PHYSICOCHEMICAL ASSESSMENT FOR SEASONAL VARIATIONS OF THE CHATHE RIVER OF DIMAPUR DISTRICT IN NAGALAND, INDIA

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ABSTRACT

An assessment of physico-chemical parameters was conducted in the Chathe River of Dimapur District, Nagaland (India) for one year to determine the quality of the river. Variations in physical parameters like air temperature, water temperature, depth, current flow, pH, conductivity, turbidity, total dissolved solids etc., and chemical parameters like dissolved oxygen, biochemical oxygen demand, free CO_2, bicarbonate alkalinity, chloride, calcium hardness, total hardness etc., were assessed for a year to find the variations in their values for different sites in the river are correlated to the impact of season, geographical locations and pollution. Pearson's correlation coefficient was calculated for each of the parameters to find the degree of relationship and their significance or insignificance between the parameters. The average values of different parameters were compared with the guidelines prescribed by EPA & WHO to determine the quality and environmental status of the river.

Keywords: Chathe River, Physico-chemical parameters, water quality assessment, Nagaland

Introduction

Running water is amongst the most threatened ecosystem of the world. Any river ecosystem flowing through any state or nation determines the health and socio-economic growth of that area, due to its versatile uses like waste disposal, electricity generations, irrigations and fishery. The river is a heterotrophic and open system because it depends for energy from outside in contrast to standing water and other terrestrial system. This energy is supplied mainly by allochthonous sources like leaf litters etc. or nutrient rich exudates carried by rainwater. Subsurface seepage also brings nutrients leached from nearby agricultural or residential land and also forests (Duttamunshi & Duttamunshi, 1995). Every river and stream is unique. Neither two waterways contain the same type and distribution of substrates, the same hydrologic regimes, the identical kinds and amounts of dissolved solids and gases, nor do they receive identical inputs of allochthonous materials and radiant energy. The river is in a dynamic state of change with respect to its geological age and bio-geochemical characteristics. But, the activities of human beings upset this dynamic state, resulting in deterioration of aquatic environment. Anthropogenic activities have strong effects leading to widespread modification of the physical habitat and consequently of biotic communities and ecological functioning (Poff *et al.*, 1997). Therefore, river or stream restoration requires an understanding of the structure and function of stream corridor ecosystems and the physical, chemical and biological processes that shape those (Hu *et al.,* 2007). Any interference in the aquatic ecosystem is at once reflected by the change in the physical and chemical characteristics. So, the measurement of physico-chemical characteristics is a convenient way to examine the changes in water quality (Singh *et al.*, 1980; Trivedy *et al.*, 1987; APHA, 2003) and to create a public awareness, which could help in implementing water quality improvement programmes to protect the river against any further degradation. In India, the physico-chemical parameter of several rivers has been the subject of detailed investigations. These include the Kali (George *et al.*, 1966); the Sabarmati (Venkateswarlu & Jayanthi, 1968); the Moosi (Venkateswarlu, 1969); the Alakananda (Badola & Singh, 1981); the Cauveri (Somasekhar, 1983); the Jhelum (Raina *et al.*, 1984); the Cooum (Konnur *et al.*, 1986); the Periyar (Sankarnarayan *et al.*, 1986) & the Ganga (Singh, 1997).

There are many rivers flowing through the state of Nagaland in India. A few of them are Dhansiri, Dikhu, Tsurang, Meguiki, Lanyi, Tesuru, Likhimro, Zubza, Chathe etc. Many small channels from Medziphema united together near New chumukedima area to form the Chathe river (*25°46'07.4" N, 93°48'31.1" E*) which then moved through the Dimapur district having a total stretch of around 42.78 km in Nagaland and finally as the Bakala river (*25°58'21.9" N, 93°46'35.6" E*) meet at the river Dhansiri in Karbi Anglong district, Assam (Fig.2). The river Chathe is a perennial river characterised by pools, riffles and runs at different segments of its river bed. It has fragmented water flow during winter & pre-monsoon season. The river shows blue-line river flow during monsoon & post-monsoon season depending on normal rainfall.

Materials and methods:

Study area:

The study was conducted in the Chathe river of Dimapur district, Nagaland (India) for one year from December, 2012 to November, 2013. Three sampling sites of the river in

Chumukedima-Seithekema (A) area of dimapur district (Fig.1) were selected for the study, which are:

Zone I. It was the upstream region, considered as the controlled area having a total stretch of around 2.17 km (from *25°47'12.4"N & 93°48'05.4"E* to 25°*47'46.8"N & 93°48'16.1"E*) and width varying between 13.71 m to 28.58 m. This area is composed of pebbles, sand, clay and hard rock bed. This area was selected as the control area (or, reference area) to compare with the other areas. Vegetation of the area includes trees, grass, shrubs around the mountain slopes in the periphery and minimum of aquatic macrophytes in the river bed. The watershed properties of the area are mostly agricultural and animal farm runoff, but not residential. The area may receive fewer amounts of traffic pollutants, sewage effluents, agricultural watershed and animal farm runoff but, comparatively less disturbed than the other selected areas.

Zone II. It was the midstream region between the controlled area and the dam having a stretch of around 446.52 m (from 25°*47'46.8"N & 93°48'16.1"E* to *25°47'50.7"N & 93°47'58.3"E*) and width varying between 15.76 m to 28.02 m. This area is composed of pebbles, clay and sand. Vegetation of the area includes trees, grass, shrubs around the mountain slopes at the bank and almost none of aquatic macrophytes. The watershed properties of the area are mostly agricultural

Fig.1: GIS Map of the studied area in the Chathe river of Nagaland, India (Source: Google map)

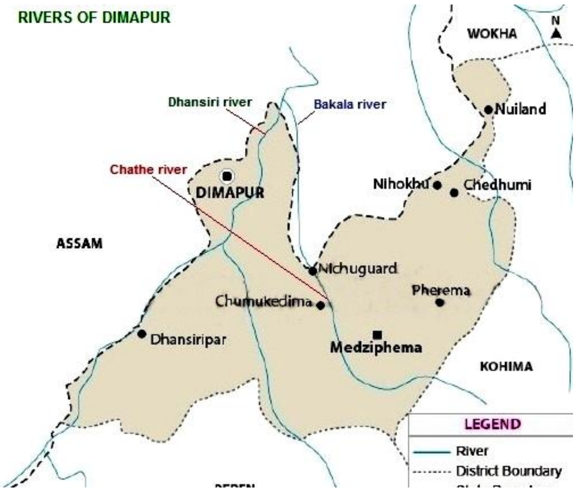

Fig.2: Confluence of the Chathe River with the river Dhansiri in Karbi Anglong district of Assam

(Source: mapsofindia.com)

and also residential. The area receives moderate municipality discharges and traffic pollutants, but no agricultural watershed.

Zone III. It was the downstream region after the dam, having a stretch of around 1.48 km (from *25°47'51.2"N & 93°47'57.2"E* to *25°48'29.2"N & 93°47'42.3"E*) and width varying between 8.56 m to 42.29m. This area is composed of pebbles, sand, clay and rock bed. Vegetation of the area includes a moderate population of trees, grass, shrubs around the mountain slopes at the bank, which is comparatively less than Zone I and II. But, this area has comparatively more aquatic vegetation than Zone I. The watershed properties of the area are mostly agricultural and residential. The area receives a good amount of municipality discharges, agricultural watershed, animal farm runoff, eroded wastes of construction areas and traffic pollutants.

Sample collection

Composite water samples (sub-surface and middle depth) was collected from each sampling site thrice every month for a year, in separate 2000 ml bottles for analysing FCO_2, bicarbonate, chloride, calcium hardness, total hardness, turbidity, pH etc. and 500ml BOD bottles for analysing the amount of dissolved oxygen for each site. The bottles were filled just under the water surface without allowing any air bubbles into the sample. The sample for studying DO was fixed at the site following modified Winkler's method. For analysing BOD, the samples were collected in two 500ml BOD bottles from each site. These sample bottles for DO and BOD were brought to the laboratory in an icebox.

Analytical procedures

Air temperature and humidity were measured at the site with the help of Pacer's hygro-thermometer (Model- TH406). Water temperature was measured at site by mercury bulb thermometer. pH was measured at site by Hanna's pH meter (pHep, Model-HI96107). Conductivity and TDS were also measured at site by Hanna's conductivity-TDS meter (DiST, Model-HI96303). Turbidity of the water was measured by Deluxe turbidity meter (Model-EI335) in the laboratory. Depth of water was measured by sacchi disc and flow of stream current was measured by digital Water Velocity Meter (Global Flow probe, Model-FP111).

Free CO_2 was determined by using Phenolphthalein indicator (Welch, 1952). Total alkalinity was analysed by titration (Trivedy *et al.*, 1987). The estimation of total hardness, calcium hardness, and chloride was made following APHA (2003), Carbonate and bicarbonate alkalinity was measured according to Welch (1952). For estimating DO, modified Winkler method was followed (Trivedy *et al.*, 1987). Biochemical oxygen demand (BOD) was determined after incubating the sample in the dark at 20°C in BOD incubator (Deluxe automatic, Model- N7003) for 5 days (Winkler method).

The collected data were processed in MS-Excel (Ver.2007) to find the average values for each parameter and their standard deviations. The correlation significance among the different parameters was found following Pearson's "r" calculations in MS-Excel (Ver.2007).

Result & discussion

Air temperature: The air temperature was varied between maximum 35.33° C ± 2.1 during September in Zone I and minimum 16.50° C ± 0.5 during January in Zone III (Fig. 3). Changes in air temperature have marginal impact on water temperature fluctuation. In this study water temperature was found to be more than air temperature during February. The humidity in the studied area was varied between maximum 78.67% ± 6.5 during November and minimum 45% ± 13.0 during August in Zone III (Table. 1, 3, 5).

Water temperature: Variation in water temperature is much slower than air temperature. Yet it could be a limiting factor for the aquatic organisms due to their low tolerance limit even to very small changes in water temperature. The reproductive activity and metabolic rates of aquatic organisms are affected by water temperature. A 10°C rise in water temperature could double the rate of physiological and reproductive function of some aquatic species which increases the demand for oxygen, thus creating a temporary oxygen deficit in the river. Water temperature could vary due to seasons, current flow, turbidity, plant population of the streamside areas and wastewater input. Thermal stratification in a river may create

Table 1: Mean values of water parameters in different seasons (Zone I)

Parameters	Winter			Pre-monsoon			Monsoon			Post-monsoon		
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov
AT (˚C)	22.50 ±3.122	16.67 ±0.577	18.83 ±1.041	23.67 ±2.082	30.50 ±2.179	32.67 ±3.512	34.00 ±1.414	34.33 ±2.082	33.33 ±3.215	35.33 ±2.082	31.67 ±2.082	29.33 ±0.577
WT (˚C)	20.50 ±1.323	17.67 ±1.041	20.67 ±0.577	22.50 ±1.323	27.50 ±0.866	26.50 ±2.291	28.75 ±1.061	31.50 ±0.500	29.50 ±2.784	32.00 ±1.000	29.33 ±1.528	26.33 ±0.289
Hum. (%)	66.33 ±6.028	63.67 ±11.015	58.33 ±7.638	65.00 ±2.646	67.00 ±2.646	63.00 ±4.583	71.50 ±3.536	61.33 ±2.082	48.67 ±4.933	46.33 ±4.163	65.00 ±7.937	73.67 ±5.132
Depth (m)	0.638 ±0.014	0.694 ± 0.007	0.722 ±0.035	0.720 ±0.015	0.839 ±0.063	1.032 ±0.136	1.203 ±0.012	1.263 ±0.055	1.695 ±0.647	0.889 ±0.167	0.735 ±0.042	0.777 ±0.013
CF (m/s)	0.226 ±0.025	0.196 ±0.013	0.166 ±0.060	0.185 ±0.021	0.367 ±0.016	0.737 ±0.133	0.308 ±0.004	0.404 ±0.226	0.842 ±0.212	0.503 ±0.143	0.190 ±0.065	0.169 ±0.052
pH	8.37 ±0.115	8.37 ±0.208	7.87 ±0.058	7.77 ±0.115	7.87 ±0.058	7.53 ±0.058	7.65 ± 0.071	7.53 ±0.058	7.87 ±0.153	8.03 ±0.115	8.23 ±0.058	8.43 ± 0.115
Cond. (mS/cm)	0.127 ±0.044	0.152 ± 0.033	0.249 ±0.021	0.232 ±0.029	0.260 ±0.071	0.147 ±0.059	0.235 ±0.035	0.200 ±0.074	0.104 ±0.021	0.138 ±0.076	0.093 ±0.015	0.105 ±0.005
Turb. (NTU)	6.07 ±1.790	8.37 ±1.007	15.47 ±1.002	26.30 ±9.418	32.33 ±2.747	113.00 ±24.249	23.65 ±4.738	65.03 ±43.680	144.00 ±53.861	50.63 ±19.601	17.63 ±5.335	5.89 ±0.369
TDS (mg/L)	64.67 ±22.942	77.33 ±17.039	127.33 ±10.970	118.67 ±15.011	133.00 ±36.715	74.67 ±30.616	120.00 ±18.385	101.67 ±38.083	52.33 ±10.970	70.33 ±38.889	47.00 ±8.185	53.33 ±2.517
DO (mg/L	12.93 ±0.61	12.20 ±0.520	12.23 ±0.289	9.60 ±0.800	7.87 ±0.611	8.13 ±0.462	7.80 ±0.849	8.53 ±0.231	8.67 ±0.833	9.93 ±0.28	10.03 ±0.802	11.17 ±0.55

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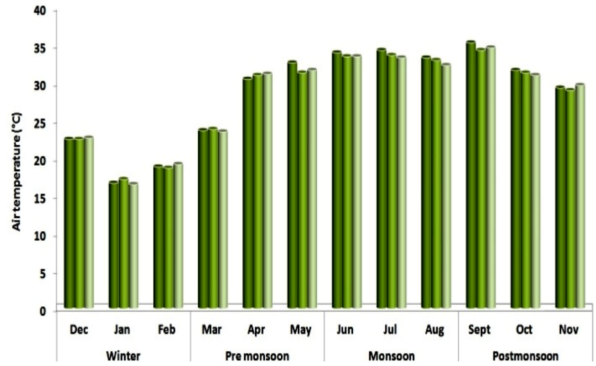
BOD (mg/L)	1.53 ±1.172	0.87 ±0.987	0.80 ±0.200	0.40 ±0.200	1.73 ±1.026	2.67 ±0.808	1.10 ±0.141	3.33 ±0.306	3.49 ±1.132	2.36 ±0.317	0.60 ±0.200	0.33 ±0.115
FCO_2 (mg/L)	7.67 ±1.528	3.67 ±0.577	4.67 ±0.577	9.00 ±2.646	4.33 ±0.577	5.33 ±0.577	5.50 ±0.707	6.33 ±0.577	7.00 ±1.000	9.00 ±1.000	8.33 ±0.577	10.67 ±0.577
HCO_3^- (mg/L)	106.67 ±11.015	68.00 ±13.115	93.33 ±6.429	120.33 ±23.587	158.00 ±9.165	125.33 ±17.243	96.00 ±14.142	63.33 ±7.024	59.53 ±4.081	63.33 ±11.015	75.00 ±7.810	92.67 ±9.238
Chloride (mg/L)	11.34 ±0.577	13.35 ±2.522	19.02 ±2.646	19.02 ±1.732	14.01 ±1.738	13.35 ±0.583	12.51 ±0.707	16.02 ±3.005	21.02 ±1.000	20.69 ±1.155	12.01 ±2.005	11.34 ±0.577
Ca^{++} (mg/L)	0.129 ±0.010	0.168 ±0.017	0.213 ±0.021	0.188 ±0.050	0.073 ±0.024	0.062 ±0.009	0.063 ±0.006	0.070 ±0.005	0.065 ±0.010	0.070 ±0.005	0.090 ±0.013	0.106 ±0.005
$CaCO_3$ (mg/L)	32.2 ±2.42	42.0 ±4.20	53.2 ±5.28	46.9 ±12.30	18.2 ±6.06	15.4 ±2.42	15.8 ±1.48	17.5 ±1.21	16.1 ±2.42	17.5 ±1.21	22.4 ±3.21	26.6 ±1.21
TH (mg/L)	71.33 ±4.163	88.00 ±4.000	98.67 ±5.033	92.67 ±11.719	42.67 ±25.403	28.67 ±2.309	29.00 ±1.414	30.67 ±1.155	29.33 ±2.309	31.33 ±4.163	46.67 ±16.773	44.67 ±7.024

differences in range of temperature and conductivity among different layers of water. Rise in temperature usually decreases the solubility of oxygen in water and increases the pH of water, though the changes in pH may depend on the effect of various other factors. High water temperatures also could increase the toxicity of many compounds by increasing their solubility in water. Any rise in water temperature also decreases the viscosity of water which in turn increases the conductivity of water.



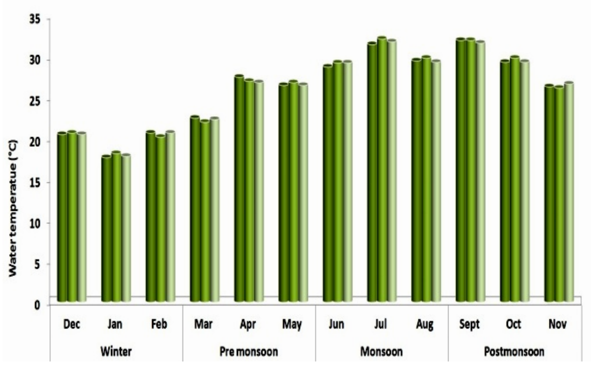


Fig.3: Air temperature

Fig.4: Water temperature

Table 2: Pearson's correlation for parameters of Zone I (N=35, df= 33)

	pH	CF	Cond.	Turb.	DO	BOD	FCO_2	HCO_3^-	CaH	TH	Chloride
WT	**- 0.384**	**0.446**	**- 0.103 ****	**0.449**	**- 0.702**	**0.462**	**0.300**	**- 0.226 ***	**- 0.785**	**- 0.834**	**0.176 ****
pH		**- 0.482**	**- 0.428**	**- 0.539**	**0.693**	**- 0.396**	**0.256 ***	**- 0.177 ****	**0.250 ***	**0.282 ***	**- 0.384**
CF			**- 0.269 ***	**0.939**	**- 0.563**	**0.700**	**- 0.105 ****	**- 0.109 ****	**- 0.587**	**- 0.603**	**0.394**
Cond.				**- 0.227 ***	**- 0.232 ***	**- 0. 104 ****	**- 0.421**	**0.443**	**0.257 ***	**0.238 ***	**0.094 ****
Turb.					**- 0.572**	**0.729**	**- 0.106 ****	**- 0.154 ****	**- 0.492**	**- 0.518**	**0.432**
DO						**- 0.445**	**0.069 ****	**- 0.208 ****	**0.682**	**0.695**	**- 0.142 ****
BOD							**- 0.232 ***	**- 0.183 ****	**- 0.570**	**- 0.586**	**0.287**
FCO_2								**- 0.146 ****	**- 0.154 ****	**- 0.157 ****	**0.004 ****
HCO_3^-									**0.010 ****	**0.101 ****	**- 0.326**
CaH										**0.960**	**0.170 ****
TH											**0.083 ****

*[**→Highly significant ($p<0.1$); *→ Significant ($p<0.05$) and 'r' values without any asterisk indicate insignificance ($p>0.05$)]*

Table 3: Mean values of water parameters in different seasons (Zone II)

Parameters	Winter			Pre-monsoon			Monsoon			Post-monsoon		
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov
AT (°C)	22.50 ±2.646	17.17 ±0.289	18.67 ±1.258	23.83 ±1.893	31.00 ±1.732	31.33 ±3.055	33.50 ±2.121	33.67 ±2.517	33.00 ±3.606	34.33 ±1.528	31.33 ±1.528	29.00 ±1.000
WT (°C)	20.67 ±2.082	18.17 ±1.041	20.17 ±0.289	22.00 ±1.323	27.00 ±1.323	26.83 ±2.021	29.25 ±1.061	32.17 ±0.289	29.83 ±2.754	32.00 ±1.500	29.83 ±0.289	26.17 ±0.289
Hum. (%)	65.33 ±4.041	61.33 ±2.082	60.00 ±8.544	63.00 ±6.083	69.67 ±14.224	67.67 ±6.429	68.50 ±4.950	63.67 ±2.309	51.67 ±10.408	51.33 ±3.512	62.00 ±5.292	76.67 ±2.887
Depth (m)	0.819 ±0.008	0.704 ±0.038	0.704 ±0.052	0.751 ±0.057	0.911 ±0.056	1.124 ±0.031	1.163 ±0.028	1.214 ±0.043	2.031 ±0.887	0.922 ±0.187	0.732 ±0.018	0.901 ±0.078
CF (m/s)	0.209 ±0.041	0.210 ±0.027	0.160 ±0.077	0.212 ±0.040	0.304 ±0.078	0.754 ±0.213	0.301 ±0.021	0.410 ±0.219	0.804 ±0.174	0.503 ±0.118	0.183 ±0.064	0.168 ±0.049
pH	8.37 ±0.153	8.43 ± 0.058	7.90 ± 0.100	7.87 ±0.058	7.83 ± 0.115	7.63 ±0.153	7.65 ±0.071	7.77 ±0.058	7.87 ± 0.058	8.13 ±0.208	8.33 ±0.208	8.30 ±0.100
Cond. (mS/cm)	0.121 ±0.052	0.142 ±0.012	0.259 ±0.051	0.278 ±0.043	0.295 ±0.033	0.155 ±0.084	0.250 ±0.049	0.210 ±0.055	0.102 ±0.020	0.170 ±0.112	0.095 ±0.010	0.094 ±0.004
Turb. (NTU)	5.57 ±1.570	8.07 ±0.321	12.83 ±2.754	17.23 ±2.780	24.00 ±4.795	104.40 ±38.542	23.20 ±4.101	63.50 ±61.946	127.67 ±42.852	51.10 ±22.458	12.07 ±1.401	6.45 ±0.776
TDS (mg/L)	61.67 ±26.502	72.00 ±6.557	132.00 ±26.287	142.33 ±22.008	151.67 ±17.156	78.67 ±43.661	128.00 ±25.456	107.33 ±28.501	51.00 ±10.392	86.67 ±58.106	48.00 ±5.000	47.00 ±2.000
DO (mg/L	13.47 ±0.808	11.77 ±0.666	10.83 ±0.404	9.33 ±0.231	8.13 ±0.231	7.73 ±0.462	8.20 ±0.283	8.27 ±0.231	8.67 ±0.833	9.53 ±0.115	9.93 ±0.28	10.87 ±0.05

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BOD (mg/L)	1.64 ±1.182	0.80 ±1.039	0.60 ±0.200	0.33 ±0.115	1.53 ±0.643	2.73 ±0.808	1.30 ±0.141	3.13 ±0.306	3.07 ±0.833	2.40 ±0.200	0.57 ±0.241	0.47 ±0.140
FCO_2 (mg/L)	6.33 ±1.528	3.67 ±1.155	4.67 ±1.155	7.33 ±0.577	3.00 ±1.000	3.67 ±0.577	3.50 ±0.707	5.33 ±0.577	7.67 ±0.577	8.67 ±0.577	8.67 ±0.577	8.00 ±1.000
HCO_3^- (mg/L)	112.67 ±7.572	81.33 ±17.474	92.67 ±7.572	124.00 ±17.321	163.33 ±13.614	144.33 ±6.028	116.00 ±8.485	72.67 ±10.263	59.67 ±5.686	65.33 ±5.033	70.67 ±6.110	78.00 ±12.166
Chloride (mg/L)	11.01 ±1.000	14.02 ±1.005	18.35 ±2.082	18.35 ±1.528	12.01 ±3.005	12.68 ±0.577	12.51 ±0.707	15.35 ±2.315	18.35 ±2.082	20.02 ±1.732	12.68 ±2.087	10.03 ±1.000
Ca^{++} (mg/L)	0.120 ±0.010	0.157 ±0.019	0.207 ±0.029	0.176 ±0.051	0.062 ±0.018	0.056 ±0.005	0.059 ±0.011	0.051 ±0.009	0.045 ±0.005	0.056 ±0.018	0.076 ±0.009	0.087 ±0.005
$CaCO_3$ (mg/L)	30.1 ±2.42	39.2 ±4.85	51.8 ±7.37	44.1 ±12.77	15.4 ±4.37	14.0 ±1.21	14.7 ±2.97	12.6 ±2.10	11.2 ±1.21	14.0 ±4.37	18.9 ±2.10	21.7 ±1.21
TH (mg/L)	69.33 ±10.066	85.33 ±4.619	97.33 ±7.024	90.00 ±12.166	41.33 ±21.385	27.33 ±1.155	27.00 ±1.414	26.00 ±2.000	26.00 ±2.000	29.33 ±5.774	41.33 ±14.468	41.33 ±1.155

Index:

AT	Air temperature	**pH**	Hydrogen ion potential
WT	Water temperature	**DO**	Dissolved oxygen
Hum.	Humidity	**BOD**	Biochemical oxygen demand
Cond.	Conductivity	**FCO_2**	Free carbon-di-oxide
Turb.	Turbidity	**HCO_3^-**	Bicarbonate alkalinity
CF	Current flow	**CaH**	Calcium hardness
TDS	Total dissolved solid	**TH**	Total hardness

Table 4: Pearson's correlation for parameters of Zone II (N=35, df= 33)

	pH	CF	Cond.	Turb.	DO	BOD	FCO_2	HCO_3^-	CaH	TH	Chloride
WT	- 0.308	0.425	- 0.078 **	0.425	- 0.665	0.501	0.329	- 0.254*	- 0.813	- 0.864	0.096 **
pH		- 0.437	- 0.487	- 0.442	0.764	- 0.373	0.384	- 0.402	0.238 *	0.303	- 0.258 *
CF			- 0.250 *	0.953	- 0.541	0.706	- 0.008 **	- 0.037 **	- 0.570	- 0.569	0.318
Cond.				- 0.243 *	- 0.292	- 0.137 **	- 0.455	0.490	0.250 *	0.247 *	0.176 **
Turb.					- 0.561	0.708	- 0.012 **	- 0.079 **	- 0.502	- 0.524	0.351
DO						- 0.398	0.174 **	- 0.237 *	0.522	0.583	- 0.217 **
BOD							- 0.130 **	- 0.094 **	- 0.609	- 0.613	0.171 **
FCO_2								- 0.583	- 0.116 **	- 0.125 **	0.242 *
HCO_3^-									0.044 **	0.088 **	- 0.361
CaH										0.958	0.250 *
TH											0.196 **

*[**→Highly significant (p<0.1); *→ Significant (p<0.05) and 'r' values without any asterisk indicate insignificance (p>0.05)*

Table 6: Pearson's correlation for parameters of Zone III (N=35, df= 33)

	pH	CF	Cond.	Turb.	DO	BOD	FCO_2	HCO_3^-	CaH	TH	Chloride
WT	-0.478	0.408	0.026 **	0.418	-0.788	0.445	0.275 *	- 0.312	- 0.804	- 0.838	0.052 **
pH		-0.453	- 0.559	- 0.544	0.718	-0.388	0.264 *	- 0.183 **	0.348	0.352	- 0.367
CF			- 0.182 **	0.940	-0.498	0.714	- 0.121 **	- 0.147 **	- 0.612	- 0.577	0.149 **
Cond.				- 0.155 **	-0.281 *	-0.020 **	- 0.427	0.517	0.146 **	0.155 **	0.324
Turb.					-0.525	0.705	- 0.103 **	- 0.159 **	- 0.563	- 0.533	0.221 **
DO						-0.365	- 0.020 **	0.140 **	0.636	0.628	- 0.227 *
BOD							- 0.166 **	- 0.134 **	- 0.616	- 0.598	0.061 **
FCO_2								- 0.682	0.087 **	- 0.007 **	0.264 *
HCO_3^-									0.043 **	0.115 **	- 0.225 *
CaH										0.958	0.323
TH											0.280 *

*[**→Highly significant (p<0.1); *→ Significant (p<0.05) and 'r' values without any asterisk indicate insignificance (p>0.05)]*

Table 5: Mean values of water parameters in different seasons (Zone III)

Parameters	Winter			Pre-monsoon			Monsoon			Post-monsoon		
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov
AT (˚C)	22.67 ±3.055	16.50 ±0.500	19.17 ±1.258	23.50 ±1.803	31.17 ±1.893	31.67 ±2.517	33.50 ±2.121	33.33 ±1.528	32.33 ±3.215	34.67 ±1.528	31.00 ±1.732	29.67 ±1.155
WT (˚C)	20.50 ±1.732	17.83 ±0.764	20.67 ±0.289	22.33 ±1.258	26.83 ±0.764	26.50 ±1.803	29.25 ±1.768	31.83 ±0.577	29.33 ±2.754	31.67 ±1.756	29.33 ±0.764	26.67 ±0.289
Hum. (%)	67.67 ±6.658	64.33 ±3.786	52.00 ±14.799	64.00 ±3.606	67.00 ±13.000	66.00 ±3.464	64.50 ±0.707	65.67 ±4.933	45.00 ±13.000	52.00 ±6.245	62.67 ±5.508	78.67 ±6.506
Depth (m)	0.791 ±0.072	0.670 ±0.045	0.658 ±0.003	0.713 ±0.069	0.807 ±0.101	1.009 ±0.084	1.098 ±0.008	1.298 ±0.217	2.191 ±0.932	0.907 ±0.254	0.742 ±0.043	0.855 ±0.015
CF (m/s)	0.213 ±0.029	0.215 ±0.032	0.150 ±0.062	0.203 ±0.035	0.300 ±0.044	0.722 ±0.176	0.289 ±0.095	0.422 ±0.179	0.801 ±0.203	0.455 ±0.130	0.193 ±0.057	0.163 ±0.032
pH	8.53 ±0.058	8.43 ±0.252	7.80 ± 0.100	7.73 ±0.252	7.73 ± 0.058	7.43 ±0.058	7.55 ±0.212	7.53 ±0.058	7.83 ± 0.153	7.83 ±0.058	8.23 ±0.252	8.37 ±0.115
Cond. (mS/cm)	0.113 ±0.032	0.140 ±0.020	0.250 ±0.048	0.222 ±0.001	0.275 ±0.030	0.182 ±0.073	0.234 ±0.026	0.211 ±0.049	0.107 ±0.032	0.169 ±0.086	0.098 ±0.024	0.109 ±0.021
Turb. (NTU)	6.23 ±2.301	8.20 ±0.700	15.37 ±2.665	19.93 ±6.574	25.97 ±2.230	106.00 ±46.293	25.65 ±0.636	60.63 ±51.414	105.67 ±24.440	53.37 ±24.298	14.20 ±3.915	5.80 ±0.436
TDS (mg/L)	57.00 ±16.523	71.00 ±10.583	128.00 ±24.880	113.67 ±0.577	140.67 ±15.948	92.67 ±37.859	119.50 ±13.435	107.33 ±25.502	54.00 ±16.823	86.00 ±43.863	49.33 ±12.097	55.00 ±11.000
DO	12.97	11.53	10.27	9.43	8.40	7.87	7.80	7.60	7.93	8.27	8.67	9.77

(mg/L)	±1.012	±0.850	±1.405	±0.586	±0.400	±0.611	±0.849	±0.400	±0.702	±0.231	±0.833	±0.981
BOD (mg/L)	1.57 ±1.104	0.93 ±1.102	0.60 ±0.200	0.27 ±0.115	1.60 ±0.917	2.67 ±0.702	1.30 ±0.141	3.07 ±0.416	2.80 ±0.346	2.33 ±0.306	0.51 ±0.162	0.47 ±0.140
FCO_2 (mg/L)	7.33 ±1.528	3.67 ±0.577	8.33 ±1.528	6.33 ±0.577	3.00 ±1.000	4.00 ±1.000	5.50 ±0.707	6.33 ±0.577	8.33 ±0.577	9.33 ±1.528	8.67 ±0.577	9.67 ±0.577
HCO_3^- (mg/L)	111.00 ±5.568	82.67 ±5.774	92.67 ±25.007	113.00 ±10.817	166.00 ±8.888	125.67 ±15.308	97.00 ±1.414	67.67 ±14.012	56.33 ±2.887	59.33 ±9.452	67.67 ±4.933	84.00 ±2.000
Chloride (mg/L)	12.01 ±1.000	13.01 ±1.005	20.69 ±3.218	19.02 ±2.000	14.35 ±0.577	12.68 ±0.572	12.61 ±0.566	15.02 ±2.005	17.35 ±3.792	20.36 ±2.315	11.68 ±2.087	11.68 ±0.577
Ca^{++} (mg/L)	0.120 ±0.010	0.151 ±0.017	0.191 ±0.020	0.165 ±0.024	0.062 ±0.005	0.048 ±0.005	0.058 ±0.003	0.059 ±0.008	0.054 ±0.005	0.064 ±0.005	0.076 ±0.009	0.098 ±0.005
$CaCO_3$ (mg/L)	30.1 ±2.42	37.8 ±4.20	47.6 ±4.85	41.3 ±6.06	15.4 ±1.21	11.9 ±1.21	14.6 ±0.14	14.7 ±2.10	13.3 ±1.21	16.1 ±1.21	18.9 ±2.10	24.5 ±1.21
TH (mg/L)	66.67 ±8.327	84.00 ±4.000	100.00 ±14.422	87.33 ±5.774	40.00 ±20.785	25.33 ±1.155	27.00 ±1.414	27.33 ±2.309	26.00 ±2.000	28.67 ±2.309	41.33 ±14.468	40.67 ±1.155

The water temperature in the study area of Chathe River was found to be varied between maximum 32.17° C ± 0.3 during July in Zone II and minimum 17.67° C ± 1.0 during January in Zone I. The water temperature was found maximum during monsoon and minimum during the winter season of the year (Fig.4). The study has shown a highly significant negative correlation ($p<0.1$) between conductivity and water temperature in Zone I and II, but highly significant positive correlation in Zone III of the study area (Table. 2, 4, 6). In this study, a highly significant positive correlation was found between chloride and water temperature in all the zones. pH, calcium & total hardness has shown an insignificant negative correlation with water temperature in all the zones. A significant negative correlation ($p<0.05$) was found between water temperature and bicarbonate in Zone I and II. An insignificant negative correlation ($p>0.05$) was found between the amount of dissolved oxygen and water temperature in all the zones. An insignificant positive correlation was found between BOD and water temperature in all the zones.

Depth: Increase in depth of a river usually increases the flow of current in water body. The river's discharge is also dependent on the depth of a river. The depth also contributes in creating thermal or photic stratification in the river, which in turn provide a wide range of habitat for aquatic creatures.

The present study has shown a maximum depth of 2.191 m ± 0.9 during August in Zone III and minimum was 0.638 m ± 0.01 during December in Zone I of the Chathe River (Fig. 7). The depth of a river is directly influenced by the average rainfall during the months of a year. According to the simulated rainfall data from GPCC, highest accumulated rainfall was observed in May (381.37 mm) and August (311.35 mm). Lowest accumulated rainfall was observed in February (9.39 mm). There was no rainfall in December and January (Fig.5).

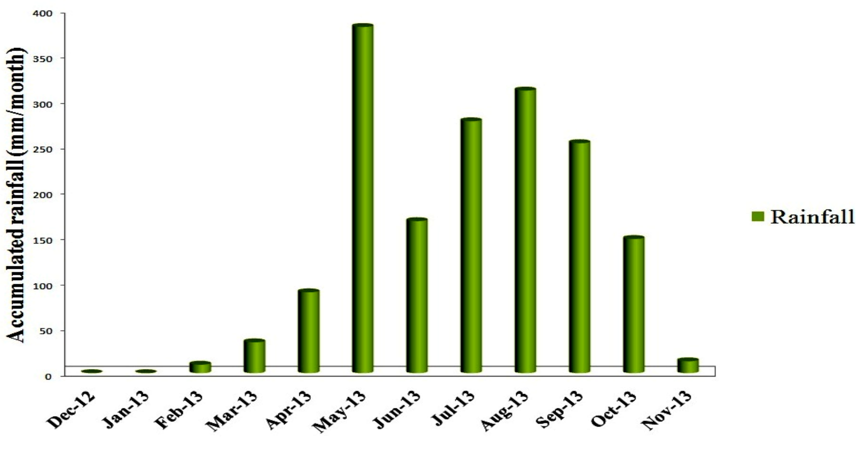

Fig.5: Monthly accumulated rainfall in Dimapur district, Nagaland for Dec.12-Nov.13 (Source: Monthly GPCC_RAIN.004 product)

Current flow: Current flow is unidirectional in a lotic system. It is one of the most important physical factor because it maintain a balance of nutrients between different strata of water body, influences the distribution of temperature and salinity. Current carries oxygen to the deeper layer of the river and carries away the waste materials. Flow of current also carry eggs, larva of aquatic creatures and transport small aquatic organisms from one place to another creating a wide distribution of diversity along a wide range of the river.

Maximum flow of current in the Chathe River was found 0.842 m/s ± 0.2 during August in Zone I and minimum was 0.150 m/s ± 0.06 during February in Zone III (Table. 1, 3, 5). The river is very sluggish in its annual water flow but downhill movement of water create optimum turbulence of water over the rocks and pebbles. Maximum riffling of water was found in Zone I and II during the months of normal rainfall. Highest flow of water was found in May and August (Fig.8). As a rocky mountain river water velocity was highly dependent on water level and in turn on average rainfall (Fig.5). The current flow of the river was found to be much less around the seasons of the year in comparison to other sluggish river of India like the Ganges which has a current flow of 0.39-2.18 m/s (Joshi *et al.*, 2009). Current flow was found to have a highly significant negative correlation ($p<0.1$) with free CO_2 and bicarbonate alkalinity in all the zones of study area (Table. 2, 4, 6). A negative correlation was found between Current flow and conductivity in Zone I and II which was significant ($p<0.05$), and a highly significant ($p<0.1$) correlation in Zone III (Table. 6). The study has shown a highly significant positive correlation between current flow and chloride only in Zone III (Table 6).

pH: Most of the aquatic organisms usually prefer a pH range of 6.0–9.0 (Ellis,1997). The pH values between 6.5 to 8.5 were required to maintain the productivity of water and normal physiology of aquatic life (Jhingran, 1985). Any extreme value above or below this range could disturb the fecundity and increase the rate of mortality of the organisms. The higher or lower value of pH other than the normal range also increases toxicity by increasing the solubility and mobility of various compounds in water. It may result in eutrophication of the system thus increasing the oxygen deficit of the water body. pH varies with the concentrations of bicarbonate (HCO_3^{-}) and carbonate (CO_3^{2-}) ions, though the concentration of CO_2 is independent of pH. Increases in bicarbonate and carbonate ions increase the pH & CO_2. Increase in amount of CO_2 (i.e. Carbonic acid) or other acids decrease the pH of the river. Thus, the river is usually buffered by a complex CO_2-Bicarbonate system.

The pH of the study area of the Chathe River was varied between maximum 8.53 ± 0.06 during December and minimum 7.43 ± 0.06 during May in Zone III (Table. 1, 3, 5). The study has shown a predominant pH during winter and post-monsoon season (Fig.9). Chakrabarti *et al.*, (1984) observed the maximum pH value in November and December in

Allahbad. Increase in pH is directly correlated with the low level of water and increase in discharge of sewage effluent. During pre-monsoon and monsoon season pH was reduced in all the zones due to the increased level of water (Fig.7 and 9), higher rate of respiration and decomposition of organic wastes. Though pH is usually decreased by an increase in concentration of FCO2, but pH has been found to be positively correlated with free CO_2 which was significant ($p<0.05$) in Zone I and III (Table. 2, 6), but insignificant ($p>0.05$) in Zone II (Table. 4) during this study. Despite the presence of higher concentration of FCO_2 during winter and pre-monsoon seasons, pH was increased by photosynthesis and influx of sewage effluents containing high level of detergent or soap based product indicating moderate pollution in the water. pH was also found to be negatively correlated to bicarbonate in all the zones. The correlation was highly significant (pH<0.1) in Zone I and III, but insignificant in Zone II. An insignificant negative correlation was found between pH and chloride in Zone I and III, but a significant value was observed in Zone II. Also, pH has shown an insignificant negative correlation with BOD in all the zones ($p>0.05$) (Table. 2, 4, 6). In this study, pH has shown an insignificant negative correlation with turbidity in all the zones. The lower pH during the monsoon season was due to turbidity as described by Gupte *et al.*, (2013)

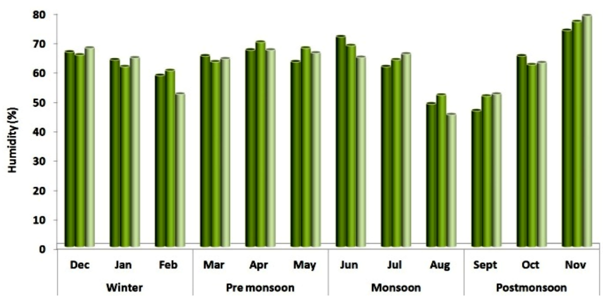

Fig.6: Humidity

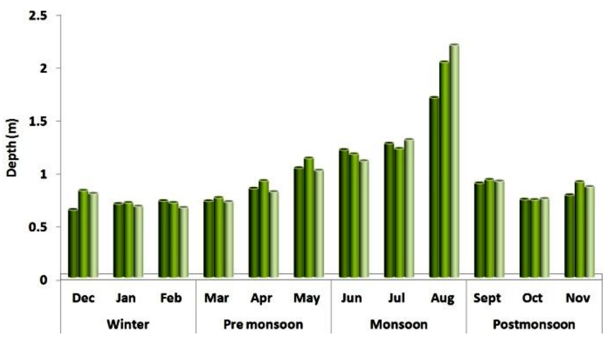

Fig.7: Depth

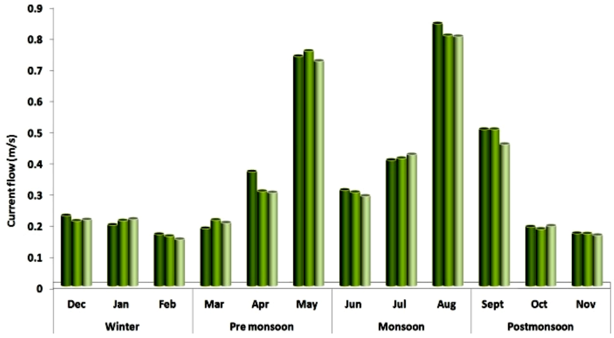

Fig.8: Current flow

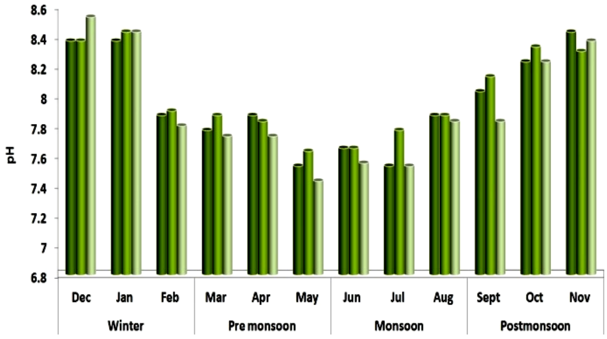

Fig.9: pH

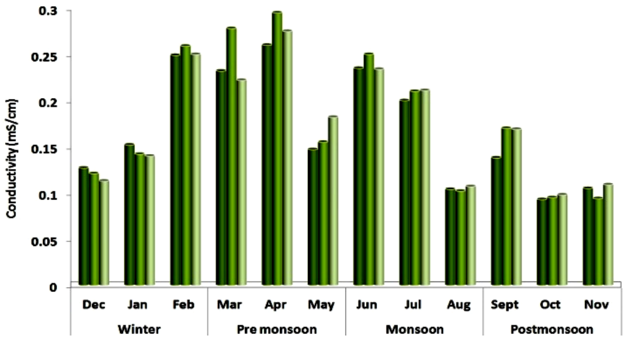

Fig.10: Conductivity

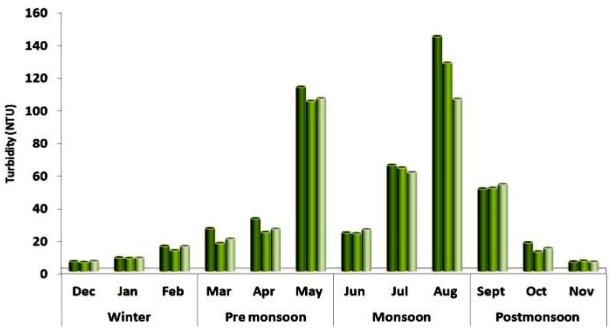

Fig.11: Turbidity

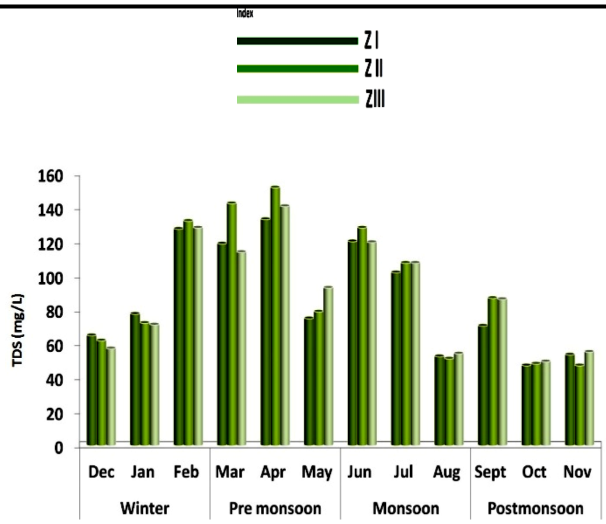

Fig.12: Total dissolved solid

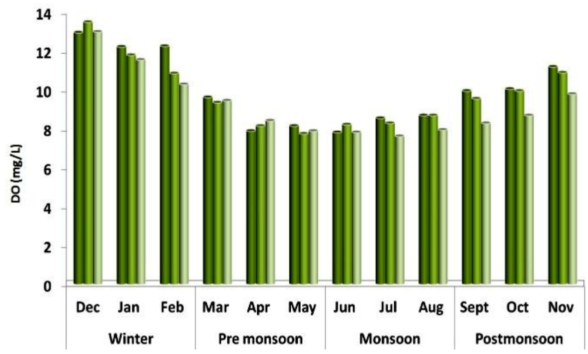

Fig.13: Dissolved oxygen

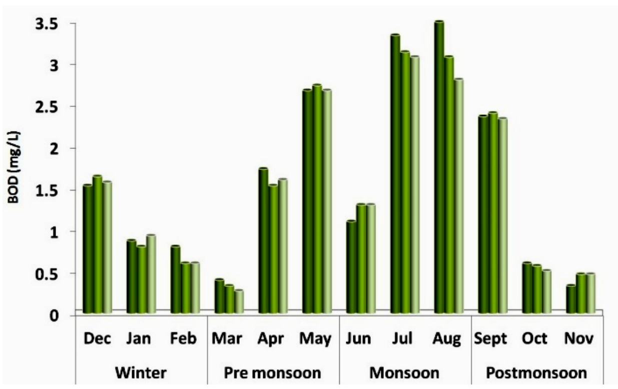

Fig.14: Biochemical oxygen demand

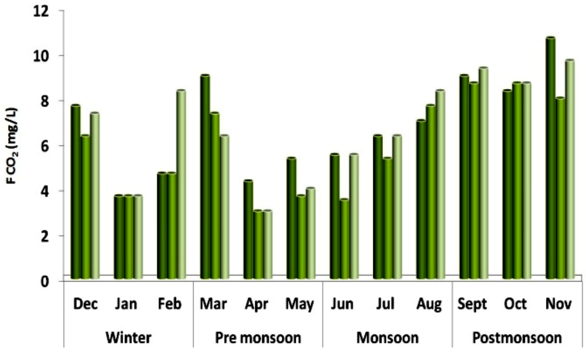

Fig.15: Free CO_2

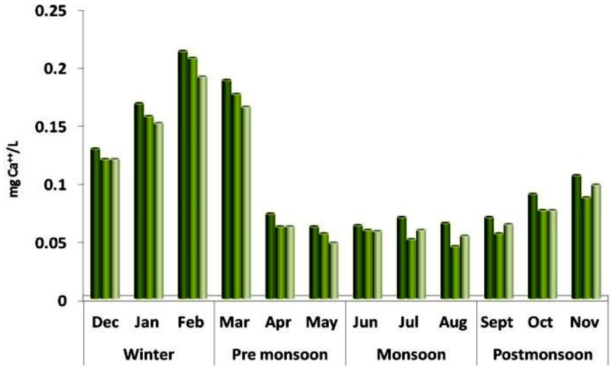

Fig.16: Calcium hardness

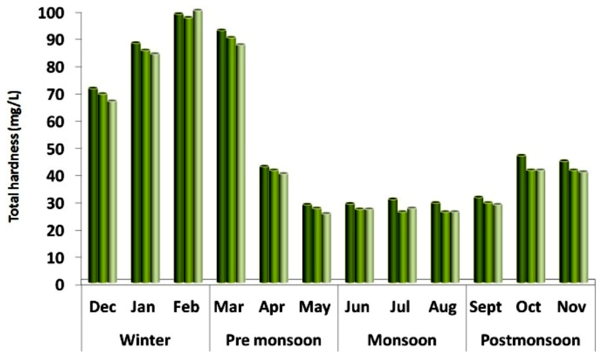

Fig.17: Total hardness

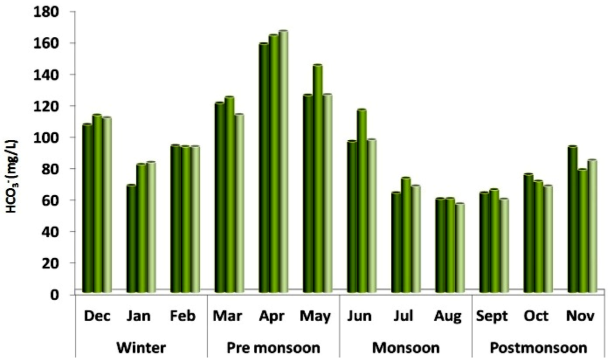

Fig.18: Bicarbonate

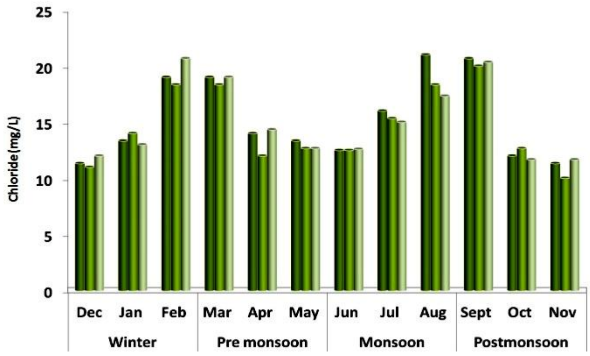

Fig.19: Chloride

Conductivity: Conductivity is the flow of electric current by mobile ions in water which is expressed in µS or mS per centimetre. Increase in the amounts of ions dissolved in water increase the conductivity of water. Seawater has more conductivity (EC ≤ 55 mS/cm) than the freshwater system

(EC = 0.05–2 mS/cm) at 25°C temperature. Again the river that passes through the area rich in clay

soil or limestone soils have more conductivity than the stream passing over the granite bedrock because these contain more non-ionisable components. A sudden fluctuation in conductivity indicates

the pollution of water because, wastewater or agricultural watershed contribute chloride, phosphate or nitrate ions into the stream thus increasing the conductivity and when organic compounds are discharged into the river decrease the conductivity of water as they don't dissociate into the ions.

In the study of parameters of the Chathe River, maximum conductivity observed was 0.295 mS/cm ± 0.03 during April in Zone II and minimum 0.093 mS/cm ± 0.02 during October in Zone I (Table. 1, 3, 5). Conductivity was found maximum during the later part of winter, greater part of pre-monsoon and monsoon season (Fig. 10). A highly significant positive correlation ($p<0.1$) was found between conductivity, Calcium hardness and total hardness in Zone III, but a significant positive correlation in Zone I and II (Table. 2, 4, 6). Conductivity was negatively correlated with BOD in all the zones which was highly significant ($p<0.1$). A highly significant positive correlation was observed between conductivity and chloride in Zone I and II. Conductivity was found to be positively correlated with bicarbonate alkalinity in all the zones, but the correlation was insignificant $p>0.05$). Presence of many ions like chloride, bicarbonate, sodium, calcium, magnesium etc., in smaller amounts could increase the conductivity in the waterbed, but bicarbonate ion is a predominant factor of conductivity in freshwater system. Conductivity was negatively correlated with turbidity. The correlation was highly significant in Zone III ($p<0.1$) but, significant in Zone I and II ($p<0.05$) (Table. 2, 4, 6). Conductivity was found to be negatively correlated with dissolved oxygen in all the study area. The correlation was significant in Zone I and III ($p<0.05$), but insignificant in Zone II ($p>0.05$). There was no abrupt fluctuation found in conductivity over the studied seasons in the river indicating an unpolluted nature of water.

Turbidity: Turbidity is the amount of solids, which remain suspended in the water of a river. The amount of these suspended solid is directly proportional to the range of turbidity of the stream which could be expressed in NTU. Turbidity in river is increased by the influx of sewage effluent. High turbidity in water lowers the conductivity. Rise in the value of turbidity increases the temperature of the water & decreases the amount of dissolved oxygen. Highly turbid water reduces the light penetration, which in turn reduce the productivity of the ecosystem and deposition of fine sediments could alter the habitat of aquatic organisms.

In the present study, maximum turbidity observed in the Chathe River was 144 NTU ± 53.9 during August in Zone I and 5.57 NTU ± 1.6 during December in Zone II. Highest turbidity was observed during May and August (Fig.11), which could be related to heavy rainfall during those months (Fig. 5). Higher percentage of turbidity is contributed to the river during high precipitation through agricultural waste watershed, domestic waste runoff, animal feeding farm runoff, flow of roadway contaminants, erosion of rock bed etc. Usually turbidity is higher in downstream region of the river, contributed by downhill flow from upstream region of the river. Turbidity has shown a highly significant negative correlation ($p<0.1$) with free CO_2 and bicarbonate in all the zones (Table. 2, 4, 6). A positive correlation was observed between turbidity and chloride in all the zones. The correlation was highly significant in Zone III ($p<0.1$), but insignificant in Zone I and II ($p>0.05$) (Table. 2, 4, 6).

Turbidity was found to be negatively correlated with conductivity in all the studied zones. The correlation was highly significant in zone III ($p<0.1$), and significant ($p<0.05$) in zone I and II. An insignificant ($p>0.05$) positive correlation was found between turbidity and water temperature in all the zones. Turbidity was negatively correlated with dissolved oxygen in this study, which was found to be insignificant (Table. 2, 4, 6). During high turbidity, the suspended particles in water absorb the heat from sun which in turn is transferred to the water molecules, thus increasing water temperature. As warm water surface become fully saturated with less dissolved oxygen, so lowers the amount of dissolved oxygen in water.

Total dissolved solid: Any solute or ion particles smaller than 2 µm in size which remain dissolved in water, are referred to as TDS. Increase in the amount of TDS increase the conductivity of water. Very high concentration of TDS can reduce the productivity of the river, species diversity and fecundity of most of the aquatic organisms due to the osmotic intolerance caused by high salinity.

Maximum TDS was found as 151.67 mg/L ± 17.2 during April in Zone II and minimum as 47 mg/L ± 8.2 during the month of October in Zone I in annual analysis of the Chathe River (Table. 1, 3, 5). TDS was found maximum during the later part of winter and early part of pre-monsoon season (Fig. 12). The amount of TDS is positively correlated with conductivity of water.

Dissolved oxygen: The amount of dissolved oxygen is considered as the most important determinant of a healthy stream. It is necessary for respiration of all the aquatic organisms including zooplankton. Phytoplankton use dissolved oxygen for respiration in absence of sunlight. Microorganisms like bacteria and fungi contribute to the recycling of nutrients to the stream by decomposing organic material in presence of dissolved oxygen. Oxygen is added to the river water by aeration through running water, wind, waterfall etc., or diffusion of oxygen into the water from surrounding atmosphere or as a waste product of photosynthesis by aquatic plants etc. Increase in salinity, temperature and turbidity decreases the amount of dissolved oxygen in water. At surface or mid-surface layer of a river can hold less dissolved oxygen than deeper layer of the stream, because amount of dissolved oxygen increases with the increase in pressure and decrease in temperature.

The amount of dissolved oxygen in the Chathe River was found varied between maximum 13.47 mg/L ± 0.8 during December in Zone II and minimum 7.6 mg/L ± 0.4 during July in Zone III (Table.1, 3, 5). According to Ali (1993), concentration of DO higher than 5mg/L is considered as best for any aquatic productivity. DO levels in river water usually increase when, the water passes over Dam and also there is a consistent remixing of aerial oxygen by turbulence of water (IUCN, 1994). During post-monsoon and winter season of the year, dissolved oxygen was found to be more than pre-monsoon and monsoon. During pre-monsoon and monsoon seasons of the year, amount of DO was less due to a sharp increase in water temperature, turbidity, rate of decomposition etc. (Fig.13). The amount of dissolved oxygen was varied almost uniformly during most of the months of the year in different zones, indicating the stability & unpolluted nature of the studied zones. A negative correlation was found between the amount of dissolved oxygen and chloride which was highly significant ($p<0.1$) in Zone I and II but significant ($p<0.05$) in Zone III (Table. 2, 4, 6). Highly significant negative correlation was found between dissolved oxygen and free CO_2 in Zone III, which was also observed by Mathew (1975) and Verma (1969). This is obvious due to the presence of more aquatic vegetation and a large amount sewage or municipality discharge in this area. Dissolved oxygen was found negatively correlated with bicarbonate in Zone I and II. The correlation was highly significant in Zone I ($p<0.1$) and significant ($p<0.05$) in Zone II. But, a highly significant positive correlation ($p<0.1$) was found between them in Zone III. Dissolved oxygen was found to be negatively correlated with water temperature, biochemical oxygen demand and turbidity in all the zones.

Biochemical oxygen demand: BOD is the amount of oxygen consumed by bacteria and fungi to decompose the organic materials aerobically. The organic wastes, agricultural or industrial run off etc. act as the major food sources for some micro-organisms like bacteria and fungi. These organisms play an important role to recycle the nutrients back to water body by decomposing the wastes in presence of oxygen. Higher value of BOD is considered as an indicator of the polluted and unhealthy status of the river because, excess of agricultural, municipality or domestic waste discharges add nutrients and organic wastes into the water body, which increase the rate of multiplication and metabolism of bacteria and saprobes. It reduces the amount of oxygen available for aquatic organisms by consuming the major share for decomposition.

Maximum BOD found in the Chathe River was 3.49 mg/L ± 1.1 during August in Zone I and minimum was 0.27 mg/L ± 0.1 during March in Zone III (Table. 1, 3, 5). Higher BOD in zone I is mostly contributed by agricultural watershed, animal feed-farm runoff etc. These usually contribute a high amount of organic wastes and nutrients into the water body. BOD was found more during the pre-monsoon and monsoon season of the year (Fig.14). The water of the river containing BOD in the range of 1-3 mg/L could be considered as unpolluted as discussed by Khan *et al.* (1999a, b). Highly significant positive correlation ($p<0.1$) was found between BOD and chloride in Zone II and III. In this study, BOD was found to be negatively correlated with free CO_2. The correlation was found highly significant in Zone II and III ($p<0.1$), and significant in Zone I ($p<0.05$). Highly significant negative correlation ($p<0.1$) was found between BOD and bicarbonate in all the zones (Table. 2, 4, 6) BOD was found positively correlated with water temperature as the rate of multiplication of bacteria and saprobes increases with the optimum increase in temperature and so the rate of decomposition of organic wastes.

Free Carbon Dioxide: Due to the low partial pressure, very less amount of FCO_2 could be added to water from surrounding environment. FCO_2 is often added to the water by microorganisms through aerobic and anaerobic decomposition of organic matter or by respiration of aquatic fauna and rarely from surrounding environment. The amount of FCO_2 will be higher at night because plants would be producing FCO_2 by utilising dissolved oxygen (DO) for their respiration. So increase in the amount of FCO_2 will decrease dissolved oxygen in water. The dissolved CO_2 will react with water molecule to form carbonic acid. Increase in concentration of carbonic acid decrease the pH in water body. Dissociation of carbonic acid will form bicarbonate ion and hydrogen. If bicarbonate concentration is more than FCO_2 it increases pH of the water or vice versa.

In the Chathe River, maximum FCO_2 found was 10.67 mg/L ± 0.6 during the month of November in Zone I and minimum 3 mg/L ± 1.0 during April in both Zone II and III (Table.1, 3, 5). FCO_2 was found predominant during the post-monsoon season of the year (Fig.15). Lowest concentration of FCO_2 was found from April to June. Vyas and Kumar (1968) also observed the absence of FCO_2 in June during their study in Indrasagar tank of Udaipur (India), due to an increase in photosynthetic activities of phytoplankton and algae during premonsoon and monsoon. According to Ali (1993), FCO_2 in excess of 20 mg/L could be considered as lethal for aquatic life. Higher concentration of FCO_2 was found during February in Zone III. During pre-monsoon and November high concentration of FCO_2 was found in Zone I. This indicates an increase in decomposition of organic matter during those months due to maximum influx of animal farm runoff, agricultural watershed and sewage effluent in these areas. A negative correlation was found between free CO_2 and bicarbonate in all the zones, and the correlation was highly significant ($p<0.1$) in Zone I (Table. 2, 4, 6). FCO_2 was found to be negatively correlated with calcium hardness in Zone I and II, and positively correlated in Zone III, which was highly significant. A highly significant negative correlation was found between FCO_2 and DO in Zone III. Photosynthesis by phytoplankton and other aquatic plants reduce the concentration of FCO_2 and their respiration increases DO in water. But highly significant positive correlation between FCO_2 and DO in Zone I and II was due to less aquatic vegetation, high gradient turbulence of water and presence of organic wastes in moderate amounts in these areas. Total hardness was found to be negatively correlated with FCO_2 and was highly significant in all the zones. A positive correlation was found between FCO_2 and chloride in all the zones. The correlation was found highly significant ($p<0.1$) in zone I and significant ($p<0.05$) in Zone II and III (Table. 2, 4, 6). A highly significant negative correlation was found between FCO_2 and turbidity in all the zones. FCO_2 was found to have a positive correlation with water temperature, which was only significant in Zone III ($p<0.05$). This is due to the influx of a good amount of organic wastes in this area.

Bicarbonate alkalinity: Bicarbonate (HCO_3^-) ions appear in the water by dissociation of carbonic acid (H_2CO_3). But when Ph level is high, bicarbonate ion is broken down to carbonate ion (CO_3^{2-}) and H^+, which lowers the Ph. Thus, this reaction acts as buffer in water body. Alkalinity is directly dependent on the abundance of phytoplankton in the water body which break bicarbonate into carbonate and CO_2 (Srivastava & Patil, 2002). Alkalinities at or above 20 mg/L trap CO_2 and increase the concentrations available for photosynthesis by phytoplankton, which remove CO_2 (i.e. carbonic acid) thus increasing pH (Wurts & Durborow, 1992). At pH < 4.5, only CO_2 and H_2CO_3 will dominate but no bicarbonate or carbonate would be available. At higher pH, dissociation of Carbonic acid will produce bicarbonate, but limited or no CO_2 would be available. At intermediate pH, bicarbonate will dominate in water (Allan & Castillo, 2007).

Bicarbonate alkalinity of the Chathe River was varied between maximum 166 mg/L ± 8.9 during April and minimum 56.33 mg/L ± 2.9 during August in Zone III (Table. 1, 3, 5). Bicarbonate concentration was found maximum during winter and pre-monsoon season of the year (Fig.18). Bicarbonate alkalinity remains high during winter due to low temperature and rainfall (Rahman *et al*, 2015). Bicarbonate alkalinity was found to be lowest during monsoon due to heavy rainfall, as also observed by Michael (1968) and Verma (1969). Concentration of bicarbonate remains high in water bodies falling within the pH range of 7.0-9.0 (George et al., 1966). Water with low alkalinity is termed as weakly buffered which are susceptible to the changes in pH due to photosynthetic activity (Deas & Orlob, 1999), as well as decomposition of organic wastes. A highly significant positive correlation ($P<0.1$) was found between bicarbonate alkalinity, calcium hardness and total hardness in all zones of the Chathe river during the period of study (Table. 2, 4, 6). A negative correlation was observed between bicarbonate and FCO_2, which was highly significant in Zone I of the studied area.

Highly significant ($P<0.1$) negative correlation was observed between bicarbonate concentration and turbidity of the Chathe River in all the zones (Table. 2, 4, 6). BOD has shown a highly significant negative correlation with bicarbonate concentration of the studied zones. Bicarbonate concentration has shown a negative correlation with chloride of the studied area. The correlation was found significant ($p<0.05$) only in Zone III.

Calcium hardness: Calcium is mainly present in water as calcium carbonate, which is less soluble in water. In presence of CO_2, calcium carbonate is converted to soluble calcium bicarbonate. Calcium carbonate or bicarbonate acts as a source of natural alkalinity. But calcium ions contribute more to the hardness of water than alkalinity. Ca^{++} ion is leached into water from various rocks like marble, limestone, calcite etc. At moderate concentration (around 17.1- 60 mg/L) Ca^{++} ion may contribute to some of the most important biological processes like Blood clotting, formation of bone, shells of aquatic organisms, cell wall of aquatic plants and metabolic reactions in fishes etc. Ca^{++} ion also protect the aquatic organisms against metal toxicity to some extent. EPA has not set any safety standard for calcium hardness.

During the period of the study, maximum calcium was found as 0.213 mg/L Ca^{++} ion $\pm$ 0.02 and 53.2 mg/L calcium carbonate $\pm$ 5.3 during February in Zone I of the Chathe River. Minimum calcium was found as 0.045mg/L Ca^{++} ion $\pm$ 0.01 & 11.2 mg/L calcium carbonate $\pm$ 1.2 during August in Zone II (Table. 1, 3, 5). Calcium hardness in the river was found more during winter and early part of pre-monsoon season of the year (Fig.16). A highly significant positive correlation ($p<0.1$) was found between calcium hardness and chloride in Zone I, and a significant correlation ($p<0.05$) was observed in Zone II (Table. 2, 4, 6). In Zone III, the correlation was insignificant ($p>0.05$). Calcium hardness was positively correlated with bicarbonate concentration in all the studied area, which was found to be highly significant. A positive correlation was found between the concentration of calcium and conductivity. The correlation was significant in Zone I and II and highly significant in Zone III of the Chathe River (Table. 2, 4, 6). A significant positive correlation was observed between calcium concentrations with pH in Zone I & II during the period of study.

Total hardness: Total hardness of water is usually caused by bivalent cations like Ca^{++}, Mg^{++} etc. The hardness of a river reflects the measure of the influence of human activity and also geology of the area. Though there is no standard set for the level of hardness by EPA, but acceptable concentration of total hardness in freshwater is usually considered in the range of

15-375 mg/L as $CaCO_3$, calcium hardness of freshwater in the range of 10-250 mg/L and magnesium hardness in the range of 5-125 mg/L (Source: Vernier).

During the study of parameters of the Chathe River, the total hardness of the area was found to be varied between maximum 100 mg/L ± 14.4 during January and minimum 25.33 mg/L ± 1.2 during May in Zone III (Table. 1, 3, 5). Total hardness in the river was found maximum during winter and early part of the pre-monsoon season of the year (Fig.17) Total hardness was found to be positively correlated with the concentration of chloride (Table. 2, 4, 6). The correlation was highly significant ($p<0.1$) in Zone I and II, and significant ($p<0.05$) in Zone III. The amount of chloride has direct relationship with the total hardness of the water body because, chloride can influence the noncarbonate hardness in the water body. A positive correlation was found between total hardness and conductivity of the area. The correlation was found highly significant in Zone III, and significant in Zone I and II. A highly significant negative correlation was found between total hardness and FCO_2 of the studied area. In Zone I, a significant positive correlation was found between total hardness and pH.

Chloride: Chloride is one of the major inorganic anion in river which is added to the water by dissociation of sodium chloride and calcium chloride. Agricultural watershed, septic tank effluent, animal wastes are the major sources of chloride in water. During "low flow" seasons of the year when evaporation is more than the precipitation, concentration of chloride increases. A range of 45-155 mg/L of chloride in a river is considered as normal. Increase in concentration of chloride ions increase the salinity, which in turn increase the conductivity of water. Higher concentration of chloride could be lethal for aquatic organisms.

Amount of chloride in the studied area of the River Chathe was varied between maximum 21.02 mg/L ± 1.0 during August in Zone I and minimum 10.03 mg/L ± 1.0 during November in Zone II (Table. 1, 3, 5). Amount of chloride was found more during the later part of winter and early part of pre-monsoon and also during the later part of monsoon and early part of post-monsoon seasons (Fig.19). A highly significant positive correlation ($p<0.1$) was found between water temperature and chloride in all the studied area (Table. 2, 4, 6). Amount of chloride was found to be negatively correlated with dissolved oxygen in all the zones because, the water with higher salinity can hold less oxygen at any given temperature. The correlation was highly significant ($p<0.1$) in Zone I and II, and significant ($p<0.05$) in Zone III. A highly significant positive correlation was found between the amount of chloride and conductivity in Zone I & II i.e., high salinity increases conductivity of water. Chloride was found to be positively correlated with total hardness in the studied area of the River Chathe. Though, the correlation was highly significant ($p<0.1$) in Zone I and II, and significant ($p<0.05$) in Zone III, but total hardness is mainly attributed to the *carbonate hardness* (i.e., carbonate and bicarbonate of calcium, magnesium etc.) and very rarely to *noncarbonate hardness* (by chloride of calcium, magnesium etc.) (Wilson, 2010). A significant positive correlation ($p<0.05$) was found between chloride and free CO_2 in Zone II and III, and the correlation was highly significant ($p<0.1$) in Zone I. During this study, a positive correlation was found between the amounts of chloride and turbidity. The correlation was highly significant in Zone III ($p<0.1$), but insignificant ($p>0.05$) in Zone I and II of the Chathe River. Chloride was also found negatively correlated with pH of the water. The relationship was found significant only in Zone II. A highly significant positive correlation ($p<0.1$) was found between chloride and BOD in Zone II and III, during the period of study (Table. 2, 4, 6).

Conclusion

Assessment of physico-chemical parameters of the three selected zones in the Chathe River has shown the marginal differences between themselves. The upstream region (Zone I) of the river though is an undisturbed area in comparison to other two zones, but shown a very little differences in the observed values of different physico-chemical parameters. Despite of the presence of a dam between midstream (Zone II) and downstream (Zone III) region and also being influenced by more residential, agricultural and traffic disturbances, downstream region of the Chathe River has shown uniform values of parameters to that of upstream region with a very few marginal differences. It indicates that the additive effect of many factors at a time maintain the homeostasis of the ecosystem despite of the influences of various external factors within an acceptable limit. Further studies could be extended in this regard to estimate the influence of these factors in maintaining homeostasis in the river. According to the EPA's guidelines for water quality standard, dissolved oxygen should not be less than 4 or 5 mg/L; water temperature must not exceed 32.2°C; pH in the range of 6.0 – 9.5; TDS should be below 500mg/L; alkalinity should not be less than 20 mg/L (75 -200mg/L) and conductivity in the range of 0.1 – 2 mS/cm for any freshwater stream. EPA has not given any guideline for maximum hardness. WHO also has prescribed guidelines for maintaining the quality for drinking water. According to WHO (2004), TDS in drinking water should not exceed 1000mg/L; chloride concentration must be lower than 250 mg/l; pH in the range of 6.5-8.5 and hardness should be less than 500mg/L of $CaCO_3$. Barnes (1998) recommended that to maintain native fish populations in Rivers and streams, random monthly values of turbidity should never exceed 100 NTU. When the observed values different parameters of Chathe river was compared to the guidelines of EPA, WHO & Barnes, it was found that water temperature (17.67-32.17°C), dissolved oxygen (7.6-13.47mg/L), pH (7.4-8.5), alkalinity (56.3-166mg/L), hardness (maximum 53.2 mg/L $CaCO_3$ and 100mg/L of total hardness), TDS (47-151.67mg/L) of the river was within the safe limit of the guidelines to establish the river as an unpolluted healthy stream suitable for drinking as well as ecological productivity. Turbidity (5.57-144 NTU) of the river was little higher than Barnes's recommendations, but in absence of heavy rainfall the limit of turbidity in the river rarely exceed 60 NTU. The average value of physicochemical parameters of the Chathe River discussed here are the measures of the year 2012-2013. Further studies on these parameters are recommended for future workers to establish a concrete fact about the river.

Fig.20: Zone I (Chathe River)

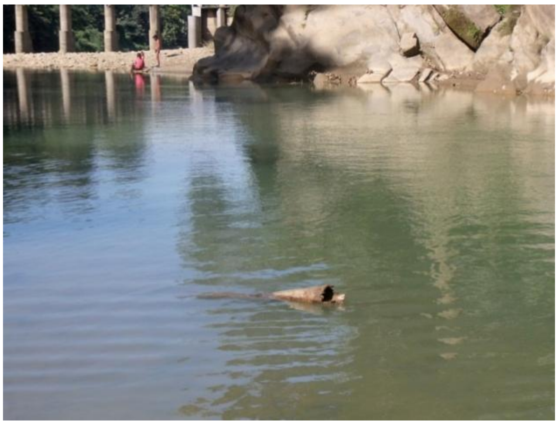

Fig.21: Zone II (Chathe River)

Fig.22: Zone III (Chathe River)

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