or general land slope, size, length, slope and condition of stream channels, depressional storage and pondage due to surface channel obstruction forming natural detentions
F. R.J. Chorley (1967)	Linear aspects of the basin both topological and geometrical, areal aspects of basin, relief aspects of basin
G.M.G. Wolman (1967)	Catchment area, size of channel, shape of channel, falls, rugosity of channel, pattern, valley form and dimensions-pattern in plan, shape in cross-section

Source: Earth Surface Forms and Processes A geomorphological approach by Kalyan Sakar and Indrani Sarkar (p. 443).

Table 1.1 Topographic attributes of drainage basin.

Dimension	**Basin**	**Network**	**Channel reach**	**Channel cross - section**
Area	Drainage basin area	Area of stream channels	Are of channel	Channel cross-section area
Length	Basin length, Basin perimeter	Drainage density, Stream length,	Channel length, channel sinuosity	Width
Shape	Basin shape	Drainage pattern and Network shape	Channel shape	Shape
Relief	Basin relief, Basin slope	Network relief, Network slope	Channel relief, channel slope	Depth

Source: Earth Surface Forms and Processes A geomorphological approach by Kalyan Sarkar and Indrani Sarkar (p. 444).

From the study of the mountain River Basin Rayeng, the previously mentioned attributes of fluvial system in the given table would be comprehensive through detail field study and secondary data analysis.

2. Mapping of the natural resources

In the present study geomorphic map, geological map, land use map, vegetation map, land capability map, soil map have been prepared. These must be supportive for the resource mapping of this mountain river basin. For the management of resources this study may reveal the appropriate way. For the sustainable development of the basin, area mapping of the resources is essential. Thus from the study rational ways of development may be revealed.

3. **Natural hazards management**

The study area suffers from soil erosion and landslides. Detailed study concerning the landslides and soil erosion of the area would be accommodating to find out the ways to mitigate the said problems.

4. **Environmental management**

Because of interference of man in environmental processes, the ecological balance of study area has been disturbed. Unplanned growth of settlements, plantations, and agricultural practices are the main reasons of environmental deterioration of the study area. Detail study regarding the causes responsible for environmental deteriorations of basin will be helpful to find out the measures to diminish the said problem.

5. **Management of geomorphic processes of the basin**

Man also considered as a geomorphic agent, in respect to his inadvertent and planned effects on geomorphic processes and forms. Geomorphic processes may modify by the interference of man directly or indirectly. Such modification in geomorphic processes may hinder the natural activity of the river. In the study area construction of bridges, channel diversion in small scale, construction for hydel project of Tista in the channel of Rayeng River, modify the natural flow of the river Rayeng. Because of deforestation, practice of agricultural on vulnerable landslides zones and soil erosion zone huge amount of loads artificially added in channel of Rayeng and Rambi rivers. These loads ultimately debouch in the Tista River causing the problem of siltation in river Tista. So from the magnitude of the interference would be estimated and probable solution to minimize the interference of man would be found out. In this way, the present study may play significant role in managing environment to reduce the intensity of potential degradation of natural resources of the basin.

1.3 Aims and objectives

The present study has been undertaken to fulfill the following aims and objectives:

1. To study the Relationship among morphometric properties of the drainage basin.
2. To examine the relationships between basin morphometry and other characteristics of the environment.
3. To assess the impact of human activities on the process responded system in the drainage basin.
4. To examine the magnitude of landslide and soil erosion in the drainage basin as enhancing factor of huge sediment load.
5. To comprehend the man induced changes of the natural behaviour of the drainage basin.
6. To detect scientific methods for the proper management of the basin can be beneficial to the local people.

1.4 Hypothesis

The researcher in his study will establish following hypothesis:

1. There is an intricate relationship between the Physiography and fluvial activity.
2. Fluvial attributes are correlated to each other.
3. Channel geometry is the dynamic manifestation of the interaction of relief, geology and climate.
4. Landslides and soil erosion in the mountain river basin influence the geomorphic characteristics of river.
5. Human interferences in process response system resulted to deterioration of fluvial environment.

1.5 Methodology

Methodology usually means the methods which are applied to make out the problem, analysing it and then concluding it. Methodology of the study is represented by a flow chart (Figure 1.3). For the study of geomorphic characteristics of Rayeng Basin a variety of methods have been used at the different stages of study as follows:

Pre-field study

Rayeng Basin is chosen for the study of geomorphic characteristics of river basins chiefly on the mountain terrain. To comprehend the areal dimension of the basin systematic mapping of the area has been adopted from the topographical (SOI) sheet bearing the number 78A/8 and 78B/5 having scale 2 cm to 1 km. The basin is placed in Darjeeling District within the three Blocks namely Rangli-Rangliot, Kurseong, and Kalimpong -I respectively. Thus for detail Block-wise maps of the study area have been collected from the Administrative Atlas of West Bengal, Census of India 2001.

For the investigation of the structural components, stratigraphic set up, lithology and geological features, geological map of Darjeeling and Sikkim Himalaya published by the Geological Survey of India has been consulted. Satellite images of IRS 1C LISS III 19th January, 2006 and IRS P6 LISS III 26th January, 2006 of National Remote Sensing Centre (NRSC), Hyderabad has been consulted for better perception of the overall condition of the study area. Land use map of the study area is collected for the detailed land use pattern of the study area. The study area is primarily visited to make an expedient planning for the field study. To estimate the extent of landslides historical records of the mentioned phenomenon of the concerned area are collected as it is one of the crucial factors responsible for the degradation of the basin. The soil map, landslide susceptibility map are collected to get thought regarding environmental deterioration of the study area as it is to related fluvial system. Meteorological data (2005-2010) of the concerned area is collected to analyse the impact of climate on the morphological characteristics of Rayeng River.

Field study

Field study in geomorphological research is indispensable as to get appropriate understanding of the geomorphological phenomenon of the study area. The methodology for the field study adopted in the field as follows:

First of all the basin has been investigated except areas where the basin is inaccessible or not possible to reach to conjure up overall sensitivity regarding the basin properly. To analyse the basin morphology and hydrology several investigations have arranged in different periods systematically. Cross section area, hydraulic radius, depth, wetted perimeter, discharge, velocity, suspended sediment loads at different selected cross section of Rayeng River and Rambi River (a tributary of Rayeng) have been measured both in monsoon and non-monsoon period in year 2008, 2009 and 2010 correspondingly.

For estimating the intensity and degree of landslide different landslide affected areas of the basin have been observed and vulnerability of the landslide has been measured through direct investigation. Rate of soil erosion of some selected spots of the basin measured from the 2008 to 2010. Samples of the soils are collected from the field to assess the moisture content, field capacity, wilting capacity etc.

Post field study

For detail analysis of the entire study following chronological methods have been followed:

To explain the geomorphology of the basin a geomorphological map is prepared from the respective topographical map of concerned area. Satellite images of the basin have been studied to get accurate knowledge about the physical landscape of the study area.

A geological map of the basin is prepared based on the geological map of the Darjeeling and Sikkim Himalaya published by the Geological Survey of India for analysing the geology of the study area. A composite map is prepared based on the geomorphological map and geological map of the study area to correlate geology and geomorphology of the basin. Meteorological data have analysed to know the control of climate on fluvio-geomorphic processes of the basin.

For detail analysis of the morphometry of the basin different morphometric attributes are calculated. To analyse the linear aspects of the basin stream ordering (after A.N. Stahler, 1964), stream numbering, bifurcation ratio, stream lengths, length ratio, sinuosity indices meandering properties and stream junction angles are calculated from the drainage map of the Basin, which is prepared based on the topographical sheets.

Areal aspects of the basin are analysed in terms of geometry of basin shape (after Horton, 1932; Miller, 1935; Stoddart, 1965 and Schumm, 1956), law of basin perimeter, area height ratio, law of basin area, stream frequency, drainage density (after R.E. Horton, 1932), drainage texture (after G.H. Smith and Horton, 1945) and roughness index. Analysis of the relief aspects of the basin incorporated hypsometric analysis (after F.J. Monkhouse and H.R. Wilkinson, 1967), clinographic analysis (after Stahler, 1962 and Finsterwalder, 1980), slope analysis (after C.K. Wentworth, 1930), relative relief (after Smith, 1935), dissection index (after Dov Nir, 1957) and channel slopes (after R.E. Horton, 1945 and Morisawa, 1952). Longitudinal profile and cross profiles are prepared from the topographical map and field data respectively. Different cross sections are presented based on the field study to analyse the behavioral changes in hydraulic characteristics in different period.

Various statistical techniques are applied to analyse the relationship between various morphometric attributes of the basin. In this perspective, regression, correlation coefficient etc are calculated with the help of SPSS 10.0 statistical software.

To assess the magnitude of soil erosion of the basin, Universal Soil Loss Equation (USLE) is applied. Systematic mapping of soil erosion has also been done to get clear idea concerning the impact of soil erosion on the fluvio-geomorphorphic characteristics of the basin. The estimated soil erosion of the basin is compared with the actual soil erosion of some selected area of the basin.

The factors blamed for the landslides of the basin area are analysed. For this purpose geological structure, characteristics of rainfall, geomorphology of the basin are analysed properly. Man induced factors responsible for landslides in this basin are also studied. Intensity of environmental degradation in the basin area estimated based on the previous records and field observation. In this connection behavioral changes of fluvio-geomorphic characteristics of the basin due to environmental degradation have been assessed. To assess the usefulness and potentiality of resources of the basin land capability classification has been adopted.

GIS software has been used to visualizing and mapping of different aspects related to study. Manual techniques are also applied for mapping of some aspects of the basin.

Finally from the overall study conclusion has been made and some measures for the utilization of the resources of the basin are suggested.

Materials and Methods for Study

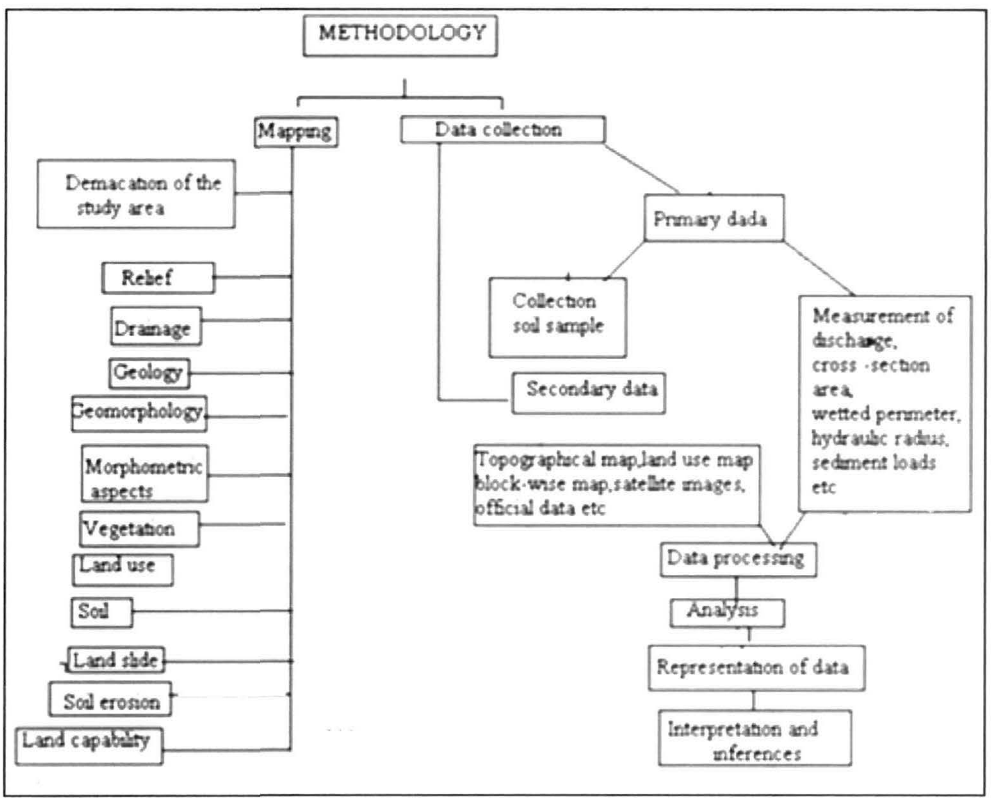

Figure 1.3 Flow chart showing data base and methodology of the study.

1.6 Limitations of the study

There are some limitations of this study as follows:

a) The topographical sheets of the study area published by Survey of India based on survey in 1960s. New updated topographical sheets have not yet been available. So the information from the topographical sheet may not be describing the contemporary status.

b) Many parts of the basin are inaccessible. So, comprehensive fieldwork in these parts was hindered.

c) Due to scantiness of fund sophisticated instruments were not feasible to employ in the field study. For more cherished study such advanced instrument would be used.

1.7 Literature Review

For the better insight of this research work, a number of literatures are conferred with thoroughly. Following previous works on river basin characteristics and its connected Phenomenon have been studied:

"*Administrative Atlas of West Bengal*" published by the Directorate of Census operations, West Bengal (2001). In this Atlas, it is described that the Darjeeling District is lying in between 26° 27′10′′ and 27° 13′15′′ N latitudes, and 87° 59′30′′ E and 88° 53′00′′ E longitudes. The Darjeeling Himalayas including Duars extends in the northern part of the District. The hill ranges extend from northwest to southeast alignment, its elevation varies from 300 to 3000 m above mean sea level, and many hill peaks are concentrated in its limit. The Darjeeling District Spur is remarkable zone. The District is characterised by its physical configuration, drainage pattern and geological structure. Tista, Great Rangit, Mechi, Balasan and Jaldhaka mainly drain the District. There is subtropical and temperate type of forests. On the hill slopes and Darjeeling spur, many tea gardens are found well developed. The growth of vegetation is greatly influenced by the climatic condition, which has developed the subtropical forest. The mountain stream Rayeng is a right bank tributary of Tista River. The basin comprises the parts of the areas of three C.D Blocks of Darjeeling District i.e. Rangli-Rangliot, Kurseong, and Kalimpong -I respectively. Northern, western, and northwestern tracts of the basin covered Rangli-Rangliot Block. Southern tract of the basin occupied the northern part of the Kurseong Block. At the confluence of Rayeng and Tista the basin covered the few part of western tract of Kalimpong Block-I.

Final report published by Prof. Mamata Desai, Project Coordinator, Department of Ecology & Environment, Netaji Institute for Asian studies, 1, Wood Burn Park, Kolkata on "*Identification and Mapping of Hazard prone areas regarding landslide in the Darjeeling Himalaya*". From the mentioned report, widespread information gathered concerning important river, important roads, Geological layout, soils, climate, forests and land use pattern.

"*The Gazetteer of Sikkim*" introduced by H.H. Risley (Indian Civil Service, companion of the Indian Empire Officer 'D' Academic Françoise). In this gazetteer, geology, physiology, soil, vegetation, rivers of the Darjeeling Himalaya described thoroughly.

"*Daling Group and Related Rocks*" Special Publication No. 22, Geological Survey of India, Calcutta, India, in this publication S.K. Acharya and K.K. Ray (1989) discussed in detail about the geological features related to Daling group in Darjeeling Himalaya. The authors affirmed that in Darjeeling Himalaya, tectonic units take place in the reverse order of stratigraphic superimposition. In the Darjeeling hill the Daling group is comprised of low-grade metamorphic rocks, while the Darjeeling Group consists primarily of gneisses. Rocks of the Paro Sub-group have characteristics similar to the Darjeeling Group are present at lower elevations.

A paper in the title of "*Inverted metamorphism in the Sikkim-Darjeeling Himalaya" was* published by Geological Society of India by P.K. Banerji, P.K. Guha, and L.C. Dhiman, (1980). In this paper P.K. Banerji explained that the occurrence of lineaments, hot springs, lakes, waterfalls, abrupt changes in river gradient, and erraticity in terrace distribution suggested that the area has been undergoing differential uplift along a number of regional and local sub-vertical faults in the Darjeeling Himalaya.

"*Reconsidering Himalayan river anticlines Geomorphology*" in this paper D.R. Montgomery and D.B. Stolar (2006) explained brightly the control of geologic structure on the geomorphology of the Himalayan river basins.

"Timing of recent out of sequence active deformation in the frontal Himalayan wedge: insight from the Darjeeling sub-Himalaya, India" a paper by M. Mukul, M Jaiswal, A.K. Singhvi (2007) analysed the geological setup of the Darjeeling Himalaya and influence of geology on the geomorphology on it.

In the book *"Geology of Himalayas"* Gansser discusses regarding the geology of eastern Himalaya scrupulously.

"*The geomorphology of southeast Australian mountain streams*" a thesis paper presented by Chris J. Thompson in 2006, scholar of physical, environmental and mathematical sciences (Geography) Australian Defence Force Academy, University of New South Wales, is apprehensive with the study of the morphology and sediment transport dynamics of mountain streams. This paper is supportive for enhanced perceptive of significant relationships between drainage area and bank full area, with mean depth and discharge of the mountain streams.

A paper primed by Florida Department of Transportation in December 2004 under the title *"Regional channel characteristics for maintaining Natural Fluvial Geomorphology in Florida streams"* is concerned with the cumulative result of the geological history of the Deschutes River Basin is that the basin has distinct geologic, hydrologic and geomorphic attributes when compared to other Western U.S. rivers. The main outcomes of this study are that the present streams network of Florida and valley morphology has resulted from tens of millions of years of tectonic, volcanic and erosional process. The vast extent of young and permeable volcanic rocks and poorly developed surface channel network in the Southern Deschutes River has resulted in a hydrologic system buffered by substantial ground water flow. The steady stream flows coupled with low sediment supply have resulted in extremely low rates of sediment delivery of the Deschutes River. From the study of these paper fluvio-geomorphic characteristics of the mountain, streams and the man-induced changes in the fluvial characteristics appreciably understood.

"*The Lish–Gish basin – A study of its water resources*" by S.R. Basu and L. Ghatwar (1984) is concerned with the fluvio–geomorphic characteristics of the Lish–Gish basin. The main outcomes of this paper are that the fluvio-geomorphic characteristics of the mountain streams of the Darjeeling are highly controlled by the geology and climate of the concerned region.

A paper posture the title *"A Quantitative Study Of The Longitudinal And Cross Profiles (1989-1994) of The River Balasan In The Darjeeling District of West Bengal"* Published In "*Indian Journal of Geomorphology*", Volume 15 (2010), by Sunil Kumar De of Tripura University. He explained that the epeirogenic history of the basin Balasan has been characterized by intermittent uplifts of the Himalayas interrupting the smooth running of a cycle of erosion and thereby, produced a number of sub-cycles or epi-cycles along the long profile of the River Balasan, demarcated by definite breaks of slope. From the cross-sections of three different gauge lines of both monsoon and non-monsoon periods, it is seen that no definite trend of change of the channel has occurred during the six years of study. Although the filling of the channel has been alternated by scouring, there is no definite trend in it.

Ro Charlton in his book in the title of "Fundamentals of Fluvial Geomorphology" (2006) has analysed competently concerning the fluvial system, flow regime, sediment sources, large scale sediment transfer, flow in channels, processes of erosion, transport and deposition, channel form and behaviour, system response to change and managing river channels.

''Geomorphological analysis of drainage basin: An introduction to Morphometry and Hydrological parameter'' a paper presented by P.K. Sen. (1993), Professor of Burdwan University is concerned with the geomorphological characteristics of the drainage basin. The striking outcomes of this study are that there is correlation between the morphometric attributes of basin. Unexpected alteration in the river system caused due to human interferences.

The paper under the title of *''Applying a fluvial Geomorphic classification system to watershed Restoration''* is presented by Terry Benoit and Jim Wilcox. In this paper, he envisaged that the fluvial geomorphic classification system is a valuable tool for supporting the decision-making resource professionals and for helping, the public be aware of the morphological characteristics of the different alternatives and the probable responses and risks. The classification system is also a victorious tool that helps increase our power of scientific observation. The system is not the answer in itself, but is a mechanism for seeking answers. From this paper, precise idea regarding the fluvial geomorphic classification has been conceived.

"Rivers of the Bengal" a written by Kumud Ranjan Biswas (IAS), volume – I, "*Rivers of the Bengal Delta*" by S.C. Majumder, "*The Ancient system of Irrigation in Bengal*" Sir William Willcocks, *"Recent Changes in the Delta of the Ganges"* by James Fergusson provided a lot of information concerning the river systems of Bengal. These are useful to expand clear-cut knowledge about the nature of the rivers of Bengal.

K. Bagchi, 1942 "*The flood problem (A case study for geographical background)*" has appreciably consulted.

A research based book "*Geomorphology of Damodar Basin*" by S.N.P Gupta concerned with the analysis morphometric properties of Damodar Basin. This book is very much accommodating for the study of basin morphometry.

The book "*River Basin Morphology*" by Hijam Ibeyaima Devi concerned with the morphometric analysis of basin properties. This book is considerably helpful for appropriate understanding of mountain river basin.

John C. DoornKamp, and C.A.M, King, 1971 "*Numerical analysis in Geomorphology- An introduction*" has consulted for the morphometric analysis and research methodology.

"Morphometric analysis of Gostani River Basin in Andhra Pradesh State, India using spatial information technology" is a paper written by Nageswara Rao. K, Swarna Latha, Arun Kumar and M. Hari Krishna published in "*International Journal of Geomatics and Geosciences"*. In this paper morphometric characteristics of Gostani River Basin are analysed by spatial information technology (SIT) i.e. Remote Sensing (RS), Geographical Information System (GIS) and Global Positioning System (GPS). GIS and image processing techniques have been adopted for the identification of morphological features and analyzing their properties of the Lower Gostani River Basin (LGRB) area in Andhra Pradesh state, India. The basin morphometric parameters such as linear and aerial aspects of the river basin were determined and computed.

"*Fluvial Processes in Geomorphology*" written by Luna B. Leopold, M, M, Gordon Wolman and John P. Miller (1964) explained deliberately as regards the fluvial processes. The authors applied the quantitative techniques to assess the fluvial processes.

"*Soil Erosion Mapping with universal soil loss equation and GIS*" a paper presented by C. Mongkolsawal, P. Thirangoon, S. Sriwongsa of KhoKaen University, KhonKaen , Thailand. The intention of this study is to ascertain spatial information of soil erosion using the universal soil loss equation (USLE) and GIS. The main result of this is that, it is feasible to spatially and quantitatively analyze multi-layer of data within a watershade using GIS technology in combination with remote sensing can provide systematic data in dynamic manner for decision–support system.

R.P.C.Morgan (1994) in his book entitled "*Soil Erosion and conservation*", discussed about the processes and mechanisms of soil erosion, factors influencing soil erosion, erosion hazard assessment, modeling of soil erosion, measurement of soil erosion, strategies for erosion control, crop and vegetation management, soil management, mechanical methods of erosion control and implementation of soil erosion control method.

"*Studies on the structural stability of some soils of West Bengal*" a paper represented by C.J. Thampi and Asit Kumar Mukhopadhay (1973). The authors have collected four representative soils from Nadia, Brigham, 24 Parganas and Darjeeling Districts of West Bengal .Based on their investigation they started that status of aggregation of these soils varies considerably. The structural stability of Brown forest soil is than the remaining three soils. Thus the Brown forest soils are more resistant to soil erosion in the textural context

"*Riverbank and Coastal Erosion Hazards: Mechanism and Mapping*" is a paper by Sunando Bandyopadhyay, University of Calcutta (2007). He explained specifically about the techniques to measure the magnitude of riverbank erosion. Causes of riverbank erosion have been discussed in this paper scientifically.

A paper under the title of "*Using Field* Indices *of Rill and Gully in order to Erosion Estimating and Sediment Analysis-Case Study: Menderjan Watershed in Isfahan Province, Iran*" Masoud Nasri, Sadat Feiznia, Mohammad Jafari, and Hasan Ahmad , published in "International Journal of Human and Social Sciences(2009). In This paper researchers have affirmed that increased exploitation of land resources in the upper parts of catchments results in increased sediment yield and elevated nutrient loads in runoff that reduces water quality and availability to downstream users. Furthermore, control of sedimentation in reservoirs requires that all the potentially significant sediment sources and sinks are known. Gully erosion is often the main source of sediments. Gully erosion has been long deserted for the reason that it is difficult to study and to predict.

"Soil erosion modeling using RULES and GIS on the Imha watershed, South Korea" a thesis paper submitted by Hyeon Sik Kim, Department of Civil Engineering, Colorado State University Fort Collins, Colorado Spring (2006). The final outcomes of his study were that most of the Imha watershed is forested and only 15 percent is used for agriculture with paddy and crop fields. This mountainous watershed has steep slopes around 40%. Due to this topographical characteristic, most of the watershed is vulnerable to severe erosion. Soil erosion from steep upland areas has caused sedimentation in the Imha reservoir. It has also deteriorated the water quality and caused negative effects on the aquatic ecosystem.

"Assessment of soil erosion based on the method USLE; Çorum Province" a paper by Fazlı Engin Tombuş, Mahmut Yüksel, Murat Şahin, İbrahim Murat Ozulu and Mustafa Coşar, of Turkey(2005). This study was established to predict the average of soil loss (tons/hectare) per year by combining the USLE method and geographic information system.

"A summary of techniques for measuring soil erosion" Prepared for the Ministry for the Environment and the Regional Councils' Land Monitoring Group by Dr. Douglas L. Hicks, Ecological Research Associates (NZ) Northern Office, and North Auckland November 2001. In this paper, field techniques for measuring soil erosion is demonstrated clearly.

"Assessment of soil erosion in the Nepalese Himalaya, A case study in Likhu Khola valley, Middle Mountain Region" this study was performed by (1997) Dhruba Pikha Shrestha of International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, the Netherlands. In this study he concluded that soil erosion is a crucial problem in Nepal where more than 80% of the land area is mountainous and still tectonically active. Although deforestation, overgrazing and intensive agriculture due to population pressure, have caused accelerated erosion, natural phenomena inducing erosion, such as exceptional rains, earthquakes and glacial-lake-outburst flooding in the high Himalayas are also common. It is important to understand the erosion process under normal conditions and to assess the magnitude of problem so that effective measures can be implemented.

"Assessing of soil compaction using some soil properties caused by agricultural machinery traffic" this paper was presented by G.R. Mari and Ji Changying (2007). In this

paper, the author discussed in detail about the compaction of soil based on different soil properties.

"Assessing the USLE *crop and management factor C for soil erosion modeling in a large mountainous watershed in Central China"* (2006) in this paper Sarah Schönbrodt, Patrick Saumer, Thorsten Behrens, Christoph Seeber and Thomas Scholten inferred that the *C* factor represents the vegetation cover and crop and management practices and thus is a major and sensitive factor in the USLE in order to predict the long-term annual average soil loss potential. Considering several sub factors, the calculation of C factor values from field investigations is very time consuming. An adequate alternative for larger researches areas is the assignment of C factor values from literature, which correspond to land use classes, e.g., classified with Landsat TM images. Further, the NDVI based on Landsat TM images serves as an environmental covariate of vegetation.

"Ecosystem vis-à-vis landslides - A case study in Darjeeling Himalaya, Impact of Development on environment" a research paper is prepared by S.R. Basu and S. Sarkar (1987) is concerned about the interference of man in the geomorphic process and unexpected change made environmental disorder damaging the environmental system. The outcomes of this paper are that the fluvio-geomorphic unexpected abrupt changes in rivers and streams of the Darjeeling Himalaya due to plantations and unscientific farming practices, pasturing on the hill slope. Increase in the vulnerability of landslide due to construction of roads on the hill slope ignoring the geological structure. This paper is helpful for better understanding about man-induced alteration in environmental system.

Prof. Subash Ranjan Basu and his Research fellow Biswajit Bera, University of Calcutta (2007) in a paper under the title *"Landslide Hazard zonation mapping"* explained the techniques of landslides hazard Zonation mapping. The authors assessed the intensity of landslides in Singtam-Ranipool sector of East Sikkim anchored in the field study and ready a hazard zonation mapping of the study area.

"Ambootia Landslide Valley — Evolution, Relaxation, And Prediction (Darjeeling Himalaya)" a paper by Leszek Starkel (Krakow) published in the journal *"Studia Geomorphologica Carpatho- Balcanica"* Vol. XLIV, (2010). Based on his study the author concluded that the Ambootia landslide valley has reached a stage of maturity and stabilization over the last few years. This is primarily the result of revegetation and the development of anti-erosion measures across the valley floor. Only a number of steep rocky parts are still exposed to small rock falls, slumps, and slides. Localized earth flows may become accidentally triggered on the vertical walls of niches formed in colluvial deposits and debris flows in the main river channel during episodes of high intensity

rainfall. It cannot be ruled out that after decades of bedrock weathering by continuous rainfall since the 1968 landslide, the upper niche of the landslide valley may retreat again or the main gully may become dissected again by robust debris flow. In the Darjeeling Himalaya, there exist many deep and wide valleys segmenting mountain slopes. Such valleys probably formed in a manner similar to that of the Ambootia landslide valley via the combined long-term effects of gravitational processes and linear erosion. Long-term observations carried out in the Ambootia landslide valley have shown that the stabilization of a large landslide is a gradual process and requires several decades of time in order for this type of process to reach completion.

"An Integrated Approach for Landslide Susceptibility Mapping Using Remote Sensing and GIS" this paper prepared by S. Sarkar and D.P. Kanungo and published in the journal "*Photogrammetric Engineering & Remote Sensing*" Vol. 70, No. 5, May 2004. In this paper the authors concluded that the landslide susceptibility maps help in decision making, while implementing a development project in the terrain. It is always better to avoid the highly susceptible zones but, if not possible, corrective measures must be worked out to minimize the probability of landslide occurrences.

"*Geomorphology and River Management*" a paper by Avijit Gupta, School of Geography, University of Leeds, published in the book *"Society Development and environment*" edited by Ranjan Basu and Sukla Bhaduri (2006). In this paper the authors discussed that how geomorphology influences the use of river water for the construction of dams and irrigation projects. He also analyzed that how geomorphological characteristics of river basins are altered due anthropogenic activities. He argued that rivers could usually be only partially restored or managed to coexist with changed conditions of their drainage basin.

Guruprasd Chattapadyay, Professor of Geography, Visva Bharati expressed that flood is a climatic hazard in his paper *"Flood as a Climatological hazard"* published in 2007. He also discussed in detail regarding method to measure the magnitude of food and preparation of flood affected zonation mapping.

"Traditional methods of forest and water disaster management by Mangham Tribal People" (2007), a paper by Nirmal Kumar Mahato and Archan Bhattacharya published in the book "Recent development of Disaster Management". In this paper, the authors inferred that tribal knowledge, a valuable part of the traditional knowledge system, could be used success fully to manage the forest and water resources of concerned area.

"*Geomorphology and vegetation on hillslopes: Interactions, dependencies, and feedback loops*" by A. Richard Marston (2009), Department of Geography, Kansas State

University. In this paper the author explained that hillslope vegetation and landforms, however, co-evolve. One key is to understand the role of time, disturbances, and feedbacks that link vegetation and geomorphology on hillslopes. The effects of vegetation on mass movement and landscape evolution are being studied in new ways. Many regional studies claim that vegetation becomes less relevant as one move to larger and larger watershed scales, but eco-region analysis offers a contrasting view. Whereas these efforts have produced vehicles of understanding that are simple, ordered, unified, and harmonious, they often do not reflect the complexity that leads to multiple possible outcomes place-dependent results. Recent perspectives focus on the two way interplay between vegetation and hillslope geomorphology, where establishing cause and effect linkages is made difficult by confusing factors (spatial–temporal scale, location, convergence, divergence, nonlinearity, thresholds, and feedbacks).

A paper "*Disturbance regimes of stream and riparian systems a disturbance-cascade perspective*" presented by Futoshi Nakamura, Frederick J. Swanson and Steven M. Wondzell were published in the journal "Hydrological processes" (2000). In this study the authors described that geomorphological processes that usually transport soil down hillslopes and sediment and woody debris through stream systems in steep, mountainous, forest landscapes can operate in sequence down gravitational flow paths, forming a cascade of disturbance processes that alters stream and riparian ecosystems. The affected stream and riparian landscape can be viewed through time as a network containing a shifting mosaic of disturbance patches linear zones of disturbance created by the cascading geomorphological processes. Ecological disturbances range in severity from effects of debris flows, which completely remove alluvium, riparian soil and vegetation along steep, narrow, low-order channels, to localized patches of trees toppled by floating logs along the margins of larger channels. Land use practices can affect the cascade of geomorphological processes that function as disturbance agents by changing the frequency and spatial pattern of events and the quantity and size distribution of material moved. A characterization of the disturbance regime in a stream network has important implications for ecological analysis. The network structure of stream and riparian systems, for example, may lend resilience in response to major disturbances by providing widely distributed refuges. An understanding of disturbance regime is a foundation for designing management systems.

In his book "*India's Water Wealth*", K.L. Rao in 1995, deliberately assesses the potentiality of the water resources of India. To assess the water resources of India he has widely discussed the fluvio- geomorphic characteristics and environmental conditions of the major river system. He suggested several measures to manage the water resource without severe damage of the environmental condition. His valuable works are appreciably helpful to assess the potentiality of water resource of a river.

"River basin development and management" in this writings François Mole, Philippus Wester and Phil Hirsch, Jens R. Jensen, Hammond Murray-Rust, Vijay Paranjpye, Sharon Pollard, and Pieter van der Zaag (2005) have been concluded that not all problems can or should be solved at the river basin level. Water quality or flood problems may be more local in scope. Watershed initiatives also signal that local governance is more effective, but how to integrate scattered initiatives within the larger basin remains a crucial question. While river basins are relevant units for planning water resource development, many problems affecting them and their solution—may well lie beyond the basins themselves. Agricultural policies, free trade agreements, demographic changes, and shifts in ideologies or societal values can all have a bearing on water use and call for dynamic and adaptive river basin management.

In the book *"Geomorphology and River Management Applications of the River Styles Framework*" (2006), Gary J. Brierley and Kirstie A. Fryirs have concluded that river styles framework provides a research and management tool with which to build up suitable catchment-specific understanding. The final achievement of this framework should be measured through its use as a learning tool and its application as a guide for planning on-the-ground river management activities. And finally, "Don't underestimate the challenge." Be realistic in framing goals, working from a premise that strives to "under promise and over deliver." Ultimately, no one is better off if the ecological integrity of the river is compromised.

In a paper *"Mountains and freshwater supply"* Hanspeter Liniger and Rolf Weingartner(2003) are with the Institute of Geography, University of Bern, Switzerland, inferred that mountains are of paramount importance for the supply of water for drinking and for food, energy and industry. Freshwater from mountain areas also supports unique ecosystems and biodiversity in both highlands and lowlands. Mountain regions are under pressure from deforestation, agriculture and tourism, and from increasing demands on their resources in the densely populated lowlands regions; they are marginal areas for human habitation, as they are limited by steep slopes, poor soils, cool temperatures and inaccessibility. The surrounding lowlands are usually more favorable for settlement, agriculture and industry, but remain dependent on the mountains for water resources.

The book entitled *"Soil Survey and Land Evaluation"* by David Dent and Anthony Young (1981) concerned with the soil erosion and conservation. In the ninth chapter of this book concepts and assumption, structure of the classification, survey procedures, using land capability classification are described in detail.

1.8 The problem of the study area

Environmental degradation and ancillary problems are the most pervasive of natural problems that hinder the economic and cultural development of the study area. Tea plantation, extensive heedless deforestations, shifting cultivations, haphazard constructional works, inadequate drainage in the other words unscientific and unplanned usage of land, has led to the establishment of the vicious cycle of degradation. Landslides, soil erosions and associated phenomenon provoke more and more silt to the Rayeng basin, which is incapable of transporting the bed loads efficiently under existing hydrological conditions especially along its lower reaches. During summer, the observed increment of the size of the bars and shoals downstream proves such condition. In order to avoid such islands in midst of the channel the river in its lower reaches attain the significant physical characteristic of braiding and this attribute to both incompetence and in capability of the river. Moreover, the narrow roads bridges spanning over the river at the foothills as well as the pillars encouraging these which are always considered as the barrier interrupting natural load movement behaviors of the rivers Rayeng and Rambi causing more and more deposition at the bottom of the bridges and thereby narrowing the outlets of the river gradually. Constriction some time more due to the entanglement of uprooted trees to the voluminous flows often multiply to many times may damaging the bridges. The picture is just opposite during the non- monsoon months when the paucity of water hinder the local people from reaping any benefit out of the soil in conjugation with the river itself.

At this crucial moment, therefore, suggestion of remedial measures and their active implementation is a vital concern to the nation as a whole, on it depends the ecological balance and geomorphological stability of this extremely vulnerable region.

References

Acharya, S.K. and K.K. Ray (1989): Daling Group and Related Rocks, Special Publication No. 22, Geological Survey of India, Calcutta, India, p. 105.

Banerji, P.K., P.K. Guha, and Dhiman, L.C. (1980): *Inverted metamorphism in the Sikkim-Darjeeling Himalaya*, Geological Society of India, 21, pp. 330–342.

Basu, S.R. & Bera, Biswajit. (2007): *Landslide Hazard Zonation Mapping,* Journal, Contemporary Issues and Techniques in Geography, Progressive Publishers, Calcutta, pp. 24-34.

Basu, S.R. & Sarkar, S. (1987): *Eco-system vis-à-vis Landslides – A Case Study in Darjeeling Himalayas, Impact of Development on Environment, Calcutta,* and Vol. 2, pp. 45-53.

C.J. Thampi and Mukhopadhay, Asit Kumar (1973): *Studies on the structural stability of some soils of West Bengal,* Faculty of Agriculture, University of Kalyani, pp. 47-52.

Charlton, Ro. (2007): *Fundamentals of Fluvial Geomorphology*, Routledge Publication, 2 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN, p. 14.

Chattapadyay, Guruprasd (2007): *Flood as a Climatological Hazard,* Journal, Recent development of Disaster Management, pp. 110-112.

Chorley, R.J.(1969): *The Drainage Basin as the Fundamental Geomorphic Unit*, Methun & Co. Ltd., GB, Vol. 2, pp. 77-99.

Chris, J. Thompson (2006): *The geomorphology of southeast Australian mountain streams*" physical environmental and mathematical sciences (Geography), Australian Defence Force Academy, University of New South Wales, pp. 1-105.

Cotton, C.A. (1948): *Landscape as developed by the processes of normal erosion,* Whitcombe and Tombs, Ltd., Willington, New Zealand, p. 509.

Dent, David and Young, Anthony (1981): *Soil Survey and Land Evaluation,* George Allen & Unwin (Publishers) Ltd. London, pp. 128 -139.

Desai, Mamata. (2006): *Identification and Mapping of Hazard Prone areas regarding landslide in the Darjeeling Hill areas.* Department of Ecology & Environment, Netaji Institute for Asian Studies, 1, Woodburn Park, Kolkata, pp. 6-17.

Directorate of census operations, West Bengal (2001): *Administrative Atlas of West Bengal,* Census of India, pp 10 – 11.

Doornkamp, J.C. and Cuchlaine, A.M.K. (1971): *Numerical Analysis in Geomorphology – An Introduction,* Edward Arnold, London, pp. 1- 65.

Florida Department of Transportation (2004): *Regional channel characteristics for maintaining Natural Fluvial Geomorphology in Florida streams,* Florida Department of Transportation, pp. 1- 95.

Froehlich, W. Starkel L. Lèszek (1991): *Ambootia landslide valley in the Darjeeling Himalaya, active since 1968.*Bulletin of the Polish Acad. Sc. Series Earth Sc. pp. 39, 2, and 11–128.

Gary, J. Brierley and Kirstie A. Fryirs (2005): *Geomorphology and River Management; Applications of the River Styles Framework*, Blackwell Publishing, Australia, pp. 4, 17 & 44.

Ghatwar, L. and Basu, S. R. (1984): *The Lish-Gish basin, a study of water Resource, Indian Journal of Power and River Valley Development.*Vol.34, pp. 125-131.

Gupta, Avijit. (2006): *Geomorphology and River Management*, Progressive Publishers, Calcutta, pp. 54-61.

Horton, R.E. (1945): *Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology*, Geol Soc. Am. Bull. pp. 56, 275-370.

Huggett John Richard (2007): *Fundamentals of geomorphology,* Routledge publication, London, pp. 185-220.

Kothari, C.R. (1990): *Research Methodology, methods and techniques,* Vishay Prakasn, New Delhi, pp. 170-184.

Mahato Nirmal Kumar and Bhattacharya Archan (2007): *Traditional methods of forest and water disaster management by Mangham Tribal People* , Journal, Recent development of Disaster Management, pp. 125-131.

Morgan, R.P.C., D.D.V. Morgan and H.J. Finney, (1982): *Stability of agricultural ecosystems, documentation of a simple model for soil erosion assessment,* International Institute for Applied Systems Analysis Collaborative Paper pp. 82-50.

Morisawa, M.E. (1958): *Measurement of drainage basin out line form.* Jour. Geol., Vol. pp. 60, 587-591.

Nakamura, Frederick J. Swanson and Steven M. Wondzell (2000): *Disturbance regimes of stream and riparian systems a disturbance-cascade perspective,* journal, Hydrological processes, pp. 63-74.

Richard A. Marston (2009): *Geomorphology and vegetation on hillslope; Interactions, dependencies, and feedback loops,* Journal of Geomorphology, USA, pp. 206 -217.

Risley H.H. (1928): *The Gazetteer of Sikkim,* Low Price Publications, Delhi, India.

Sarkar, Kalyan. and Sarkar, Indrani (2010): *Earth surface Forms and processes- a Geomorphological approach,* Mitram Publication, Kolkata, and pp. 436-507.