Chapter 1

Physico-Chemical and Sanitary status analysis of Torsa river water

1. Physico-Chemical and Sanitary status analysis of Torsa river water:

The demographic explosion of India has caused an extraordinary growth in the demand of water for domestic water supply, agriculture, industry and other purposes. Ruthless exploitation of ground water has also serious consequences. In recent years, certain cases of dangerous pollution of ground water have been reported from different parts of the country, especially with toxic heavy metals and arsenic. Scarcity of water, therefore, demands for a better exploitation of hydrological resource and development and improvement of water techniques and water sciences. The annual precipitation in the sub-Himalayan West Bengal and Sikkim (3000-4000 mm) is more than triple the Indian average (1150 mm), and more than 80% of it occurs between June to September. As most of the precipitation occurs within a short spell of time, frequent floods are very common menace in the catchments.

Rivers of northern West Bengal can become a potential source of water, since the rivers of Himalayan foothills presumably do not run the risk of being contaminated with toxic industrial discharges except surface runoffs from tea gardens and agricultural fields. Monitoring of river water quality of North Bengal thus has become a commitment, which is generally being overlooked for various reasons, amongst which are primarily the resource and manpower constraints, institutional inertia and public apathy due to lack of awareness.

There are four major glaciers fed rivers in this sector of country, named Teesta, Torsa, Jaldakha and Mahananda. The mean annual discharge rate of rivers, Teesta, Torsa and Mahananda, were estimated to be 645 (at Domohoni), 275 (near Hasimara) and 95 (at Fulbari) cubic meter/sec respectively at district Jalpaiguri of the state West Bengal, India. Average suspended sediment load of the rivers, Teesta, Torsa, and Mahananda were 6.105, 2.91 and 1.215 million metric tons/year respectively, at above-mentioned sampling sites (Bhadra *et al.*, 2003).

Torsa is second largest river of North Bengal. This is an international river, traversing four countries. It originates at China (Tibet), and flows through Bhutan with the name of 'Amo-chu' before entering India, and from India the river enters into Bangladesh. The river flows rapidly and follows a confined valley between precipitous mountains. Even in the winter, 'Amo-chu' is a fierce, swift stream. Torsa cuts across in a southeasterly direction and passes through a market town of Phuntsholing on the Indo-Bhutan border. In the west of Torsa river Baxa-dolomites form striking ridges, which can be seen from phuntsholing (Karan and Jenkins, 1967). As it leaves the foothills of Bhutan and enters the undulating Duars plain in the northern part of West Bengal, it widens into a braided channel and drains into the forest cover of Jaldapara wild life sanctuary. Water quality of this turbulent river, therefore, remains unaltered because of its environment, climatic, geologic, hydrologic, physiographic, biological and cultural backdrop. The Torsa serves as a principal source of water to the wild life, forest tribes and rural communities. The inhabitants of the Torsa catchment use well water, pond/ditch water along with the river water depending on season and purposes for which the water is used.

With the development of roadways connecting Bhutan and India and advent of modernizations in Bhutan in 1950, much urban and industrial development is noticed in and around Phuntsholing, which lies on the bank of Torsa and also in the adjoining Duars plain in India (Karan and Jenkins, 1967). Indiscriminate dolomite mining in Bhutan hillocks for cement factories has led to a large-scale seepage of dolomite in ground and surface water (Dutta, 1998; Statesman News Service, 1998). On the other hand, the swelling rural population of this region does not have services of any kind whatsoever, either for potable water or for excreta disposal. The consequent consumption of this river water, which has now degraded, is making the inhabitants of this valley more prone to diseases and health problems. Such observations also put

wild life health into question. Furthermore, with industrialization projected towards manifold increase over the current level, river water pollution will become an even greater problem and a matter of serious concern.

Objectives of the Study:

(i) Preparation of a database for the first time about the water quality of the river.

(ii) Evaluation of the impact of various anthropogenic activities leading to the pollution of the river.

1.1. Sampling stations and sample collection from the river water:

For successful monitoring of river water quality it is essential to have sufficient knowledge about the morphometric details of the subject river, selection of particular sampling site(s), sample collection methods, and preservation & maintenance of samples for parameter(s) in question. The study of morphometry, i.e., measurement of morphological features of the river basin, always provides valuable information in selecting sample collection site(s). Water quality of the river water also depends on physiographical factors, such as, basin, bank, catchments area, and settlement around the river, as well as annual sedimentation load, water volume, width, and depth of the river.

During analysis of river water quality, assortment of sampling site(s) is very important, and it should be done in the light of environmental monitoring program. The selection of actual sampling location shall depend upon the character of the water body. In case of widened region of the river many sampling sites should be selected at various corners. In monitoring the stream, which is narrow, the rapidly moving water should be thoroughly mixed laterally and vertically, hence only one sampling point needs to be selected at each location along the stream.

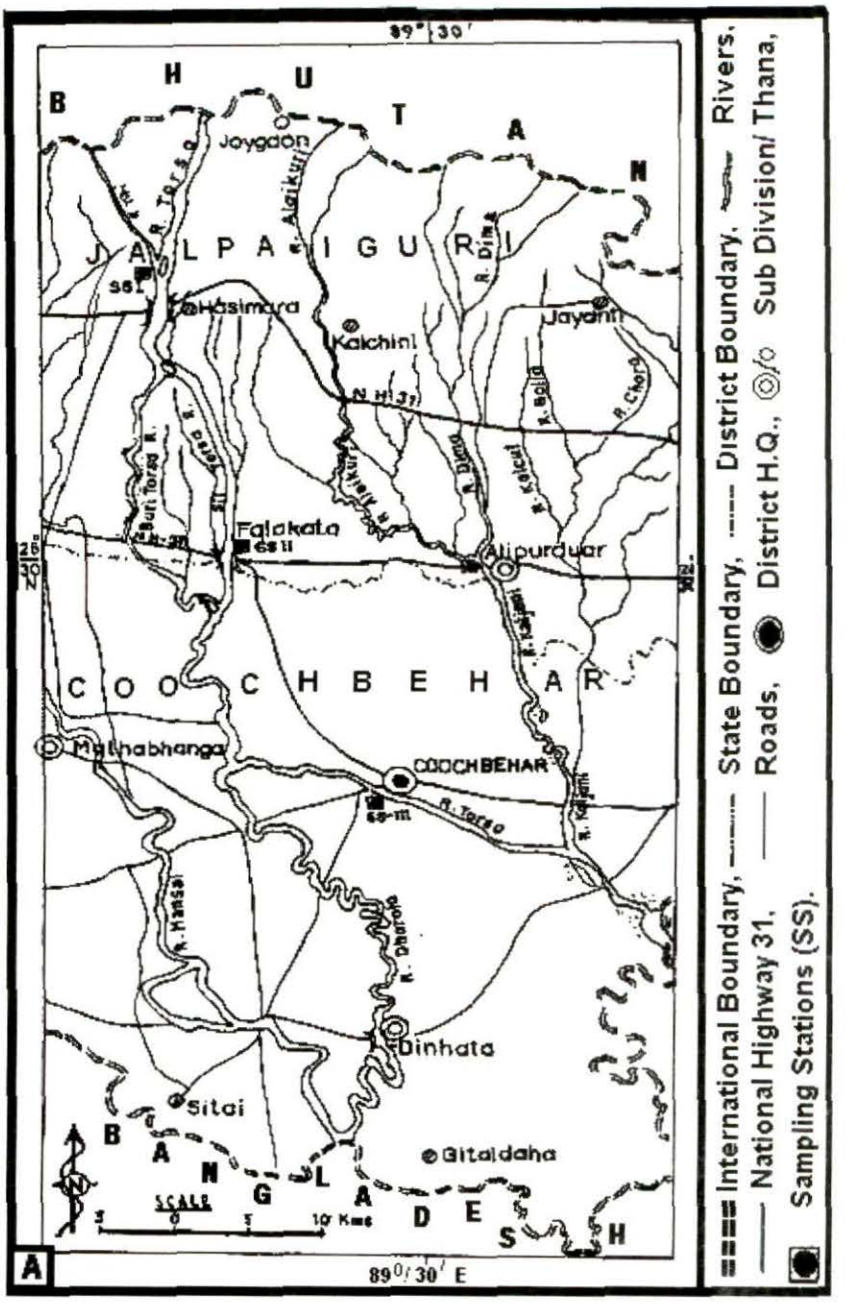
In an organically polluted river course at least one site should be selected above the outfall of the wastes and others should be selected downstream representing the zone of recent pollution. In places here the river is polluted by inorganic substances, one point above and the other point below the actual point of discharge should be selected for sampling.

Water samples collected from the river are of two main types depending on the collection principle; grab-samples, and composite samples. Grab samples are collected at a specific spot at a site over a short period of time, on the other hand, when multiple grab samples are combined and treated as a single sample, it is called composite sample. Samplers and containers should always be thoroughly cleaned before use, and should be rinsed with the sample water before collection. Preferably the amber colored glass containers with polypropylene cap should be used for the collection and preservation of samples.

After collection, analysis should be done within maximum acceptable chemical change. To minimize biodegradation and volatilization between sampling and analysis, preservation of water samples at 4 ^{0}C was recommended (APHA, 1985). Since most parameters change with time, it is imperative to preserve them in a suitable preservative prior to analysis. Dissolved oxygen, pH, temperature, alkalinity, etc. changes quickly with time, hence their estimation is to be carried out in the field only. Quantification of Nitrate, Nitrite, Ammonia, BOD, TDS, Phosphates, Turbidity, Conductance, and Detergents etc. should be performed within 24 h, whereas estimation of Hardness, COD, Chloride, Turbidity, TSS etc. should commence within 4-7 days (APHA, 1985; Manivasakam, 1980).

1.1.1. Selection of sampling stations on Torsa River:

Sampling sites on Torsa River were selected after scrutinizing topographic map of the river. For the purpose of analysis of water quality, three sampling stations were selected (Figure 1.1A). The first sample site, SS-I, is located at Hasimara, Dist, Jalpaiguri of the state West Bengal where Torsa enters into Indian territory from Bhutan, and thereby analysis of water quality at this place throws light on


89° 30'
B H U T A N
Joygaon
R. Torsa
R. Alaikuri
JALPAIGURI
R. Dim
Hasimara
Kalchini
Jayanti
N.H 31
R. Bolla
R. Chord
R. Kaljani
R. Dima
Falakata
Alipurduar
COOCHBEHAR
Mathabhanga
R. Torsa
R. Kaljani
R. Hansai
R. Dharla
Dinhata
Sitai
Gitaldaha
BANGLADESH
SCALE
5 0 5 10 Kms
A
89° 30' E
International Boundary, State Boundary, District Boundary, Rivers,
National Highway 31, Roads, District H.Q., Sub Division/ Thana,
Sampling Stations (SS).


B

Fig. Contd.

Figure 1.1. (A), Map showing sampling stations on river Torsa; (B), snap of SS-I at Hasimara,Dist. Jalpaiguri showing high sedimentation in river bed; (C), nature of river banks (left and right) at SS-II at Falakata, Dist. Jalpaiguri; D, High sedimentation at SS-III at Ghugumari, Dist. Coochbehar

different anthropogenic activities influencing the water quality of Amo-Chu (synonym Torsa at Bhutan) and also helps understand the quality of water that drains into the Jaldapara Wild Life Sanctuary of North Bengal, which is the immediate destination of the river. At this sampling site the river is very turbulent, flows at high speed through pebbles and the river basin is around 700 meter wide. After SS-I, the river is alienated into small channels and enters into Jaldapara Wildlife Sanctuary; serving drinking water to the wild life and forest tribes. While leaving the sanctuary, small channels again fuse and form two large and wide branches at village- Falakata of Jalpaiguri district, named Sil-torsa and Buri-torsa, where Siltorsa is the major and wider (890 m) stream and were our second sampling station, SS-II. The river at this site is shallow, wide and less turbulent. The bank is made up of dry white sand. After leaving site SS-II, the tributaries, Siltorsa and Buritorsa, meet at district town of Coochbehar, of the state of West Bengal, India. This was our third sample collection site, SS-III, where the depth of the river is more and flows slowly. The riverbank is made up of clay, sand and humus.

1.1.2. Sample collection:

From each sampling site, three grab samples were collected from left, right and middle of the river; all three samples were mixed and, were treated /analyzed as single sample. Water samples were collected to a final volume of 2.5 L in amber colored glass container having polypropylene cap, and were preserved at 4 ^{0}C before analysis. Samples were collected once in every month from April 2001 to March 2002, leaving the months July and August, because of heavy rainfall and flood during the monsoon which made the condition of river and roadways both equally deplorable so that the task of collecting sample became very difficult.

1.2. Physico-chemical analysis of water samples:

Detailed analyses of physical and chemical quality of the samples were completed within 48 hours after collection. Temperature, pH, conductivity, Total Dissolved Solid (TDS), Dissolved Oxygen (DO), Chloride, anionic or cationic detergent content were analyzed or quantified at the spot during sample collection. Other analyses, such as, estimation of Total Suspended Solid (TSS), Alkalinity, Turbidity, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammonia-Nitrate-Nitrite 'N', Total Phosphorus, Silica, and Hardness were estimated in the laboratory.

1.2.1. Materials and Methods:

For the preparation of reagents, analytical grade chemicals and deionized double distilled water were used. Deionized double distilled water was used as negative control in experiments wherever required.

1.2.1.1. Temperature:

Temperature was recorded with the help of a digital thermometer (ELICO, India). For determination of water temperature the thermal sensor of the thermometer was dipped under approximately 30 inches from the surface of water for 5 minutes and was noted. Air temperature was noted directly from the 'air temperature display' of the thermometer.

1.2.1.2. pH:

pH was recorded with the help of a digital pH meter (SYSTRONICS, India). Before estimation of pH the instrument was standardized according to the manufacturer's instruction.

1.2.1.3. Conductivity:

The conductivity was measured by employing a conductivity meter (SYSTRONICS). The instrument was standardized according to the manufacturer's instruction.

1.2.1.4. Total Dissolved Solid (TDS):

TDS-recorder of 'Water Quality Analyzer' (PE 136, ELICO) was used to quantify TDS during collection of sample on the spot according to the manufacturer's instruction.

1.2.1.5. Total Suspended Solid (TSS):

For estimation of TSS, 100 ml water sample was passed through a dry, pre-weighed Gooch crucible (BOROSIL) and was evaporated to dryness in a hot air oven for 1h at 103-105 ^{0}C followed by rapid cooling in a vacuum desiccator. The calculation and expression of TSS in mg/l was done using formula, (W2-W1) X 10 [W1= weight of the dried residue and Gooch crucible after complete evaporation; and W2= Weight of the Gooch crucible].

1.2.1.6. Dissolved Oxygen (DO):

DO was measured with the help of a 'DO-meter' of 'Water Quality Analyzer' (PE 136, ELICO) at the spot during sample collection according to the manufacturer's instruction.

1.2.1.7. Chloride (Cl^-):

Chloride estimation was performed by means of 'Visco-color ECO Chloride Test kit' (Macherey-Nagel) according to the instruction provided in the information booklet associated with the kit. 1-10 ppm concentration NaCl solution was used as standard.

1.2.1.8. Detergents (anionic and cationic):

With the help of 'Aqua-quant Kit for Detergents' (GLAXO) was used for the quantification of anionic and cationic detergent content of the river water following procedure given in 'Information Booklet' supplied by manufacturers.

1.2.1.9. Total Alkalinity:

Total alkalinity was determined by titrating 100 ml sample against 0.01 N HCl using methyl orange indicator until the yellow color changes to pink. Total alkalinity was measured by the formula, Total Alkalinity as $CaCO_3$, mg/ml= {(A X 0.01) X 50} [A= ml of total HCl used].

1.2.1.10. Turbidity:

Turbidity free water (showed turbidity value <0.03 NTU) was used to prepare reagents and was used as a negative control. A 'Nephelometer' (model CLS 2D, ELICO) was used for quantification. Stock turbidity suspension having turbidity value of 400 NTU, was prepared by mixing 5m 1% hydrazine sulfate and 5 ml 10% hexamethylenetetramine. The

turbidity value of 1-10 times diluted stock turbidity suspension was used as standard and compared with the data obtained form samples. The turbidity was expressed as Nephelometric turbidity units (NTU) with the formula, [M X (N+O)]/O, [M= NTU of diluted sample, N= volume of diluted water; O= sample volume taken for dilution].

1.2.1.11. Biochemical Oxygen Demand (BOD):
The oxygen content of the water sample filled in a BOD bottle (vol. 300 ml) was recorded with the help of 'DO-meter' and the BOD-bottle was transferred in a BOD incubator at 20 ^{0}C for 5 days. After 5 days of incubation the oxygen content of the subject water was recorded again. The BOD of the sample was expressed by the calculation, BOD mg/l= [{(D0-D5) X 10}/3], [D0= oxygen content of the sample in 'zero' day; D5= oxygen content of the sample in 5th day].

1.2.1.12. Chemical Oxygen Demand (COD):
COD is the measure of oxygen consumed during the oxidation of the oxidizable organic matter by a strong-oxidizing agent. Potassium dichromate in the presence of sulfuric acid is generally used as an oxidizing agent in determination of COD. The glassware used for estimation of COD were washed with chromic acid and then washed in deionized double distilled water to remove all organic matter. To determine COD, 20 ml water sample was taken in a COD flask and 10 ml of 0.025 N potassium dichromate, 0.05 gm of Ag_2SO_4 and 0.07 gm $HgSO_4$ was added. After adding 30 ml sulfuric acid the sample was refluxed for 2h on a hot plate. The volume of the refluxed liquid was increased by adding 140 ml water and was titrated with 0.1 N ferrous ammonium sulfate using ferroin indicator. A blank set was also prepared using same quantity of the chemicals. The COD, mg/ml, was calculated by {(b-a) X 0.025 X 400} [b= ml of titrant with blank; a= ml of titrant with sample]

1.2.1.13. Total Ammonia 'N' content:
In 50 ml water sample, 5.0 ml concentrated sulfuric acid and 0.5 ml copper sulfate was added and was refluxed in a Micro-Kjeldahl distillation apparatus. Liberated ammonia was collected in 2.5 ml of 0.4 N H_2SO_4. A blank set was also run using same quantity of the chemicals. The volume of the distillate was made up to 50 ml by adding double distilled water and 1.0 ml Nessler's reagent [an alkaline solution of potassium tetraiodomercurate (II)] was added and mixed. Photometric measurement of the resultant brown color was estimated in a UV-Vis Spectrophotometer (SIMADZU, Japan) at 425 nm. The data obtained was compared with a standard curve generated by using known quantity of NH_4Cl.

1.2.1.14. Total Phosphorus:
In order to estimate total phosphorus, 25 ml water sample was digested in a Kjeldahl flask in presence of 1.0 ml H_2SO_4 and 5.0 ml HNO_3 until the volume of the sample became 1.0 ml. The volume of the digested product was diluted by adding 20 ml water and neutralized with the help of 5 N NaOH. After neutralization, 2.0 ml ammonium molybdate followed by 5 drops of $SnCl_2$ was added. The intensity of the blue color was measured at 690 nm within 5-7 minutes and the quantification of total phosphorus content was done from the standard curve.

1.2.1.15. Nitrate 'N':
To 10 ml water sample, 2.0 ml of 30% NaCl and 10 ml of concentrated H_2SO_4 were added and mixed thoroughly by gentle swirling by hand. To the mixture, 0.5 ml of brucine reagent was added and then placed in hot water bath for 20 minutes. The optical density at 410 nm was determined in an UV-Vis spectrophotometer at 410nm. The nitrate 'N' content was estimated from a standard curve prepared by the same method using known amount of KNO_3.

1.2.1.16. Nitrite 'N':
Estimation of nitrite was done by adding 1.0 ml each of 0.5% EDTA, 0.6% sulphanilic acid, alpha-napthylamine hydrochloride and 16% CH_3COONa solution in sequence, in 50 ml sample. A wine red color appeared and absorption at 520 nm was recorded, from where nitrite content was estimated using a standard curve.

1.2.1.17. Silica:
To the 50 ml water sample, 1.0 ml of 50% HCl solu-

-tion was added and was mixed thoroughly for 10 min after adding 2.0 ml ammonium molybdate, followed by addition of 1.5 ml oxalic acid. The blue solution was analyzed for absorption at 420 nm. The OD was plotted in a standard curve to get the quantity of nitrite.

1.2.1.18. Total Hardness:

For estimation of hardness, ammonia-buffer solution was prepared by adding Solution-I and Solution-II. Solution-I was prepared by dissolving 16.9 g NH_4Cl in 143 ml concentrated NH_4OH, and solution-II was 50 ml aqueous solution of 1.179 g EDTA and 0.78 g $MgSO_4.7H_2O$. In 50 ml water sample 1.0 ml each of ammonium-buffer and 5% Na_2S was added, and titrated with 0.01 M EDTA in presence of Eriochrome black T indicator. The mg/ml hardness was calculated in terms of $CaCl_3$ from the formula, (V X 20) [V= volume of EDTA used].

1.2.1.19. Calcium Hardness:

Ca-hardness can be estimated by titrimeric method using Murexide indicator at a very high pH. To 50 ml water sample, 2.0 ml of 1 N NaOH was added and titrated with 0.01 M solution of EDTA, and was calculated by using formula, (V X 8) [V=volume of EDTA used).

1.2.1.20. Magnesium Hardness:

Magnesium hardness was calculated from the data obtained from the analysis of total hardness and Ca-hardness by the formula, Mg^{2+} mg/l= [{(Th-Ch) X 400.8)/ (50 X 1.645)] [Th= Total hardness; Ch= Ca-hardness].

1.2.1.21. Statistical Analysis:

For statistical analysis SPSS Package for Windows 10.0 was used.

1.2.2. Results and discussion:

The data generated from physico-chemical analysis of Torsa river water in different sampling months (May 2001 to April 2002, except July and August) for three sampling sites (SS-I, SS-II, and SS-III) are enlisted in Table 1.1.

1.2.2.1. Temperature:

Interesting spatial and temporal thermal changes occur when solar radiation and atmospheric temperature come in contact with river water surface. Thermal change can affect both chemical and biological properties of river water. Increase in temperature of natural water tends to accelerate chemical reactions, lowers solubility of gases, changes taste and odor due to higher metabolic activity of organisms. Air and water temperature of Torsa basin ranged between 22-37 ^{0}C and 17-29 ^{0}C respectively. Highest water and air temperature was observed in the month of September 2001 at SS-II and lowest temperature of both water and air was recorded in January 2002 at SS-III. On an average lowest water and air temperature was recorded in winter (December & January) and highest was observed during summer (May- October). When plotted both against different months, both water and air temperature showed similar types of fluctuation curve, thereby facilitating to conclude that water of river Torsa was not polluted with thermal pollutants.

1.2.2.2. pH:

Quantification of H^+ ion concentration of water is a very important parameter to assess water quality. In rivers or ponds, pH increases during day, largely due to photosynthesis and decreases at night because of respiratory activity. Natural water has pH nearly 7.0 – 8.0, and variations of that range indicate pollution. Average pH range of the river water showed minimum fluctuation around the year, ranged 7.7- 9.0, which is comparable to the pH range of other rivers, such as Kaljani, of the same geographical location. The pH value recorded for Torsa is little higher (Figure 1.2) than the recommended value set forth by World Health Organization (7.0- 8.5) and hence it could be assumed that water contained carbonates with or without bicarbonate but do not have free carbonic acids (Manivasakam, 1980).

1.2.2.3. Conductivity:

Conductivity is a numerical expression of the ability of an aqueous solution to carry electric current. Temperature, ions and their concentrations, mobility, valence etc. can influence conductivity of water. Freshly prepared distilled water has conductivity range of 0.5- 2.0 μΩ/cm and in United

States conductivity of potable waters ranges generally from 50- 1500 μΩ/cm (APHA, 1985). The range of conductivity of Torsa water (100-270μΩ/cm) is safely within the range of portability. During summer months, such as May and June, conductivity ranges between 100-156 μΩ/cm, and in the month of November this was found a little higher (222.4-270 μΩ/cm) in all three sampling stations.

1.2.2.4. Total Dissolved Solid (TDS):

Many salts, such as carbonates, bicarbonates, chlorides, sulfates, phosphates, sodium, potassium, iron etc., are found dissolved in natural waters. A high concentration of dissolved solids increases the density of water, affects osmoregulation of fresh water organisms, reduce solubility of gases (like O_2) and utility of water for drinking, irrigation, and industrial purpose. In all three sampling stations higher TDS were recorded during November and December, and highest value for TDS was recorded in sampling station SS-III as 380 mg/l in the month of June, whereas in other months of the year TDS of the water did not exceed 262.7 mg/l. TDS content of Torsa was found within the limit of maximum desirable limit for drinking water as proposed by APHA (500 mg/l).

1.2.2.5. Total Suspended Solid (TSS):

TSS content of water depends on the amount of suspended particle, soil, silt, and is directly related to turbidity of water. Disposal of sewage and industrial effluents contributes suspended matter to river and streams. According to Indian Standard Institution (ISI), water having TSS less than 50 mg/l is recommended suitable for drinking and industrial purpose. Torsa showed wide variation in TSS, ranging between 15.6 - 650 mg/l, round the year in all three sampling sites. TSS content of the river water in the month of May at SS-III (650 mg/l), and during June, September and October, in all three sampling stations, was not only recorded higher (128.8 – 481.2 mg/l) but also much more above the desirable limit set forth by ISI.

1.2.2.6. Dissolved Oxygen (DO):

Oxygen dissolved in water is a very important parameter for determining water quality, because it implies about the physical and biological processes going on in water. The source of oxygen in water is either the atmosphere itself or the photosynthetic activity of phytoplanktons. Diffusion of atmospheric oxygen into water further depends upon temperature, movement and salinity of water. Autotrophic population also serves as a potential source of dissolved oxygen. Depletion of dissolved oxygen from river water can be assisted by several factors, the foremost of which is presence of organic pollutants or organic wastes. However, presence of oxidizable inorganic substances, such as hydrogen sulfide, ammonia, nitrites, ferrous iron, etc., can also deplete the oxygen content of water. Lower dissolved oxygen content, i.e. DO of less than 3 mg/l, has been proved to be lethal for fishes as well as for other aquatic life. The DO for Torsa river water, ranged between 5.2- 8.5 mg/l in all three sampling stations round the year, and, when average annual fluctuation of DO and water temperature of the river water was plotted, a reverse curve originated (data not shown), which clearly indicated that there was inverse relationship between these two parameters. Low temperature and high aeration rate during winter was possibly responsible for increased amount of dissolved oxygen (7.8- 8.5 mg/l). The torrential nature of the river could be held responsible for the average high value of DO throughout the course of this river. While studying DO content of Bhigarathi River at Himalayan foothills like, Uttarkashi, Tehri and Deoprayag, similar observation was reported (Gautam, 1990), where the river water was found to be saturated with dissolved oxygen (7.0- 10.9 mg/l).

1.2.2.7. Chloride:

Chloride ion (Cl^-) is one of the major inorganic anions in water and wastewater. River water rich in chloride ion is unfit for irrigation because of its toxicity to plants. High chloride containing water also harm metallic pipes and accelerate corrosion by other factors (APHA, 1985; and Manivasakam, 1980). Chloride content of Torsa varied between 3.5- 10.9 mg/l and the highest value was recorded during September and October and lowest value was observed in February at SS-III. The average chloride content of Torsa was recorded higher compared to Kaljani (1.7- 4.2 mg/l). Venkateswarlu

and Jayanti (1968) concluded that the values of chloride are associated with organic pollution in some rivers and reservoirs, the main source of which is sewage or wastewater, as NaCl is a common article of diet and passes unchanged through the digestive system.

1.2.2.8. Detergents (anionic and cationic):

Detergent contamination in the river directly takes place from sewage disposal and washing of cloths and utensils in river water. Higher detergent content prevent solubility of oxygen from atmosphere due to formation of foam and contribute high phosphate to water. At higher concentration detergents exerts toxic effects in aquatic life. Cationic detergent content of Torsa was in the undetectable range and anionic detergent content ranged between 0.1- 2.0 mg/l.

1.2.2.9. Total Alkalinity:

Quantification of alkalinity implies the presence of hydroxyl ions in a given water body. This is an important parameter used in corrosion control and helps in evaluating the buffering capacity of wastewater. Bases such as carbonates, bicarbonates, hydroxides, phosphates, silicates, borates etc. present in water contributes to the alkalinity, and is regarded as total alkalinity. In river water, high alkalinity over 100 mg/l, generally favor the growth of phytoplankton, especially the blue-green algae, and thereby increase the risk of eutrophication. In the current study total alkalinity value of Torsa ranged between 50.3- 585.5 mg/l, the lowest alkalinity value was observed in February in all three sampling stations and highest alkalinity value was observed at SS-I in June. The range of alkalinity recorded in Torsa was found higher compared to Bhagirathi passing through the mountains (16- 60 mg/l) (Gautam, 1990) and Kaljani (53.3- 95 mg/l) (Bhadra *et al.*, 2005).

1.2.2.10. Turbidity:

Turbidity in natural water arises due to the presence of suspended matter such as clay, silt, organic matter, phytoplankton and other microscopic organisms. It is determined indirectly by measurement of penetrability of light in water, which is dependent on size, shape and refractive index of suspended particles. Turbidity has direct relation with primary productivity of water body. According to WHO water bodies having turbidity less than 5 NTU can serve the purpose of drinking. In Torsa, except September, annual average of turbidity data calculated was much lower (1.0- 5.7 NTU) and thereby does not affect primary productivity. During September the turbidity range was observed between 6.0- 20.5 NTU in all three sampling sites, and highest turbidity was recorded in SS-III at Coochbehar in the sampling month of September.

1.2.2.11. Biochemical Oxygen Demand (BOD):

BOD is an expression of consumption of oxygen by microorganisms in aerobic degradation of the biodegradable organic waste present in water bodies. Therefore it is an indirect measurement of organic waste load of water, and thus higher BOD will indicate high organic pollution of water. According to the 'Royal Commission of sewage disposal', water having BOD more than 5 mg/l is unsafe for domestic use (Her Majesty's Stationary Office, 1972). The BOD value of Torsa ranged between 0.6- 3.0 mg/l (Figure 1.2) which is comparable to the BOD recorded in a tributary of Torsa, river Kaljani (BOD ranged between 0.2- 2.5 mg/l) (Bhadra *et al.*, 2005), but less than mountainous Bhagirathi where BOD ranged between 1.5- 6.9 mg/l (Gautam, 1990). The average BOD values of water calculated from ten samples collected round the year for each sample site, showed that the water of SS-III has more BOD (1.64 mg/l) followed by SS-I (1.04 mg/l) and SS-II (0.9 mg/l).

1.2.2.12. Chemical Oxygen Demand (COD):

COD may be defined as the measurement of oxygen, which is required in oxidizing the organic compounds present in water by means of chemical reactions involving oxidizing substances. The estimation of COD is of great importance, since high COD resulting from the presence of toxic chemicals poses unfavorable conditions for the growth of microorganisms. COD of Torsa ranges between 1.2- 8.5 mg/l and highest value of 8.5 mg/l was recorded at SS-III during February (Figure 1.2). The most notable observation was that, the COD of SS-III was recorded higher in all sampling months

compared to SS-II and SS-I; therefore, biologically resistant organic substance content of SS-III was definitely higher than other two sampling sites. The average COD range of Torsa was much lower than its tributary Kaljani where [19.5- 162.4 mg/l COD] (Bhadra *et al.*, 2005).

1.2.2.13. Total Ammonia 'N':

Free ammonia in river water almost invariably originates from animal wastes and decomposition of organic matters. Urea enriched fertilizers used in agriculture also contaminate river water through runoff, and are converted into ammonia by aquatic microorganisms. Total ammonia 'N' content of Torsa was observed to be very high in January, April, May, June, November and December, and the highest value was observed in the month of June at SS-II (26.8 mg/l) (Figure 1.2). The total ammonia 'N' content of Torsa was recorded to be very high compared to the other river of the same geographical region, such as Kaljani (0.1- 1.3 mg/l) and Teesta (0.5- 1.1 mg/l) (Bhadra *et al.*, 2003).

1.2.2.14. Total Phosphates:

The source of phosphate in the river water is either industrial effluents of metal finishing companies or sewage disposal or both, as phosphates are normal constituents of human excreta. Phosphate contamination in nature can also takes place from fertilizers, soaps and detergents. Water rich in phosphate salts, favor eutrophication and result algal bloom and can interfere in lime-softening process, or aid hard scale formation in boilers. The phosphate content of Torsa, however, showed a wide range of variation, 0.15- 102 mg/l (Figure 1.2). Higher phosphate content of Torsa was recorded in the month of February and March (66.5- 99.6 mg/l) and lowest was observed in October at SS-I and SS-II.

1.2.2.15. Nitrate 'N':

In the river water the most important source of nitrate is biological oxidation of nitrogenous organic matter of both autochthonous and allochthonous origin. Domestic sewage and agricultural runoff have been regarded as the main sources of allochthonous nitrogenous organic matter. Metabolic wastes of aquatic community and dead organisms add to autochthonous nitrogenous organic matter. There are nitrifying and amonifying bacteria, which are known to play significant role in oxidation of such organic matter; mainly certain nitrogen-fixing bacteria (e.g., *Azotobacter*) and algae (e.g., *Anabaena, Nostoc* etc.) can fix molecular nitrogen in the form of nitrates. High concentration of nitrate in water indicates pollution, as water become rich in nutrients and favor growth of blue-green algae, which in turn can produce cyanobacterial toxin and make water unsafe for consumption. High nitrate content in drinking water may result into blue baby syndrome in infants. Nitrate 'N' content of Torsa ranged between 0.21- 10.4 mg/l and the highest nitrate content was observed during September and October (6.4- 10.4 mg/l) and the lowest value was recorded during November (0.21- 0.32 mg/l). According to WHO the maximum desirable limit for nitrate in drinking water must not exceed 50 mg/l. Therefore water of Torsa river cannot be regarded as nitrate contaminated. But compared to nitrate content of mountainous Bhagirathi, which was in the range of 0.09- 2.2 mg/l (Gautam, 1990), the nitrate content of Torsa is definitely higher.

1.2.2.16. Nitrite 'N':

Nitrite occurs at a very low concentration in river water, because nitrite in water is formed either by oxidizing ammonia favored by aerobic nitrifying bacteria (e.g., *Nitrosomonas*) or by reducing nitrates facilitated by aerobic denitrifying bacteria (e.g., *Pseudomonas*). Presence of even minute quantity of nitrite in water has been indicative of organic pollution. Water having nitrite content of more than 0.1 mg/l is unsafe for consumption. The nitrite content of Torsa was recorded to range between 0.002- 0.009 mg/l throughout the year. The low level of nitrate as well as nitrite in comparison to ammonia nitrogen in most of the sampling months indicated that the nitrogenous organic matter was undergoing oxidation or nitrification and that the process was far from being complete.

1.2.2.17. Total Silica:

Silica may remain in water in colloidal or in particulate form which can pass through filter with pore size of 0.5 µm. Natural water having silica

Table 1.1: Values of physico-chemical features of waters of Torsa River (April 2001-March 2002) at three sample sites

Physico-chemical characteristics		January 2002	February 2002	March 2002	April 2001	May 2001	June 2001	September 2001	October 2001	November 2001	December 2001
Air temp. (°C)	a	22.5 ± 0.3	27.0 ± 0.3	28.0 ± 0.3	29.0 ± 0.3	28.0 ± 0.2	29.0 ± 0.3	36.0 ± 0.3	31.5 ± 0.3	26.5 ± 0.2	24.5 ± 0.2
	b	24.6 ± 0.3	28.0 ± 0.3	28.5 ± 0.3	28.5 ± 0.2	30.0 ± 0.3	27.5 ± 0.2	37.0 ± 0.4	31.5 ± 0.3	25.5 ± 0.2	26.0 ± 0.3
	c	22.0 ± 0.2	27.5 ± 0.3	29.0 ± 0.35	30.0 ± 0.3	31.0 ± 0.3	28.5 ± 0.2	36.5 ± 0.3	34.0 ± 0.2	28.0 ± 0.2	25.0 ± 0.2
Water temp. (°C)	a	17.5 ± 0.1	22.5 ± 0.2	22.5 ± 0.1	24.0 ± 0.2	24.1 ± 0.3	25.0 ± 0.2	26.0 ± 0.2	25.5 ± 0.2	21.5 ± 0.2	20.5 ± 0.2
	b	20.0 ± 0.1	23.0 ± 0.2	23.5 ± 0.1	25.0 ± 0.1	27.5 ± 0.2	26.0 ± 0.1	29.0 ± 0.1	25.5 ± 0.1	20.5 ± 0.2	23.0 ± 0.3
	c	17.0 ± 0.1	23.5 ± 0.2	23.0 ± 0.1	25.0 ± 0.1	27.5 ± 0.1	24.0 ± 0.2	25.5 ± 0.2	27.0 ± 0.1	23.0 ± 0.1	20.0 ± 0.2
pH	a	8.1 ± 0.1	9.0 ± 0.1	8.3 ± 0.1	8.0 ± 0.1	7.9 ± 0.1	8.5 ± 0.2	7.8 ± 0.2	7.7 ± 0.1	8.5 ± 0.1	8.3 ± 0.2
	b	8.2 ± 0.1	8.2 ± 0.1	8.4 ± 0.1	8.3 ± 0.1	8.1 ± 0.2	7.9 ± 0.1	7.7 ± 0.1	7.9 ± 0.1	8.3 ± 0.2	8.2 ± 0.2
	c	8.3 ± 0.1	8.4 ± 0.1	8.4 ± 0.1	8.1 ± 0.1	7.8 ± 0.1	8.2 ± 0.2	7.8 ± 0.2	7.8 ± 0.1	8.1 ± 0.1	8.1 ± 0.2
Conductivity (µMho/cm)	a	155.5 ± 2.2	130.4 ± 1.7	181.4 ± 1.8	175.0 ± 1.2	110.0 ± 1.1	100.0 ± 1	116.0 ± 1.3	115.4 ± 1.5	222.4 ± 2	135.0 ± 1.3
	b	115.0 ±1.5	176.5 ± 2.1	180.5 ± 1.7	171.2 ± 1.3	150.0 ± 1.3	156.0 ± 1.5	147.3 ± 1.4	135.9 ± 0.9	250.3 ± 2.4	175.0 ± 1.7
	c	160.5 ± 2.1	184.5 ± 2.3	195.5 ± 2	185.0 ± 1.5	150.0 ± 1.4	110.0 ± 1.7	166.6 ± 1.6	166.6 ±1.8	270.0 ± 2.6	185.0 ± 2.0
TDS (mg/l)	a	100.3 ± 0.3	66.4 ± 0.1	96.6 ± 0.25	99.2 ± 0.3	101.3 ± 0.3	101.3 ± 0.3	62.6 ± 0.1	63.3 ± 0.1	235.3 ± 0.3	229.3 ± 0.3
	b	90.2 ± 0.2	90.0 ± 0.2	93.1 ± 0.2	97.3 ± 0.3	84.4 ± 0.1	82.4 ± 0.2	79.4 ± 0.15	75.3 ± 0.1	225.6 ± 0.2	235.3 ± 0.3
	c	95.6 ± 0.3	94.5 ±0.3	100.7 ± 0.3	90.0 ± 0.2	102.5 ±0.3	380.0 ± 0.3	89.9 ± 0.2	91.6 ± 0.2	220.9 ± 0.2	262.7 ± 0.4
TSS (mg/l)	a	30.3 ± 1.5	42.1 ± 2	56.6 ± 2.3	49.3 ± 2.3	32.3 ± 1.6	196.7 ± 2.5	156.6 ± 1.7	246.4 ± 2.5	44.9 ± 2	15.6 ± 0.3
	b	25.3 ± 1	31.2 ± 1.5	43.2 ± 2	35.1 ± 1.6	31.8 ± 15.	128.8 ± 2	213.5 ± 2.4	324.5 ± 3.1	56.3 ± 2.1	26.6 ± 0.4
	c	28.7 ± 1.3	36.9 ± 1.8	45.6 ± 2.1	55.3 ± 2.3	650 ± 5.3	128.8 ± 2	243.4 ± 2.5	481.2 ± 3.7	55.7 ± 2.1	26.3 ± 0.6
Turbidity (NTU)	a	1.0 ± 0.3	2.1 ± 0.5	3.6 ± 0.3	2.3 ± 0.4	1.3 ± 0.6	5.7 ± 1.5	6.0 ± 1.7	5.4 ± 1.5	1.9 ± 0.7	1.6 ± 0.3
	b	1.3 ± 0.1	2.2 ± 0.5	3.2 ± 0.2	2.1 ± 0.6	1.8 ± 0.5	4.8 ± 0.9	13.5 ± 2.4	5.5 ± 1.1	1.3 ± 0.1	1.6 ± 0.4
	c	1.7 ± 0.3	1.9 ± 0.4	3.6 ± 0.9	1.8 ± 0.7	1.0 ± 0.3	4.8 ± 0.7	20.5 ± 2.5	4.2 ± 1.0	1.7 ± 0.1	1.3 ± 0.1
Alkalinity (mg/l)	a	105.7 ± 0.3	50.3 ± 0.3	90.6 ± 0.2	109.6 ± 0.1	130.0 ± 0.1	585.5 ± 0.2	88.5 ± 0.2	98.6 ± 0.3	105.7 ± 0.1	125.6 ± 0.2
	b	100.0 ± 0.2	62.1 ± 0.1	85.2 ± 0.2	90.3 ± 0.2	113.4 ± 0.1	91.6 ± 0.2	86.6 ± 0.2	109.3 ± 0.3	122.6 ± 0.2	115.3 ± 0.1
	c	98.6 ± 0.6	66.2 ± 0.5	100.3 ± 0.6	92.1 ± 0.3	410.2 ± 0.3	91.8 ± 0.4	74.4 ± 0.2	105.6 ± 0.1	100.1 ± 0.2	111.2 ± 0.2
Total Hardness (mg/l)*	a	55.6 ± 0.6	73.4 ± 0.5	70.6 ± 0.7	55.1 ± 0.5	36.7 ± 0.3	36.7 ± 0.6	33.0 ± 0.3	51.0 ± 0.4	82.6 ± 0.7	115.9 ± 0.7
	b	61.3 ± 0.9	91.8 ± 0.6	87.9 ± 0.7	63.6 ± 0.5	44.1 ± 0.7	39.2 ± 0.4	36.7 ± 0.4	57.1 ± 0.6	131.3 ± 0.8	125.6 ± 0.4
	c	59.9 ± 0.3	110.2 ± 0.7	90.1 ± 0.5	75.0 ± 0.5	39.2 ± 0.5	56.1 ± 0.5	46.5 ± 0.3	71.0 ± 0.6	141.3 ± 0.7	130.2 ± 0.7
Ca-Hardness (mg/l)*	a	23.5 ± 0.3	18.4 ± 0.3	21.6 ± 0.3	20.0 ± 0.3	9.7 ± 0.2	9.7 ± 0.3	8.7 ± 0.3	15.9 ± 0.2	20.2 ± 0.3	21.0 ± 0.1
	b	21.1 ± 0.4	27.2 ± 0.2	25.6 ± 0.2	21.3 ± 0.4	13.2 ± 0.3	11.2 ± 0.4	11.7 ± 0.4	18.2 ± 0.2	59.5 ± 0.3	25.6 ± 0.3
	c	20.1 ± 0.3	27.2 ± 0.3	25.3 ±0.3	20.9 ± 0.2	15.2 ± 0.2	32.3 ± 0.3	13.2 ± 0.2	18.9 ± 0.3	77.6 ± 0.5	29.3 ± 0.2
Mg-Hardness (mg/l)*	a	32.1 ± 0.2	55.0 ± 0.2	49.0 ± 0.3	35.1 ± 0.1	27.0 ±0.1	27.0 ± 0.2	24.3 ± 0.1	35.1 ±0.2	62.4 ± 0.2	94.9 ± 0.2
	b	40.2 ± 0.3	64.6 ± 0.2	62.3 ± 0.3	42.3 ±0.3	30.9 ±0.2	28.0 ± 0.3	25.0 ± 0.2	38.9 ± 0.4	71.8 ± 0.3	100.0 ± 0.3
	c	39.8 ± 0.2	83.0 ±0.2	64.8 ±0.3	54.1 ±0.1	23.9 ±0.3	23.8 ± 0.3	33.3 ± 0.2	52.1 ± 0.3	63.7 ± 0.1	100.9 ± 0.4

Table contd.

Physico-chemical characteristics		January 2002	February 2002	March 2002	April 2001	May 2001	June 2001	September 2001	October 2001	November 2001	December 2001
DO (mg/l)	a	8.5 ± 0.1	8.2 ± 0.1	8.0 ± 0.2	7.5 ± 0.1	6.9 ± 0.1	6.7 ± 0.2	7.2 ± 0.1	7.5 ± 0.2	8.3 ± 0.2	8.5 ± 0.2
	b	8.2 ± 0.2	8.3 ± 0.1	8.3 ± 0.1	7.1 ± 0.2	5.9 ± 0.2	5.2 ± 0.3	6.5 ± 0.1	7.2 ± 0.1	8.2 ± 0.3	7.8 ± 0.2
	c	8.1 ± 0.1	8.0 ± 0.1	7.5 ± 0.1	6.3 ± 0.1	7.1 ± 0.1	7.5 ± 0.2	7.0 ± 0.2	7.1 ± 0.1	7.5 ± 0.2	7.8 ± 0.3
BOD (mg/l)	a	0.6 ± 0.1	0.7 ± 0.1	0.9 ± 0.1	1.0 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	1.1 ± 0.1	2.5 ± 0.3	0.7 ± 0.2	1.5 ± 0.3
	b	0.6 ± 0.1	0.7 ± 0.1	1.5 ± 0.2	0.8 ± 0.1	0.6 ± 0.2	0.3 ± 0.2	1.3 ± 0.1	2.0 ± 0.1	1.0 ± 0.3	0.5 ± 0.1
	c	2.0 ± 0.2	1.5 ± 0.2	1.5 ± 0.1	0.8 ± 0.1	1.9 ± 0.2	0.7 ± 0.1	0.9 ± 0.2	3.0 ± 0.3	2.3 ± 0.2	2.1 ± 0.2
COD (mg/l)	a	2.6 ± 0.3	2.7 ± 0.1	3.1 ± 0.1	2.5 ± 0.2	1.5 ± 0.2	1.5 ± 0.3	5.5 ± 0.2	4.8 ± 0.2	4.0 ± 0.3	1.3 ± 0.3
	b	2.2 ± 0.5	7.8 ± 0.3	3.7 ± 0.2	3.6 ± 0.3	2.3 ± 0.2	1.2 ± 0.3	4.9 ± 0.3	5.0 ± 0.2	4.3 ± 0.3	1.6 ± 0.4
	c	3.1 ± 0.2	8.5 ± 0.1	5.9 ± 0.3	3.1 ± 0.3	2.9 ± 0.1	3.5 ± 0.3	5.2 ± 0.2	7.5 ± 0.3	5.4 ± 0.3	3.1 ± 0.2
Total Ammonia 'N'(mg/l)	a	18.8 ± 0.4	1.1 ± 0.1	3.2 ± 0.1	9.5 ± 0.2	15.2 ± 0.3	15.2 ± 0.3	0.13 ± 0.01	0.69 ± 0.01	22.5 ± 0.3	15.2 ± 0.4
	b	14.3 ± 0.3	1.3 ± 0.1	1.1 ± 0.1	15.1 ± 0.3	20.2 ± 0.5	26.8 ± 0.5	0.9 ± 0.1	0.71 ± 0.01	19.3 ± 0.3	7.7 ± 0.1
	c	18.7 ± 0.4	0.32 ± 0.1	1.14 ± 0.1	10.3 ± 0.3	19.0 ± 0.3	16.1 ± 0.3	0.07 ± 0.01	0.4 ± 0.01	14.4 ± 0.2	9.1 ± 0.2
Nitrate 'N' (mg/l)	a	0.52 ± 0.12	4.3 ± 0.4	2.3 ± 0.3	0.57 ± 0.2	0.32 ± 0.1	0.41 ± 0.03	8.4 ± 0.5	6.4 ± 0.34	0.32 ± 0.1	0.7 ± 0.2
	b	0.61 ± 0.13	6.2 ± 0.3	6.0 ± 0.6	0.63 ± 0.3	0.34 ± 0.2	0.46 ± 0.12	10.4 ± 0.3	9.2 ± 0.32	0.23 ± 0.2	0.9 ± 0.1
	c	0.72 ± 0.2	7.0 ± 0.5	8.2 ± 0.5	1.2 ± 0.2	0.41 ± 0.1	0.48 ± 0.2	10.0 ± 0.3	7.4 ± 0.26	0.21 ± 0.1	0.9 ± 0.2
Nitrite 'N' (mg/l)	a	0.006 ± 0.001	0.005 ± 0.001	0.006 ± 0.001	0.005 ± 0.002	0.007 ± 0.001	0.003 ± 0.001	0.002 ± 0.001	0.007 ± 0.001	0.006 ± 0.001	0.003 ± 0.001
	b	0.005 ± 0.001	0.006 ± 0.002	0.007 ± 0.001	0.005 ± 0	0.008 ± 0.001	0.006 ± 0.001	0.005 ± 0.001	0.009 ± 0.002	0.008 ± 0.001	0.007 ± 0.002
	c	0.006 ± 0.002	0.006 ± 0.001	0.007 ± 0.001	0.007 ± 0.001	0.008 ± 0.001	0.006 ± 0.002	0.004 ± 0.001	0.009 ± 0.002	0.008 ± 0.002	0.007 ± 0.001
Total PO_4^{2-} (mg/l)	a	6.1 ± 0.2	95.3 ± 0.2	92.6 ± 0.4	48.6 ± 0.2	22.0 ± 0.1	22.6 ± 0.2	38.8 ± 0.2	0.15 ± 0.01	8.3 ± 0.2	17.5 ± 0.3
	b	6.4 ± 0.1	75.6 ± 0.3	66.5 ± 0.3	52.5 ± 0.2	75.6 ± 0.3	47.5 ± 0.4	40.1 ± 0.3	0.15 ± 0.01	10.3 ± 0.3	15.2 ± 0.1
	c	5.1 ± 0.1	86.9 ± 0.2	99.6 ± 0.5	85.2 ± 0.4	72.1 ± 0.3	102 ± 0.6	49.4 ± 0.3	0.69 ± 0.02	10.7 ± 0.2	10.4 ± 0.1
Chloride (mg/l)	a	6.5 ± 0.2	6.0 ± 0.1	5.5 ± 0.2	7.6 ± 0.1	9.6 ± 0.2	6.5 ± 0.2	6.0 ± 0.1	7.7 ± 0.1	6.0 ± 0.2	8.5 ± 0.3
	b	7.0 ± 0.1	5.2 ± 0.1	4.9 ± 0.1	6.3 ± 0.1	6.9 ± 0.3	9.2 ± 0.3	7.6 ± 0.3	8.2 ± 0.2	7.5 ± 0.2	8.0 ± 0.4
	c	7.5 ± 0.3	3.5 ± 0.1	4.1 ± 0.2	5.2 ± 0.1	7.6 ± 0.2	9.8 ± 0.3	10.4 ± 0.4	10.9 ± 0.3	8.0 ± 0.3	7.5 ± 0.3
Detergent mg/l (anionic)	a	0.5 ± 0.13	0.2 ± 0.05	0.8 ± 0.12	nd	nd	nd	nd	1.1 ± 0.12	1.5 ± 0.22	0.5 ± 0.06
	b	0.3 ± 0.15	0.1 ± 0.13	0.74 ± 0.08	nd	nd	nd	nd	0.9 ± 0.02	1..0 ± 0.13	0.75 ± 0.34
	c	0.2 ± 0.11	0.2 ± 0.07	1.1 ± 0.2	nd	nd	nd	nd	0.7 ± 0.04	2.0 ± 0.35	1.5± 0.21
Total Silica (mg/l)	a	7.3 ± 0.2	8.3 ± 0.2	9.5 ± 0.2	4.3 ± 0.1	0.57 ± 0.02	0.52 ± 0.02	0.3 ± 0.01	0.33 ± 0.01	7.3 ± 0.3	8.7 ± 0.2
	b	4.9 ± 0.16	6.3 ± 0.1	7.8 ± 0.2	5.2 ± 0.14	0.67 ± 0.03	0.67 ± 0.03	0.35 ± 0.015	0.38 ± 0.01	4.0 ± 0.2	4.5 ± 0.1
	c	5.2 ± 0.2	10 ± 0.5	11.2 ± 0.6	6.2 ± 0.21	0.70 ± 0.04	0.63 ± 0.01	0.4 ± 0.03	0.5 ± 0.03	4.5 ± 0.17	4.0 ± 0.1

Standard deviations are denoted by ±. a = Sample Site I (SS-I) at Hasimara under Torsa Bridge; b = Sample Site (SS-II) at Falakata under Sil Torsa Bridge; c = Sample Site III (SS-III) under Ghughumari Torsa bridge at Cooch Behar; *, in terms of $CaCl_3$.

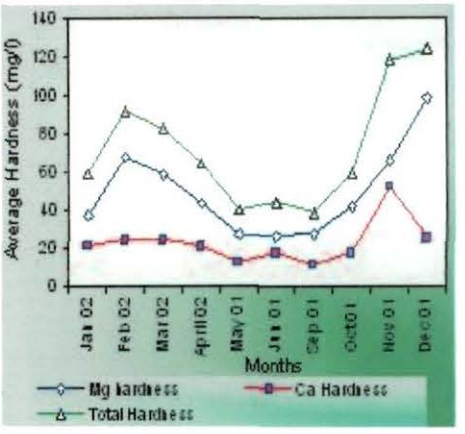
content of 1-30 mg/l and above (>40 mg/l) is undesirable for industrial use (APHA, 1985). Soluble and suspended silica was found to form scale in pipeline and in high-pressure-steam-turbine blades. Total silica content of Torsa ranged between 0.3-11.2 mg/l, below the maximum permissible limit set forth by APHA. Highest silica content was recorded in March at SS-III and the lowest was observed in September at SS-I.

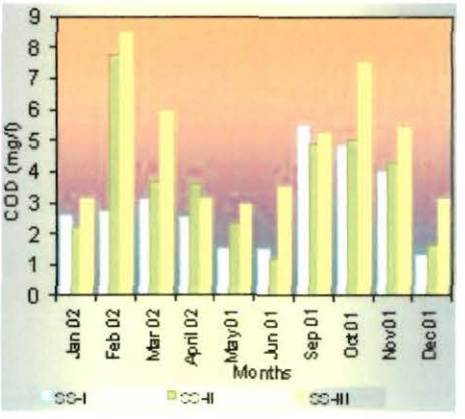
1.2.2.18. Total Hardness:

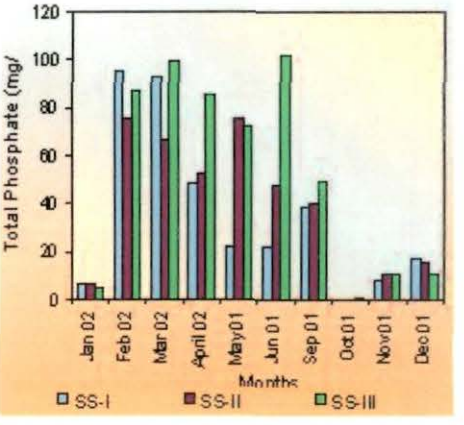
Alkaline earth metal cations, predominantly calcium and magnesium, are the main elements imparting hardness to river water. However, to a little extent, ions such as, Fe^{2+}, Mn^{2+}, and Sr^{2+} also impart hardness. When simple boiling can eliminate hardness, it is called temporary hardness, which results due to the presence of carbonate or bicarbonate ions in water. But simple boiling cannot eliminate permanent hardness contributed by Ca^{2+} and Mg^{2+} ions. Hard water is not suitable for bathing and washing due to less lather formation with soap. In high-temperature-boiler it induces scale formation inside and demand more heat to reach boiling point. Water having hardness value more than 300 mg/l is undesirable for dying and textile industries (Manivasakam, 1980; Swarup *et al.*, 1992). The hardness value for Torsa ranged between 33- 141.3 mg/l, where the higher hardness value during dry season (November and December) might be the consequences of dolomite mining in the upstream of the river.

1.2.2.19. Calcium and Magnesium hardness:

Both Ca and Mg are abundant in natural water, as both are leached from rocks and their concentration in river water depends upon nature of the basin. In aquatic environment, calcium and magnesium are important mineral. Ca is required in large quantities by the mollusks and the vertebrates, and Mg is an essential constituent of chlorophyll. But both these hardness-contributing cations reduce suitability of water for domestic as well as industrial use. The Mg-hardness value of Torsa (23.8- 100.9 mg/l) was found much higher than mountainous Bhagirathi (2-27 mg/l) (Gautam, 1990). The highest Ca-hardness value was observed in the month of November at SS-II and SS-III (59.5 and 77.6 mg/l respectively),







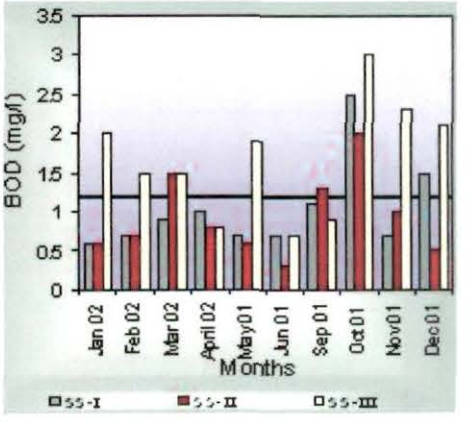


Fig. Contd.

otherwise the Ca- hardness value for Torsa was found to range between 9.7- 32.3 mg/l.

1.2.2.20. Statistical analysis of Physico-chemical data:

Low positive correlation (0.111) between phosphate and COD indicate organic pollution of river water by phosphorus containing carbonaceous material. The pH of the river water generates low correlation value (0.152) with ammonia 'N' and high correlation value (0.629) with Hardness, which indicates direct and close relation between pH and hardness. Positive correlation of 0.664 was recorded between ammonia 'N' and alkalinity, which clearly implies the reason of high alkalinity of the river. The average BOD and COD value were demonstrated significant correlation of 0.455, and is a characteristic feature of the river. Low level of nitrate as well as nitrite in comparison to high level of ammonia nitrogen indicates that the nitrogenous organic matter in river water is undergoing oxidation and nitrification, and that the process is far from being complete, which was further confirmed by the fact that the nitrate-nitrite ratio of the river was found higher at SS-II and SS-III, compared to SS-I. Negative correlation (-0.77) between ammonia and nitrate, and positive correlation between, nitrite and ammonia (0.153) and nitrite and nitrate (0.398) indicate ongoing-nitrification in river water, where ammonia is first converted in to nitrite and nitrite is then converted into nitrate.

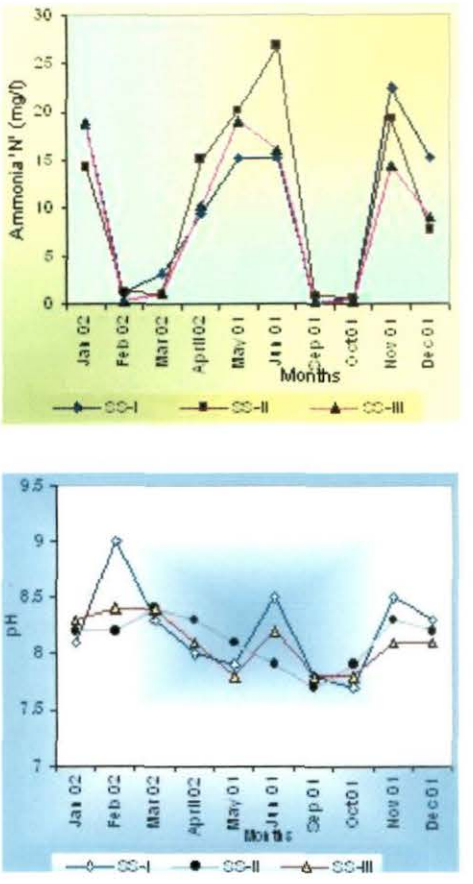


Figure 1.2. Month wise variation of some physico-chemical parameters of Torsa River in three sampling stations (SS-I, SS-II, and SS-III).

1.2.3. Conclusion:

The principle cause of deterioration river in water quality in India has been increased by gobbledygook human activities (few examples were presented in Figure 1.3 and 1.4), which is done to fulfill the basic requirements without considering far reaching side effects. Neither planned drainage system is operating to prevent disposal of sewage in river, nor any sewage treatment plant exists in this present study area of the country, which can prevent contamination of river water from domestic and/ or agro-industrial waste. During sample collection we have also noticed several despicable human activities, such as, bathing and washing clothes in river, discarding dead animals in and around river (Figure 1.4A), bathing domestic animals in river etc., odious ignorance of private or government sector officials, such as dumping of garbage on the river (Figure 1.3C); and unscientific mining activities (Figure 1.3A), etc., has led to pollution of river water and made it unfit for domestic and industrial use. The major characteristics of Torsa river water were high pH, alkalinity, Mg-hardness, total ammonia 'N' content and total phosphate, which suggests sewage pollution from catchments localities. Hence, sewage treatment planning in the catchments is necessary. High orrelation between pH and total hardness (0.629) clearly indicate soil erosion due to excessive mining of dolomites in its catchments. Elevated total phosphate 'P' content indicate pollution due to washing of clothes and high total ammonia 'N' data in some months indicate direct disposal of untreated sewage and animal wastes. As the river water is saturated with dissolved oxygen, decomposition of

organic waste does not lead to high BOD. Nitrate and nitrite content of the river water was also recorded very low. Water quality of Torsa can be maintained well by regulating disposal and dumping off of sewage and solid waste. This study will therefore be useful in future management of surface water and also may provide valuable database for further studies on water quality of other rivers of the India.

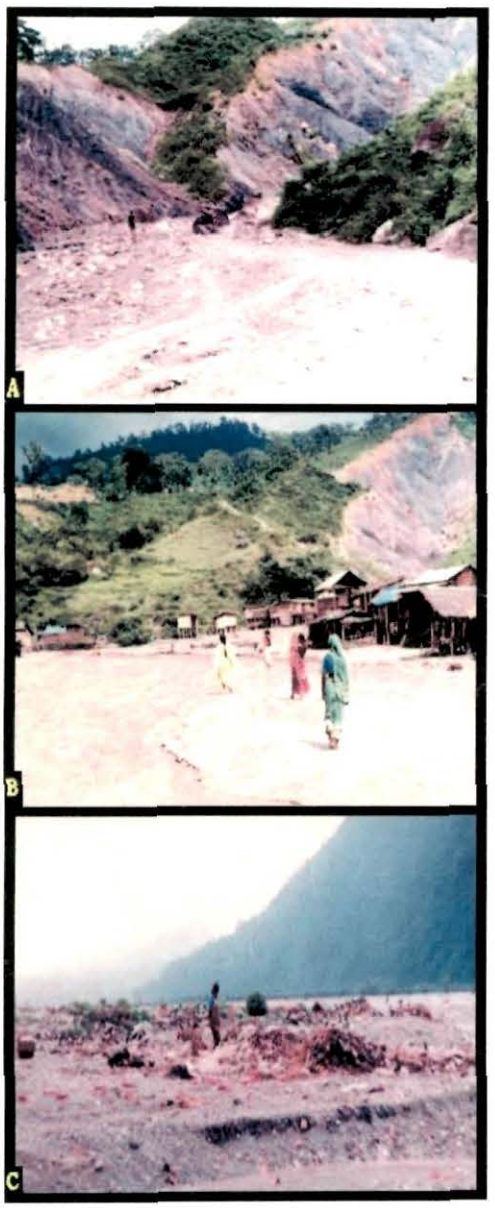


Figure 1.3. Photographs showing improper dolomite mining leading to landslides in dolomite hillocks (A, B) in the catchment area of Torsa, and dumping of solid waste of Phunosholing city of Bhutan in Torsa River bed (C), at Jaigaon Town (upstream of Sampling site-I) of district Jalpaiguri.

1.3. Sanitary quality of Torsa River water:

The feces indicating bacteria are used to measure the sanitary quality of water for recreational, industrial, agricultural and water supply purposes. The fecal indicators are natural inhabitants of the gastrointestinal tracts of human and other warm-blooded animals. They are released into the environment with feces, and are then exposed to a variety of environmental conditions that eventually cause their death. Studies have shown that fecal matter indicating bacteria survive for a few hours to several days in water, but may survive for days or months in sediments, where they remain protected from sunlight and predators. The bacteriological tests are extremely sensitive and specific in revealing evidence of contamination with sewage. It is not true that the objectives in the routine analysis of water would be to search pathogenic microorganisms. Pathogens are likely to gain entrance into water sporadically, and they do not survive there for long periods. It is known that pathogens enter into water bodies via contamination with intestinal discharges of humans or other animals. Furthermore, certain bacterial species, particularly *Escherichia coli* and related organisms designated as coliforms, fecal streptococci (e.g., *Streptococcus faecalis*), and *Clostridium perfringens*, are normal inhabitants of the large intestine of humans and other animals and are consequently present in feces. Thus the presence of any of these bacterial species in water proves fecal pollution of it. Presence of these organisms is indicative of the fact that the intestinal pathogen might also remain present in water, since, they too occur in feces (APHA, 1985; Manivasakam, 1980).

The coliform group comprises all aerobic and facultative anaerobic Gram-negative, non-spore forming, and rod shaped bacteria that ferment lactose with gas formation within 48h at 35 ^{0}C. 'Multiple tube fermentation technique' is the standard test for the quantification of coliform bacteria in water and result of the examination of replicate tubes and dilutions are reported in terms of the 'Most Probable Number' (MPN), which is based on certain probability formulas, is an estimate of mean density of coliforms in a sample. Therefore

the precision of any single test depends on the number of tubes used and examination of largest sample inocula. Adequate shaking of sample renders uniform distribution of bacteria in the sample and thereby affects accuracy of analysis. MPN tables are based on the assumption of a 'Poisson distribution' (random dispersion) (APHA, 1985).

When drinking water is analyzed, five fermentation tubes each containing 10 ml or 100 ml sample is used, because treated drinking water should not contain coliform(s) in 100 ml of water. In the examination of river water a series of tubes, at least five in numbers, are inoculated with decimal quantities of water. The object of the examination of river water generally is to estimate the density of bacterial contamination, determine source of pollution, enforce water quality standards, or trace the survival of microorganism. The multiple-tube–fermentation technique may be used to obtain statistically valid numerical values of coliform density of water bodies.

1.3.1. Materials and methods:

All the chemicals and reagents are used in the study are of analytical grades. Deionized double distilled water was used for the preparation of reagents and media. For the maintenance of pH, 'pH-meter' (SYSTRONICS) was used which was calibrated before every analysis by using 'buffer tablets' (NICE) for pH 9.0 and 4.5.

1.3.1.1. *Collection of sample:*

Samples were collected once in every month during time period of April 2001 to March 2002 leaving the months July and August, as due to heavy rainfall and flood during monsoon, collection of sample became very difficult. Water samples were collected to a final volume of 100 ml in airtight, sterile, polypropylene container, and were preserved at 4 ^{0}C. From each sampling site, three grab samples were collected from left, right and middle of the river and were mixed in the laboratory under sterile condition and, were treated/ analyzed as single sample. After collection, analysis of the sample was started within six hours.

1.3.1.2. Standard Total Coliform MPN test:

Several selective and differential media greatly expedite the process of examining water for coliform organisms. The standard microbiological technique involves three successive tests as stated in 'Standard Methods' (APHA, 1985): (a) the presumptive tests, (b) the confirmed test, and (c) the completed test. The culture media and 0.5% NaCl solution used for this purpose were sterilized in an autoclave at 121 ^{0}C for 15 min before inocula-

Figure 1.4. Photographs showing disposal of dead animal (A) and waste from animal husbandry (B,C) into Torsa River near sampling site-III at Coochbehar.

-tion. Before inoculation, samples were diluted by adding 1.0 ml water sample into 9.0 ml 0.5% NaCl solution and were mixed by vortexing.

1.3.1.2.1. Presumptive test:

Lauryl tryptose broth (tryptose, 20 µg/ml; lactose, 5 g/l; K_2HPO_4, 2.75 g/l; NaCl, 5 g/l; and Sodium Lauryl Sulfate, 0.1 g/l) having pH 6.8 ±0.2 and containing

Table 1.2. The sanitary/ microbiological quality analysis of waters of Torsa River at three sampling sites (SS-I, SS-II, and SS-III), in different sampling months between May 2001-April 2002.

Months	Sampling sites	HPC (cfu/ml)	Minimum Probable Number (MPN)/ 100 ml		
			TC	FC	FS
Jan. 2002	SS I	45X 10^3	1100	800	150
	SS II	50 X 10^3	600	100	50
	SS III	3.0 X 10^3	500	300	80
Feb. 2002	SS I	7.5 X 10^3	500	170	4
	SS II	2.0X 10^3	250	200	22
	SS III	4.8 X 10^3	900	500	240
March 2002	SS I	3.0 X 10^3	900	500	300
	SS II	9.2 X 10^3	170	110	4
	SS III	16 X 10^3	550	500	50
April 2002	SS I	16 X 10^3	1000	500	100
	SS II	25 X 10^3	900	500	240
	SS III	14 X 10^3	1100	500	240
May 2001	SS I	9.0 X 10^3	1600	900	240
	SS II	50 X 10^3	2400	1600	900
	SS III	65 X 10^3	1900	1600	80
June 2001	SS I	460 X 10^3	240	130	130
	SS II	180 X 10^3	1600	1100	300
	SS III	110 X 10^3	2600	1600	90
Sept. 2001	SS I	46 X 10^3	1600	500	80
	SS II	21 X 10^3	1600	900	240
	SS III	19 X 10^3	500	300	170
Oct. 2001	SS I	21 X 10^3	1400	900	100
	SS II	150 X 10^3	1100	600	100
	SS III	30 X 10^3	500	240	110
Nov. 2001	SS I	26 X 10^3	1600	1000	100
	SS II	110 X 10^3	1100	600	100
	SS III	49 X 10^3	1100	1000	50
Dec. 2001	SS I	80 X 10^3	1600	1600	7
	SS II	60 X 10^3	900	600	80
	SS III	90 X 10^3	1100	900	100

HPC, Heterotrophic plate count; TC, Total coliform; FC, Fecal coliform; FS, Fecal Streptococci.

0.01 g/l Bromocresol purple (acid/base indicator) were used in presumptive test for total coliform. A series of tubes (5 tubes in three sets) were inoculated with appropriate decimal quantities (10 ml in first set, 1.0 ml in second set, and 0.1 ml in third set) of diluted sample and were incubated at35 ^{0}C for 24-48h. Formation of acid and gas from lactose after incubation was evidenced from the color change of the medium and gas bubble in 'Durham tube' indicate positive reaction. The number of tubes forming acid and gas in each dilution series was noted as instructed in 'Standard Methods' (APHA, 1985) and MPN for total coliform was recorded from MPN-index table (pp.881, APHA, 1985).

1.3.1.2.2. Confirmed test:

For this test, Brillian Green Lactose Bile (BGLB) broth (HIMEDIA) with inverted 'Durham tube' was used. The tubes showing positive fermentation reaction in presumptive test was used as inocula, and 0.1 ml inoculum was added in each culture tube containing BGLB broth and was incubated at 35 ^{0}C for48h. The change in color of the medium and gas formation was recorded as positive reaction, i.e. coliform were present. Loop-full liquid cultures were taken from the tubes showed positive reaction and were streaked on Eosin-methylene Blue agar (HIMEDIA, India) plates. The small colonies having black center with greenish metallic sheen were subjected to completed test.

1.3.1.2.3. Completed test:

Black centered colonies of Eosin-methylene Blue agar plates were inoculated in lactose broth (HIMEDIA) and were tested for Gram-reaction (Paytkin, 1980). Formation of gas in 'Durham tube' and Gram-negative nature of the culture confirmed the presence of coliforms.

1.3.1.3. Fecal Coliform MPN procedure:

Elevated temperature tests for the separation of organism of the coliform group into those of fecal origin and those derived from non-fecal sources are available. The fecal coliform test was done using EC medium (Tryptose, 20 g/l; lactose, 5 g/l; Bile salts, 1.5 g/l; K_2HPO_4, 4 g/l; KH_2PO_4, 1.5 g/l; NaCl, 5 g/l; pH 6.9 ±0.2). A series of 5 tubes in three sets containing inverted 'Durham tubes' were inoculated with 10 ml, 1.0 ml, and 0.1 ml diluted (10^{-1}) samples for first, second and third sets respectively. After incubation at 35 ^{0}C for 24h, gas formation in Durham tubes was regarded as positive test. The estimation of MPN for fecal coliform was done using 'MPN index table' (pp. 881, APHA, 1985). The tubes showing positive fermentation tests for fecal coliform were subjected to confirmed and completed tests for coliform as stated above.

1.3.1.4. Estimation of Fecal Streptococci:

The term fecal Streptococci indicate a group of enterococcus present in human and animal feces, e.g., *Streptococcus faecalis, S. faecium, S. bovis, S. equines* etc. Assay of fecal Streptococci provide valuable supplementary data on bacteriological quality of lakes, streams, estuaries etc. For estimation of MPN for fecal streptococcus Azide dextrose broth (Beef extract, 4.5 g/l; tryptone, 15 g/l; glucose 7.5 g/l; NaCl, 7.5 g/l; Sodium azide 0.2 g/l; pH 7.2) was used. 10 ml, 1.0 ml, and 0.1 ml diluted (10^{-1}) water samples were added in first, second and third sets of culture tubes (each set contained 5 culture tubes) containing Azide-Dextrose broth and were incubated at 35 ^{0}C for 48h. Growth on the media indicated positive reaction and the number of tubes showing positive growth in each series were counted and MPN for Fecal Streptococci was determined from MPN index table following procedure stated in 'Standard Methods' (APHA, 1985).

1.3.2. Results and discussion:

The data describing sanitary status analysis of river Torsa at three sampling sites has been represented in Table 1.2.

1.3.2.1. Total Coliform (TC):

The total coliform count for Torsa was recorded very high through out the all-sampling months in all three sampling sites (SS-I, II & III). The lowest total coliform count (MPN/ 100 ml= 170) was recorded during March at SS-II, followed by June in SS-I (MPN/ 100 ml= 240). In SS-III, minimum of MPN/ 100 ml value for total coliform was recorded as 500 in September, October and January. Otherwise, the total coliform counts of other months were very high in all three sampling sites throughout the year (Table 1.2). A high total coliform count in Torsa clearly indicated sewage pollution of river water. At SS-I and SS-II, which are downstream to Phuntsholing (Bhutan) and Jaigaon (India), the river receives sewage and solid domestic wastes from growing settlements (Figure 1.3C) and thereby demonstrated high total coliform count.

1.3.2.2. Fecal Coliform (FC):

In most of the sampling months it was observed that more than 50% population of total coliform bacteria are fecal coliforms. In the month of December at SS-I, MPN for total and fecal coliform count of the river water are same, which indicate extreme fecal pollution of the river water (Table 1.2). Almost similar observation was also recorded during November and March at SS-III where the MPN/100 ml ratio for fecal coliform and total coliform was 0.909. In SS-II, maximum fecal coliform and total coliform ratio was observed in the month of February (0.833) followed by March (0.647). High TC-FC ratio in these months and high fecal coliform count in other sampling months (Table 1.2) in all three sampling sites clearly point towards high degree pollution of the river water by intestinal micro-organisms of human and warm blooded animals.

1.3.2.3. Fecal Streptococci (FS):

Fecal streptococci are the normal inhabitant of human and animal intestines and thus can be used as indicators of fecal pollution. In combination with fecal coliform data, data on fecal streptococci provide specific information about pollution sources because certain fecal streptococci are host specific. FC/FS ratios between 0.7- 4.4 would indicate pollution through human source whereas a ratio of <0.7 would indicate non-human mediated pollution (Goldreich and Kenner, 1969). In the present discussion, we would not like to consider those ratios where MPN/100 ml values for fecal streptococcus were found below 100 to minimize misinterpretation of ratios (APHA, 1985). The FC/FS ratio in Torsa ranged from 1.6-9.0, which further indicate high-level pollution of the river due to discharge of human excreta in to river.

1.3.3. Conclusion:

Analysis of sanitary quality of River Torsa indicated high-level pollution with human excreta, which is the principal constituent of sewage. Torsa receive sewage and organic wastes from two growing townships; Jaigaon (India) or Phuntosholing (Bhutan) before SS-I and SS-II (Figure 1.3), and from Coochbehar before SS-III (Figure 1.4). This was also evidenced from the data of chemical analysis where the ammonia 'N', phosphate 'P', Chloride, Alkalinity, COD and BOD were high. The high MPN counts of total coliform and fecal coliform point towards pollution of river water by intestinal microflora and high fecal coliform/ total coliform ratio clearly indicates towards human excreta mediated pollution. Therefore proper treatment of sewage should be done before disposal into river.

1.4. Determination of water quality index of Torsa River:

According to the book 'Field Manual for Water Quality Monitoring', the National Sanitation Foundation (NSF) surveyed 142 people representing a wide range of positions at the local, state, and national level, performed about 35 water quality tests for possible inclusion in an index. Nine factors, e.g. DO, Fecal coliform, pH, BOD, Temperature change, Total phosphate, Nitrate 'N', Turbidity, and Total solids, were finally chosen which were used for the preparation of a 100 point scale using software available in the websitehttp://www.cce.iastste.edu /research/ lutz/dmrwqn.bacteria.html. The NSF water quality indexes of Torsa was determined for every sampling site in different sampling months and were compared with water quality index legend provided in the website. In the 100 point scale the water quality index of Torsa ranges 38-46, whereas the comparative table given in the website depicts that any value between 25-50 in 100 point scale will indicate bad quality water.

1.5. Summary of the Chapter 1:

The major characteristics of Torsa river water were high pH, Alkalinity, ammonia nitrogen, phosphate, and low BOD and COD. The sanitary status analysis of the river water also revealed very high count of fecal- and total coliform count through out the year. These data clearly indicated towards the pollution of river water with sewage. High positive correlation between total hardness and pH content may be interpreted as the consequential fall out of dolomite mining at the catchments of the river. One of the important features of the river water is its high DO, which could facilitate the aerobic degradation of biodegradable wastes.