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P-IBI: An Approach for Assessing the Water Quality of the Chathe River in Nagaland (India)

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ABSTRACT

Phytoplankton Index of Biotic Integrity (P-IBI) in Chumukedima-Seithekima area of the Chathe River (Nagaland, India) was investigated for one year in 2017 to survey the association of density and diversity of phytoplankton with some of the physicochemical attributes of the waterway. Various physicochemical parameters were found to be within the recommended ranges as per the guideline of BIS (1983), except for turbidity which was extremely high during the monsoon due to an increment in surge by heavy precipitation. About 56 species of phytoplankton under 44 genera of 7 classes were recorded of which Bacillariophyceae and Chlorophyceae were the most abundant. A few genera such as *Nitzschia*, *Synedra*, *Pinnularia*, *Navicula*, *Cymbella, Ankistrodesmus*, *Chlamydomonas*, *Closterium*, *Scenedesmus* and *Crucigenia* were noticed to be the regular inhabitants of the river throughout the study period. Phytoplankton density and diversity was reduced during monsoon due to high water temperature, cloudy sky, and turbidity whereas shallow profundity and feeble warm stratification were the cause of declined density during winter. Further, Pearson's correlation analysis and PCA revealed the degree of association between phytoplankton assemblage and various physicochemical attributes of the river.

Key Words: Phytoplankton; Physicochemical; Density; Diversity; Dominance

INTRODUCTION

Rivers are indispensable component of our natural heritage. They have generally been used by human race over the centuries to the extent that, only very few are currently left in a natural condition. Since monsoon winds originated from the Bay of Bengal drive annual average precipitation in northeast India, which continues to revive the riverbed with clean water and keeps up consistency in stream velocity of the waterways in this zone. Stream velocity is the key factor in the lotic frameworks or running aquatic ecosystem impacting their environment. Spilling waters can change the condition of the streambed through disintegration and deposition, making an assortment of natural surroundings including riffles, skims and pools (Cushing et al. 2001). Being perennial, the Chathe River of Nagaland has steady stream in parts of its river bed in the midst of typical rainfall. The essential origin of water in a perennial stream can be from surface water, ground water or, a blend of both. Further, a lotic ecosystem is composed of a complex interaction of its two principal components i.e., physicochemical attributes and biotic assemblages in association with geomorphology of the waterway. The river is a persistently streaming open ecosystem as it depends on the supply of vitality from allochthonous sources conveyed by surge and air. Horticultural land, backwoods and residential areas of adjoined vicinity also bring dissolved supplements and particulate substances into the river through subsurface leakage. Some autochthonous sources of energy supplement in a river are decomposers who decay coarse particulate organic matter into fine particulate organic matter which are required during photosynthesis by phytoplankton.

The capacity of freshwater environments to keep up the natural water cycle and the biotic food web and reusing of supplements has been extremely impeded due to rapidly spreading urbanization, industrialization and expanded demand for nourishment worldwide associated with the fast multiplying human population (Hassan et al. 2005). As indicated by a report published by CPCB (2013), annual per capita renewable freshwater has declined from 6042 m^3 to 1845 m^3 in India, because of colossal populace blast and anticipated that would drop under 1000 m^3 by the end of 21^{st} century. So, there is a critical need of the hour worldwide for thorough methodological approaches to survey and screen the exact state and rate of changes of these ecosystems and to construct practically approachable protocols for restoration of the waterways (Li et al. 2010). As of late, bioassessment technique achieved greater prevalence over conventional physicochemical estimations due to its precise utilization of living organisms or their response to conclude the impact of any anthropogenic causes and for surveying the general nature of any concerned environment (Rosenberg 1998). Even the rate of pollution not recognized by seasonal chemical analysis could be reliably traced by bioassessment technique. Abundance or absence of any of the biomarkers like macroinvertebrates, fishes or phytoplankton are influenced by quality of water, as these organisms have specific requirements in terms of habitat and physicochemical attributes of the river, and thus are vital for recognizing issues generally missed by chemical analysis for analysing the ecological health of water bodies (Karr et al. 2004).

REVIEW OF LITERATURE

The physicochemical characteristics of many rivers in India has been contemplated by several investigators, most recent of which are the Yamuna (Gupta et al. 2013), the Chandrabhaga (Watkar 2015), the Nambol (Devi et al. 2015), the Vishwamitri (Patel et al. 2017). Some physicochemical factors viz., turbidity, pH, dissolved oxygen, water temperature, bicarbonate alkalinity, free CO_2 and hardness were considered as the major determinant of healthy lotic freshwater ecosystems and was reported to have significant effect on the biotic assemblage in the waterway (Yadav 2003; Singh et al. 2009). USEPA (US Environment protection agency) developed the first ever cost-effective rapid bioassessment protocol (RBP) with an extensive laboratory manual for assessing biotic integrity index of surface waters with the help of biotic assemblages like phytoplankton, benthic macroinvertebrate and fishes in association with physicochemical attributes and habitat quality of the waterway (Plafkin et al. 1989; Barbour et al. 1994). First such bioassessment technique was utilized in Russia in mid 1990's in Razdolnaya Basin and later added to Russian clean water venture since 2003 (Vshivkova et al. 2014).

Phytoplankton are perceived as the magnificent biomarker due to their instant response to the slightest environmental changes in the waterway and short life cycle (Parmar et al. 2016). Seasonal variation in density and diversity of algal classes has been studied by several investigators in several Indian Rivers (Chaudhary et al. 2009; Mukherjee et al. 2010). A significant association of fairly predictable annual cycle for algal development with primary productivity and supplement level while a decline in growth because of sullying through industrial discharge in the waterway was reported by many investigators (Dugdale 1975; Ghosh et al. 2012).

METHODOLOGY

Study Period

The present study was conducted in the Chathe River of Dimapur district (Nagaland, India) for one year from December 2016 to November 2017 on monthly as well as seasonal basis viz., winter (December-February), pre-monsoon (March-May), monsoon (June-August) and post-monsoon (September-November).

Study Area

This perennial river is originated from Medziphema of Dimapur district as a few minor channels, which are merged to form the Chathe River near New Chumoukedima area. The waterway is estimated to have a total stretch of 42.78 km in Nagaland and meet with the Dhansiri River in Karbi Anglong area of Assam as the Bakala River. For surveying the quality of the Chathe River, three stations were selected in the Chumoukedima-Seithekima (A) area of Dimapur district as follows:

ZI: This station was considered as the reference area (or, control area) located in upstream with a stretch of 2.17 km (25°47'12.4" N and 93°48'05.4" E to 25°47'46.8" N and 93°48'16.1" E) with an altitude of 232.04 m to 236.93 m. This area has a stream width of 13.71-28.58 m and channel width of 19.5 m to 39.82 m during different seasons of the study period. The area is mostly dominated by cobbles and pebbles, but sand and silt are also observed in patches. Stream flow structure of the area is mostly dominated by riffles, runs and pools. Watershed property of the area is mostly contributed by agricultural and animal farm runoff. Significant vegetation of this territory is composed of tree, grass, and scours around the mountain inclines with least of macrophytes in the riverbed. This area is relatively least disturbed in comparison to other stations (Figure.1).

ZII: This station is the midstream region with a stretch of 446.52 km (25°47'46.8" N and 93°48'16.1" E to 25°47'50.7" N and 93°47'58.3" E) located at an altitude of 237.05 m-223.04 m. Stream width of this station was observed in the range of 15.76 m-28.02 m and channel width as 17.28 m-42.02 m in various segments as well as different seasons of the study period. Riverbed-substrates of this station are dominated by pebbles and sand. Stream flow structure in the area is dominated by runs and flats. Watershed property of this area is found to be mostly agricultural and domestic runoff. Vegetation of this area is portrayed by trees, grass and bushes around the mountain incline in the stream bank and macrophytes in the riverbed. This area was recorded to receive a decent measure of traffic effluents, municipality discharges and human disturbances (Figure 1).

ZIII: This station is the downstream region located after a dam, with a stretch of 1.48 km (25°47'51.2" N and 93°47'57.2" E to 25°48'29.2" N and 93°47'42.3"E). This area is situated at an altitude of 220.37 m to 200.26 m. Stream width of this station was observed in the range of 8.56 m-42.29 m and channel width as 22.17 m -50.33 m

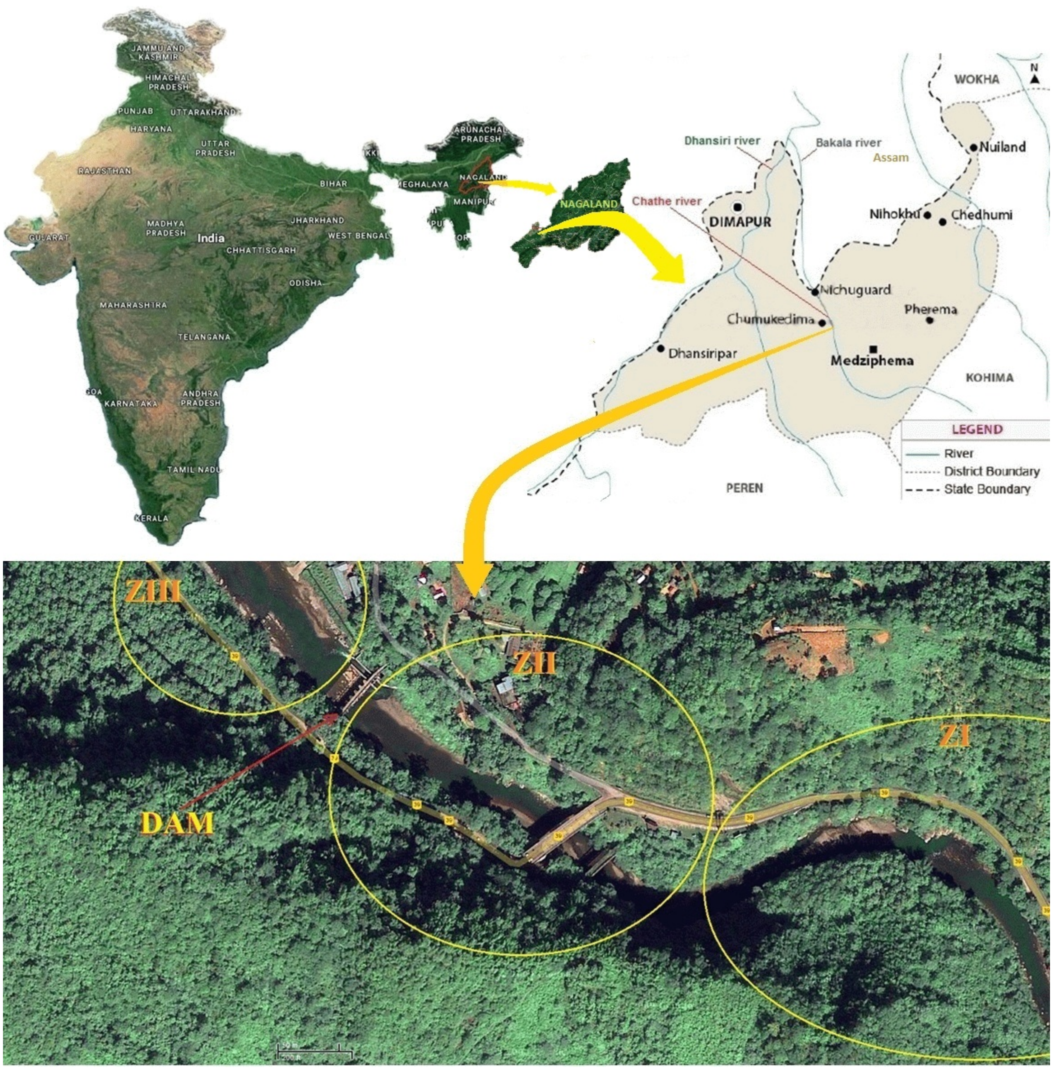


Figure 1. Map of surveyed stations of the Chathe River

in different seasons of the study period. Riverbed substrates of this station were predominated by boulder, cobble pebble and silt. Although the stream flow structure is mostly composed of riffles, runs and pools, yet flats were also found in some segment of this station. Decent measure of macrophytes in the riverbed and trees, grass, bushes in the mountain incline add to the vegetation of this area. This station was observed to receive a high measure of agricultural discharges, municipality spill-over and traffic effluents (Figure 1).

Water Sampling

Water samples were collected from sub-surface and middle-depth of all the selected zones of the river thrice every month for one year, in separately labelled 500ml BOD bottles for analyzing dissolved oxygen and BOD. Water sample was collected in dark and light bottles of 500 mL capacity to estimate phytoplankton productivity. 1000 mL capacity bottles were used to collect water samples for analyzing pH, conductivity, turbidity, free carbon dioxide, bicarbonate alkalinity and total hardness for each station. Further the sample bottles were preserved at 4ºC in the laboratory for chemical analysis.

Phytoplankton

One mL sub-sample from 10X concentration of 100ml Phytoplankton sample was added in a Sedgwick-Rafter cell and counted under compound microscope. The technique was repeated for collected samples of various stations following Gilbert (1942) and APHA (1995). Phytoplankton was identified following Palmer (1962), Prescott (1964) and Vuuren et al. (2006).

Analytical Procedures

Water temperature (WT), pH, Turbidity, Conductivity and current flow (CF) was measured by mercury bulb thermometer, Hanna's pH meter (pHep, Model-HI96107), turbidity meter (Model-EI335), Hanna's conductivity meter (DiST, Model-HI96303) and digital water velocity meter (Model-FP111, GFP) respectively. Area-average rate of precipitation per month was recorded with the help of TRMM-3B43-7 Precipitation data product (NASA).

Dissolved oxygen (DO) was estimated by modified Winkler's method (Trivedy et al. 1987); free CO_2 (FCO_2) and bicarbonate alkalinity (HCO_3^-) following Welch (1952) and total hardness (TH) following APHA (2005) were evaluated thrice every month during this investigation. Biochemical oxygen demand (BOD) was estimated by incubation of the water sample in dark at 20°C± 1°C for 5 days in BOD incubator. Primary productivity or Phytoplankton productivity viz., net primary productivity (NPP), gross primary productivity (GPP) and community respiration (CR) of the river was estimated by light and dark bottle method following APHA (1995).

Phytoplankton Assemblage

The population density of phytoplankton was measured as number of units/ml of the sample in the grids of Sedgwick-Rafter cell following Hötzel et al. (1999).

Various diversity indices like Shannon-Wiener's diversity (H), Pielou's evenness (J), Simpson's dominance (D), Simpsons diversity (1-D), Margalef's diversity (Ma), McIntosh's diversity (Mc) and McIntosh's evenness (McE) were calculated following Shannon (1949), Pielou (1966), Simpson (1949), Margalef (1958) and McIntosh (1967) respectively.

Various statistical analyses of the collected data were processed with the help of MS-excel 2007 and XLSTAT (2014) software.

RESULTS

Physicochemical Parameters

During this study, area average precipitation recorded from TRMM-3B43-7 Precipitation data (NASA) showed highest average precipitation during June (387 mm $month^{-1}$) and lowest during January (5 mm $month^{-1}$). Seasonal and monthly variations in physical and chemical parameters for three sampling stations of the Chathe River are shown in Tables 1.1 and 1.2. Maximum monthly mean water temperature was recorded during August (28.3-28.8 ºC), whereas minimum during November (16.2-16.8 ºC) in all the study areas and also in December (16.8 ºC) only in ZI. pH was recorded to be highest in ZI (8.38) during February and March, in ZII during April (8.53) and in ZIII during June (8.48) whereas, lowest pH was observed during August in ZI (7.8) and in July in ZII (7.83) and ZIII (7.82). Maximum mean conductivity in all the stations of the Chathe River was found during April (0.195-0.2 mS cm^{-1}) and minimum during August (0.06-0.067 mS cm^{-1}). Turbidity

Table 1.1. Mean ± SD of physicochemical parameters of the Chathe River

Months	WT (ºC)			pH			Cond (mS cm^{-1})		
	ZI	ZII	ZIII	ZI	ZII	ZIII	ZI	ZII	ZIII
Dec	16.8 ±0.29	17.2±0.76	17.7±1.26	8.12±0.1	8.17±0.06	8.13±0.15	0.13±0.02	0.13±0.03	0.128±0.03
Jan	18.8 ±1.61	18.8±1.26	18.8±1.26	8.1±0.1	8.13±0.06	8.08±0.08	0.162±0.01	0.163±0.01	0.163±0.003
Feb	22.8 ±2.08	22.3±1.16	22.3±1.61	8.38±0.1	8.33±0.08	8.37±0.21	0.172±0.01	0.172±0.01	0.173±0.01
Mar	21.7 ±2.57	21.5±2.29	22±2.29	8.38±0.14	8.4±0.1	8.47±0.1	0.178±0.01	0.18±0.01	0.172±0.003
Apr	24.5 ±0.5	25.3±1.04	25.2±0.76	8.37±0.13	8.53±0.24	8.47±0.12	0.2±0.01	0.195±0.01	0.195±0.01
May	26 ±0.5	26.4±0.40	26±2.18	8.28±0.08	8.33±0.15	8.25±0.05	0.112±0.03	0.112±0.03	0.112±0.03
Jun	26.7±2.19	27.2±1.13	26.2±0.28	8.28±0.18	8.5±0.14	8.48±0.04	0.1±0.01	0.1±0.01	0.1±0.01
Jul	28±1	27.7±0.76	27.8±0.76	7.82±0.43	7.83±0.45	7.82±0.5	0.08±0.01	0.077±0.01	0.077±0.02
Aug	28.3±0.99	28.3±1.16	28.8±1.11	7.8±0.2	7.87±0.21	7.9±0.35	0.06±0.01	0.062±0.003	0.067±0.01
Sep	26.8±0.76	27.3±0.46	26.5±0.5	7.9±0.4	8.02±0.23	8.22±0.37	0.093±0.02	0.084±0.01	0.09±0.02
Oct	25.2±0.76	25.2±0.76	25.5±1.80	8±0.1	7.93± 0.06	7.98±0.13	0.09±0.01	0.087±0.01	0.088±0.01
Nov	16.8±1.04	16.7±0.29	16.2±0.25	8.1±0.17	8.25±0.15	8.28±0.26	0.095±0.01	0.097±0.01	0.097±0.01

Months	Turb (NTU)			CF (m s^{-1})			DO (mg L^{-1})		
	ZI	ZII	ZIII	ZI	ZII	ZIII	ZI	ZII	ZIII
Dec	4.04±0.65	4.37±0.64	3.94±0.45	0.245±0.06	0.273±0.05	0.256±0.05	10.67±2.01	10.8±1.6	10.53±2.34
Jan	12.23±5.62	10.03±2.25	8.43±2.25	0.243±0.08	0.265±0.06	0.225±0.02	14±1.06	14±1.06	14.33±0.64
Feb	19±3.28	20.33±5.19	18.8±4.73	0.236±0.02	0.192±0.07	0.221±0.02	14.67±0.61	14.2±0.87	11.27±1.47
Mar	31.93±11.66	22.83±3.25	27.6±2.12	0.765±0.19	0.8±0.09	0.801±0.17	17.07±1.22	16.53±1.01	16.27±0.83
Apr	5.87±3.09	6.2±0.95	5.5±1.18	0.405±0.17	0.293±0.02	0.167±0.02	14.67±1.01	9.6±0.69	13.87±1.01
May	52.07±8.3	46.67±16.21	45.3±12.22	0.792±0.21	0.494±0.16	0.531±0.09	11.6±1.44	8.8±0.69	9.73±0.83
Jun	63.75±45.04	55.9±37.34	58±38.47	0.204±0.002	0.736±0.13	0.397±0.03	9±0.28	9.3±0.42	8.9±0.71
Jul	40.73±2.25	33.9±7.63	35.83±4.25	0.437±0.08	0.471±0.1	0.215±0.01	9.73±1.51	9.76±1.54	9.49±1.68
Aug	267.6±187.9	306.23±250.5	251.4±174.6	0.519±0.19	0.334±0.13	0.635±0.3	8.73±0.31	11.44±1.65	6.76±1.19
Sep	47.5±5.66	43.47±6.43	50.67±7.45	0.353±0.09	0.288±0.05	0.294±0.04	13.43±1.00	14.87±1.45	13±1
Oct	19.24±13.34	18.27±16.61	20.88±18.97	0.273±0.01	0.334±0.06	0.329±0.1	9.73±0.23	13.07±1.01	14.53±1.22
Nov	5.43±0.98	5.68±0.8	5.25±0.85	0.333±0.07	0.422±0.05	0.397±0.04	13.33±0.61	13.33±0.61	13.2±0.4

Maximum and minimum values marked in red and blue; WT: Water temperature; Cond: Conductivity; Turb: Turbidity; CF: Current flow; DO: Dissolved oxygen

was highest during August (251.4-306.23 NTU) and lowest in December (3.94-4.37 NTU) in different sampling areas of the river. Maximum mean current flow was recorded in ZI (0.792 m s^{-1}) during May, while in ZII (0.8 m s^{-1}) and ZII (0.801 m s^{-1}) in March. Calculated data of chemical parameters of three sampling sites in the Chathe River has shown highest monthly mean DO during March (16.27-17.07 mg L^{-1}) whereas lowest in ZI during August (8.73 mg L^{-1}), in ZII during May (8.8 mg L^{-1}) and in ZIII in June (8.9 mg L^{-1}). Maximum monthly mean BOD was found during August (3.81-4.08 mg L^{-1}) in different sampling areas whereas, minimum was recorded during December in ZI (0.33 mg L^{-1}) and ZIII (0.35 mg L^{-1}) while in January in ZII (0.33 mg L^{-1}). Monthly mean FCO_2 was highest in August (10.27-11.47 mg L^{-1}) and lowest during June (2-2.3 mg L^{-1}). All the sampling sites of the Chathe River showed maximum monthly mean HCO_3^- in April (154.33-159 mg L^{-1}) whereas, minimum during August (53-57.67 mg L^{-1}). Maximum monthly mean TH was recorded during December in ZI (97.33 mg L^{-1}) and in ZIII (99.67 mg L^{-1}) while, in February in ZIII (83.67 mg L^{-1}) whereas, monthly mean HCO_3^- was found to be minimum during August (29.67- 34.33 mg L^{-1}) in different sampling sites.

Maximum monthly mean primary or phytoplankton productivity was recorded in November for NPP (0.79-0.8 mg C m^{-3} hr^{-1}) and GPP (0.82-0.83 mg C m^{-3} hr^{-1}) whereas during May for CR (0.51-0.58 mg C m^{-3} hr^{-1}) in different sampling sites (Table 1.2). On the other hand, monthly mean phytoplankton productivity was estimated

Table 1.2. Mean ± SD of physicochemical parameters of the Chathe River. All values are mg L^{-1}

Month	BOD			FCO_2			HCO_3			TH		
	ZI	ZII	ZIII	ZI	ZII	ZIII	ZI	ZII	ZIII	ZI	ZII	ZIII
Dec	0.33±0.05	0.35±0.03	0.35±0.05	5.2±1.56	5.33±1.14	5.27±1.5	118.67±3.79	117.33±4.04	114±4.58	97.33±9.02	81.67±6.66	99.67±12.3
Jan	0.48±0.11	0.33±0.02	0.36±0.08	3.6±0.2	3.73±0.31	3.8±0.2	96.33±10.79	98.0±2.0	97.7±13.65	79.0±3.61	74.93±3.1	83.2±10.3
Feb	0.36±0.04	0.35±0.13	0.4±0.04	8.47±1.5	7.53±1.5	7.03±1.82	93.0±9.85	99.0±3.61	97.3±9.87	85.33±4.16	83.67±1.53	82.67±2.3
Mar	1.06±0.48	1.13±0.56	1.15±0.48	8.8±2.88	8.13±1.03	7.93±0.5	117.33±6.43	122±13.12	125.3±9.02	74.0±7.21	72.67±8.33	73.67±5.5
Apr	1.27±0.24	1.4±0.04	1.4±0.07	4.0±0.4	3.2±1.06	3.67±0.58	156.67±11.02	159±12.29	154.3±13.05	86.67±8.08	85.0±6.56	81.0±6.25
May	1.96±0.66	1.91±0.82	1.87±0.7	3.33±1.22	2.85±1.24	4.15±0.78	118±14.8	121.67±10.97	113.3±14.98	62.0±5.29	60.33±4.73	64.67±10.1
Jun	2.76±0.23	2.84±0.62	3.06±0.48	2.0±1.41	2.3±1.84	2.0±1.41	84±28.28	79.0±26.87	81.0±2.04	53.5±23.34	48.0±14.14	44.0±8.5
Jul	3.43±0.16	3.37±0.21	3.23±0.27	3.0±0.6	2.73±0.76	2.47±0.5	62.0±9.17	61.33±6.11	59.3±5.03	36.0±2.0	35.0±2.0	36.0±2.6
Aug	3.81±0.32	3.93±0.5	4.08±0.55	10.27±2.01	11.47±1.72	11.33±1.51	53.0±3.0	55.53±3.33	57.7±3.79	34.33±2.52	29.67±0.58	33.87±2.6
Sep	3.56±0.16	3.41±0.1	3.59±0.4	5.67±1.53	6.07±1.53	6.0±1.73	61.33±3.06	59.67±4.73	60.3±1.53	39.0±5.0	39.87±5.01	40.13±6.0
Oct	2.81±1.13	2.8±1.59	2.4±1.91	5.47±1.36	5.4±1.44	5.2±1.31	67.33±1.53	67.33±2.31	65.0±1	52.67±4.16	48.67±1.16	49.33±1.5
Nov	0.59±0.35	0.66±0.47	0.87±0.38	6.27±0.64	6.07±0.31	6.33±0.58	99.33±12.9	94.33±15.04	98.5±14.34	59.67±3.22	58.0±4.0	59.0±3.6

Months	NPP (mg C m^{-3} hr)$^{-1}$			GPP (mg C m^{-3} hr^{-1})			CR (mg C m^{-3} hr^{-1})		
	ZI	ZII	ZIII	ZI	ZII	ZIII	ZI	ZII	ZIII
Dec	0.65±0.09	0.62±0.07	0.62±0.08	0.67±0.09	0.65±0.07	0.64±0.08	0.03±0.01	0.03±0.01	0.02±0.01
Jan	0.55±0.08	0.51±0.06	0.54±0.05	0.58±0.08	0.55±0.04	0.58±0.04	0.02±0.01	0.04±0.02	0.04±0.01
Feb	0.31±0.03	0.31±0.03	0.3±0.02	0.73±0.02	0.69±0.01	0.71±0.02	0.42±0.02	0.37±0.04	0.41±0.03
Mar	0.41±0.09	0.46±0.04	0.45±0.05	0.61±0.04	0.67±0.08	0.66±0.06	0.2±0.12	0.21±0.11	0.21±0.1
Apr	0.19±0.04	0.21±0.04	0.25±0.07	0.72±0.01	0.71±0.03	0.67±0.06	0.53±0.03	0.5±0.02	0.42±0.02
May	0.13±0.03	0.14±0.03	0.16±0.04	0.7±0.02	0.69±0.01	0.68±0.04	0.58±0.05	0.55±0.02	0.51±0.06
Jun	0.09±0.01	0.09±0.01	0.09±0.01	0.6±0.03	0.54±0.09	0.57±0.05	0.52±0.02	0.45±0.08	0.48±0.04
Jul	0.05±0.01	0.04±0.01	0.05±0.01	0.38±0.09	0.35±0.13	0.27±0.11	0.33±0.09	0.31±0.12	0.22±0.1
Aug	0.03±0.01	0.04±0.01	0.02±0.01	0.16±0.04	0.19±0.04	0.12±0.02	0.13±0.04	0.14±0.03	0.11±0.01
Sep	0.14±0.1	0.17±0.12	0.14±0.12	0.19±0.08	0.26±0.09	0.23±0.1	0.05±0.03	0.09±0.02	0.08±0.03
Oct	0.61±0.24	0.55±0.17	0.55±0.17	0.64±0.238	0.6±0.15	0.6±0.16	0.03±0.01	0.05±0.02	0.05±0.01
Nov	0.8±0.03	0.8±0.05	0.79±0.02	0.83±0.04	0.83±0.05	0.82±0.02	0.02±0.01	0.02±0.01	0.03±0.01

Maximum and minimum values are marked in red and blue respectively. BOD : Biochemical Oxygen Demand; NPP: Net primary productivity; GPP: Gross primary productivity.; HCO_3:Bicarbonate alkalinity; FCO_2:Free Carbon dioxide; TH: Total hardness. CR: Community respiration

to be minimum during August for NPP (0.02-0.04 mg C m^{-3} hr^{-1}) and GPP (0.12-0.19 mg C m^{-3} hr^{-1}) at the sampling sites of the Chathe River (Table 12). Further, minimum monthly mean NPP was also recorded during July only in ZII (0.04 mg C m^{-3} hr^{-1}). CR was the lowest as 0.02 mg C m^{-3} hr^{-1} in ZI and ZII in November and also in ZI in January, while in ZIII in December (Table 1.2).

When Pearson's correlation was analyzed among different physicochemical parameters for the sampling sites of the Chathe River, it has shown a direct correlation ($p<0.05$) of monthly mean WT with BOD and indirect correlation ($p<0.05$) with TH, NPP and GPP (Table 2). Monthly mean pH was noticed to be directly correlated ($p<0.05$) with conductivity, HCO_3^- and GPP in all sampling sites, while with TH in majority of the sites (Table 2). Monthly mean conductivity was noticed to have a direct correlation ($p<0.05$) with HCO_3^-, TH in all the stations while with GPP in most of the sites and DO only in ZI. Further, conductivity was recorded to have an indirect association ($p<0.05$) with BOD (Table 2). Monthly mean turbidity was found to be directly correlated ($p<0.05$) with BOD in all sampling sites and with

Table 2. Pearson's correlation coefficient among physicochemical parameters of the Chathe River

Variable	Zone	pH	Cond	Turb	CF	DO	BOD	FCO_2	HCO_{3-}	TH	NPP	GPP	CR
WT	ZI	-0.31	-0.41	0.54	0.26	-0.44	0.87	-0.07	-0.47	-0.70	-0.88	-0.62	0.47
	ZII	-0.23	-0.43	0.49	0.17	-0.39	0.88	-0.05	-0.40	-0.65	-0.90	-0.65	0.52
	ZIII	-0.24	-0.40	0.57	0.14	-0.45	0.85	0.01	-0.44	-0.70	-0.90	-0.68	0.42
pH	ZI		0.80	-0.48	0.14	0.59	-0.67	-0.07	0.79	0.73	0.14	0.74	0.55
	ZII		0.69	-0.41	0.36	-0.10	-0.53	-0.30	0.77	0.66	0.09	0.69	0.56
	ZIII		0.63	-0.38	0.14	0.35	-0.39	-0.13	0.67	0.41	0.11	0.61	0.55
Cond	ZI			-0.53	0.04	0.80	-0.73	0.02	0.79	0.83	0.19	0.54	0.28
	ZII			-0.50	-0.03	0.25	-0.75	-0.12	0.83	0.91	0.25	0.60	0.27
	ZIII			-0.51	-0.15	0.56	-0.74	-0.10	0.83	0.81	0.27	0.58	0.31
Turb	ZI				0.26	-0.48	0.61	0.48	-0.51	-0.58	-0.54	-0.69	-0.02
	ZII				-0.02	-0.14	0.60	0.64	-0.46	-0.59	-0.50	-0.67	-0.04
	ZIII				0.49	-0.65	0.68	0.64	-0.49	-0.57	-0.57	-0.71	-0.04
CF	ZI					0.24	0.15	0.23	0.22	-0.16	-0.32	-0.10	0.29
	ZII					-0.04	0.18	-0.14	0.05	-0.20	-0.15	0.10	0.30
	ZIII					-0.03	0.22	0.58	0.01	-0.23	-0.08	-0.08	0.03
DO	ZI						-0.62	0.26	0.56	0.53	0.27	0.35	0.00
	ZII						-0.27	0.54	-0.14	0.16	0.47	0.03	-0.58
	ZIII						-0.50	-0.08	0.42	0.40	0.62	0.48	-0.28
BOD	ZI							-0.05	-0.71	-0.90	-0.67	-0.79	0.06
	ZII							0.10	-0.68	-0.91	-0.70	-0.80	0.10
	ZIII							0.11	-0.70	-0.92	-0.74	-0.83	0.05
FCO_2	ZI								-0.19	-0.02	0.10	-0.23	-0.35
	ZII								-0.27	-0.16	0.09	-0.29	-0.43
	ZIII								-0.15	-0.09	0.04	-0.27	-0.35
HCO_{3-}	ZI									0.81	0.24	0.70	0.38
	ZII									0.85	0.25	0.73	0.41
	ZIII									0.79	0.33	0.71	0.36
TH	ZI										0.49	0.71	0.09
	ZII										0.47	0.75	0.14
	ZIII										0.57	0.69	0.03
NPP	ZI											0.59	-0.63
	ZII											0.64	-0.65
	ZIII											0.68	-0.56
GPP	ZI												0.24
	ZII												0.17
	ZIII												0.23

Table value of 'r' at df_{10} = 0.58, at 5% confidence and significant values are shown in bold numerals

FCO_2 only in ZII and ZIII; whereas indirect association ($p<0.05$) with GPP in all sampling sites while with TH in most of the stations. Further turbidity has also shown an indirect correlation with DO in all the sites but significant ($p<0.05$) only in ZIII (Table 2). Monthly mean CF has shown a direct correlation ($p<0.05$) with FCO2 only in ZIII. Monthly mean DO was recorded to have an indirect correlation ($p<0.05$) with BOD in ZI but, direct correlation ($p<0.05$) with NPP in ZIII. An indirect correlation ($p<0.05$) was observed for BOD with HCO_3^-, TH, NPP and GPP in all the sampling areas. Further, HCO_3^- has shown a direct correlation ($p<0.05$) with TH. Monthly mean GPP has shown a direct correlation ($p<0.05$) with NPP, HCO_3^-, TH and pH; whereas indirect correlation ($p<0.05$) with WT, turbidity and BOD in all the sampling stations of the Chathe River (Table 2). Monthly mean CR has shown an indirect association ($p<0.05$) with NPP in majority of the sampling sites while with DO only in ZII (Table 2).

Phytoplankton Density

During this study, 56 species of phytoplankton under 44 genera of 7 classes (Cyanophyceae, Chrysophyceae, Bacillariophyceae, Cryptophyceae, Dinophyceae, Euglenophyceae and Chlorophyceae) were encountered in different sampling stations of the Chathe River (Table 3). A few species under the genera of Bacillariophyceae like *Nitzschia*, *Synedra*, *Pinnularia*, *Navicula*, *Cymbella* etc., while some species under the genera of Chlorophyceae like *Ankistrodesmus*, *Chlamydomonas*, *Closterium*, *Scenedesmus*, *Crucigenia* etc. were witnessed to be the most common inhabitant in the river throughout the study period. Further, some species under the genera of Euglenophyceae like *Phacus* and *Euglena* were also encountered during most of the study period. Maximum taxa richness was recorded for Chlorophyceae with 21 species followed by Bacillariophyceae (16 species), Euglenophyceae (9 species) and Cyanophyceae (6 species) whereas, Dinophyceae (2 species), Chrysophyceae (1 species) and Cryptophyceae (1 species) were least abundant phytoplankton in the river. During this investigation, Bacillariophyceae was recorded to be the most abundant class of phytoplankton as (246-260.33Unit mL^{-1}) in winter, (320-376Unit mL^{-1}) in pre-monsoon, (213.33-222.33Unit mL^{-1}) in monsoon and (286.67-327.67 Unit mL^{-1}) during the post-monsoon of the study period (Table 4). The phytoplankton density of the Chathe River was further noticed to be mostly dominated by Bacillariophyceae followed by Chlorophyceae, Euglenophyceae and Chrysophyceae in various seasons of the year (Table 4). Seasonal mean density (Unit mL^{-1}) as well as monthly density (Unit mL^{-1}) of different classes of phytoplankton in the sampling areas was recorded to be highest during premonsoon and least during monsoon (Table 4; Figure.2).

Phytoplankton Diversity Indices

Investigation of various diversity indices of phytoplankton community of the sampling stations of the Chathe River has shown a range of Shannon's diversity (H) from 1.11 to 1.43, Pielou's evenness (J) from 0.66 to 0.78, Simpson's dominance (D) from 0.3 to 0.39, Simpson's diversity (1-D) from 0.61 to 0.7, Margalef's diversity (Ma) from 0.61 to 0.95, McIntosh's diversity (Mc) from 0.39 to 0.47 and McIntosh's evenness (McE) from 0.65 to 0.76 (Table 5). Shannon's diversity (H) and Simpson's diversity (1-D) was recorded to be maximum during pre-monsoon and minimum during monsoon.

Table 3: List of phytoplankton of the Chathe River

Class	Genus	No. of species
Cyanophyceae	*Oscillatoria*	1
	Anabaena	2
	Spirulina	1
	Cylindrospermopsis	2
	Microcystis	1
Euglenophyceae	*Euglena*	4
	Trachelomonas	3
	Strombomonas	1
	Phacus	1
Chrysophyceae	*Mallomonas*	1
Chlorophyceae	*Pandorina*	1
	Chlamydomonas	1
	Pediastrum	1
	Coelastrum	1
	Scenedesmus	1
	Spirogyra	1
	Staurastrum	1
	Radiosphaera	1
	Volvox	1
	Microspora	1
	Oocystis	1
	Cosmarium	1
	Monoraphidium	2
	Dictyosphaerium	1
	Closterium	1
	Lagerheimia	1
	Crucigenia	1
	Netrium	1
	Ankistrodesmus	1
Bacillariophyceae	*Navicula*	3
	Pinnularia	2
	Synedra	1
	Nitzschia	1
	Diadesmis	1
	Diatoma	2
	Gomphonema	1
	Gyrosigma	1
	Aulacoseira	1
	Craticula	1
	Cymbella	1
	Cymbopleura	1
Cryptophyceae	*Cryptomonas*	1
Dinophyceae	*Ceratium*	1
	Prorocentrum	1

Simpson's diversity (1-D) was further recorded to be maximum during winter and minimum in late pre-monsoon only in ZI. Margalef's diversity (Ma) was found maximum during winter in ZI but during post-monsoon at other sampling stations. The lowest Margalef's diversity (Ma) was recorded during monsoon in ZI but during pre-monsoon in other stations (Table 5). Highest McIntosh's diversity (Mc) was observed in winter, pre-monsoon and post-monsoon in ZI but only during pre-monsoon in rest of the sampling stations. Pielou's evenness (J) was recorded to be maximum in monsoon in ZI but, during winter as well as pre-monsoon in rest of the sampling stations. Lowest Pielou's evenness (J) was observed during late winter in ZI and ZII whereas, in late monsoon and post-monsoon in ZIII. McIntosh's evenness (McE) was noticed to be maximum during monsoon in ZI while, during winter in ZII and ZIII. Further McIntosh's evenness (McE) was also observed at its maximum in ZII during pre-monsoon (Table 5). Minimum McIntosh's evenness was recorded in the midst of post-monsoon in all sampling areas and also during late winter only in ZIII. Simpson's dominance (D) was found highest during monsoon in all study areas and also in late pre-monsoon only in ZI. Lowest Simpson's dominance (D) was observed during pre-monsoon in all sampling stations while even in winter only in ZI (Table 5).

When Pearson's correlation was analysed between various diversity indices of phytoplankton and physiochemical attributes of three sampling stations of the Chathe River, it has shown a direct correlation ($p<0.05$) of Shannon's diversity (H) with conductivity in ZI while, with DO in ZI and ZIII (Table 6). Accordingly, Simpson's diversity (1-D) was also noticed to have a direct correlation ($p<0.05$) with conductivity in ZI while, with DO in ZII and ZIII. Moreover, Simpson's diversity (1-D) was also directly correlated ($p<0.05$) with NPP only in ZIII (Table 6). Margalef's diversity (Ma) and McIntosh's diversity (Mc) were directly correlated with DO ($p<0.05$) in most of the sampling stations. Pielou's evenness (J) and McIntosh's evenness (McE) was recorded to have a direct correlation ($p<0.05$) with conductivity and HCO_3^- in ZII (Table 6). On the other hand, an indirect correlation ($p<0.05$) of Simpson's dominance (D) was found with conductivity in ZI, with NPP in ZIII while, with DO in ZII and ZIII (Table 6).

Principal Component Analysis (PCA)

When PCA was encouraged between monthly density of various phytoplankton classes, diversity indices and

Table 4. Mean ± SD of seasonal mean density of different classes of phytoplankton

Classes	Sites	Winter	Pre-monsoon	Monsoon	Post-monsoon
Cyanophyceae	ZI	11.33 ±1.15	22.33 ±5.13	8.67 ±0.58	15.67 ±1.53
	ZII	8.33 ±1.53	13.33 ±2.08	6.67 ±2.08	11 ±1
	ZIII	9.67 ±2.52	28 ±8.89	10 ±1.73	16.67 ±1.53
Chrysophyceae	ZI	44 ±5.29	57.33 ±2.08	21 ±1	47.67 ±4.51
	ZII	30 ±11.36	58.67 ±8.33	15 ±3	36 ±7.21
	ZIII	42 ±4.36	61.33 ±4.04	24.33 ±2.08	50 ±2
Bacillariophyceae	ZI	256.67 ±14.22	376 ±11	213.33 ±13.32	327.67 ±22.9
	ZII	246 ±3.46	320 ±13	219.33 ±10.07	286.67 ±16.62
	ZIII	260.33 ±12.9	366.33 ±17.04	222.33 ±13.58	307.67 ±21.59
Cryptophyceae	ZI	4.67 ±4.02	11.33 ±7.02	0	8.33 ± 2.52
	ZII	2.33 ±2.04	11.33 ±10.26	1.67 ±1.09	6.33 ±1.53
	ZIII	4.33 ±4.04	10.23 ±9.29	0	9.33 ±0.58
Dinophyceae	ZI	2.67 ±2.52	5 ±4.36	0	4.67 ±4.16
	ZII	1.33 ±1	0	0	6 ±2
	ZIII	0	3 ±5.2	0	4.67 ±4.16
Euglenophyceae	ZI	63 ±2.65	86 ±7.21	60 ±2	74 ±2.65
	ZII	56 ±3.46	75.67 ±3.21	49 ±6	69.33 ±3.06
	ZIII	58.33 ±8.5	88.67 ±8.62	51.33 ±4.04	73.67 ±4.04
Chlorophyceae	ZI	179.67 ±8.74	193.67 ±6.66	145.33 ±8.33	168.33 ±7.09
	ZII	166.33 ±5.69	186.67 ±25.01	138.67 ±5.51	165.33 ±9.45
	ZIII	193 ±12.53	207 ±14.73	157 ±13.75	190.67 ±15.37

Index
Cyan: *Cyanophyceae,* ***Chry:*** *Chrysophceae,* ***Baci:*** *Bacillariophyceae,* ***Cryp:*** *Cryptophyceae,*
Dino: *Dinophyceae,* ***Eugl:*** *Euglenophyceae,* ***Chlo:*** *Chlorophyceae*

Figure 2. Monthly density of various classes of phytoplankton

Table 5. Monthly diversity indices of Phytoplankton of the Chathe River

Seasons	Month	H			J			D			1-D		
		ZI	ZII	ZIII	ZI	ZII	ZIII	ZI	ZII	ZIII	ZI	ZII	ZIII
Winter	Dec	1.33	1.22	1.29	0.74	0.68	0.72	0.32	0.36	0.34	0.68	0.64	0.67
	Jan	1.31	1.24	1.26	0.73	0.77	0.78	0.33	0.34	0.33	0.68	0.66	0.67
	Feb	1.28	1.21	1.22	0.66	0.68	0.68	0.34	0.36	0.36	0.66	0.64	0.64
Pre-monsoon	Mar	1.37	1.38	1.43	0.70	0.77	0.74	0.33	0.31	0.30	0.67	0.69	0.70
	Apr	1.38	1.23	1.35	0.71	0.76	0.75	0.32	0.35	0.33	0.68	0.65	0.67
	May	1.25	1.32	1.25	0.70	0.74	0.78	0.36	0.33	0.35	0.64	0.67	0.65
Monsoon	Jun	1.19	1.15	1.20	0.74	0.71	0.74	0.36	0.38	0.36	0.64	0.62	0.64
	Jul	1.21	1.11	1.17	0.75	0.69	0.73	0.35	0.39	0.37	0.65	0.61	0.63
	Aug	1.22	1.20	1.23	0.76	0.67	0.77	0.34	0.37	0.34	0.66	0.64	0.66
Post-monsoon	Sep	1.37	1.30	1.38	0.70	0.67	0.71	0.33	0.34	0.34	0.67	0.66	0.66
	Oct	1.30	1.31	1.34	0.67	0.67	0.69	0.36	0.34	0.33	0.65	0.66	0.67
	Nov	1.28	1.30	1.31	0.71	0.67	0.73	0.35	0.35	0.33	0.65	0.65	0.67

Seasons	Month	Ma			Mc			McE		
		ZI	ZII	ZIII	ZI	ZII	ZIII	ZI	ZII	ZIII
Winter	Dec	0.79	0.80	0.80	0.45	0.42	0.44	0.73	0.67	0.71
	Jan	0.79	0.64	0.63	0.45	0.43	0.44	0.73	0.75	0.76
	Feb	0.94	0.80	0.79	0.43	0.42	0.42	0.67	0.68	0.68
Pre monsoon	Mar	0.90	0.77	0.90	0.44	0.46	0.47	0.68	0.75	0.72
	Apr	0.91	0.61	0.75	0.45	0.42	0.44	0.70	0.73	0.72
	May	0.76	0.78	0.61	0.42	0.44	0.43	0.68	0.71	0.74
Monsoon	Jun	0.65	0.66	0.65	0.42	0.40	0.42	0.73	0.70	0.73
	Jul	0.66	0.66	0.65	0.43	0.39	0.41	0.74	0.68	0.71
	Aug	0.66	0.83	0.66	0.43	0.42	0.43	0.75	0.67	0.75
Post monsoon	Sep	0.93	0.95	0.94	0.45	0.43	0.46	0.69	0.66	0.70
	Oct	0.93	0.94	0.92	0.42	0.44	0.44	0.65	0.67	0.68
	Nov	0.77	0.94	0.77	0.42	0.43	0.44	0.69	0.66	0.72

Maximum and minimum values are marked red and blue, respectively.
H: Shannon-Wiener's diversity index; J: Pielou's evenness index; D: Simpson's dominance index
1-D: Simpson's diversity index; Ma: Margalef's diversity index; Mc: McIntosh's diversity index; McE: McIntosh's evenness index

physicochemical parameters of three sampling stations for various months of the study year, 11 components were extracted of which first two components with higher eigenvalues of 62.80% of total variance in ZI, 61.18% of total variance in ZII and 64.14% of total variance in ZIII (Figure.3). In ZI first component axis described 47.56% of variance alone with an eigenvalues of 10.94 whereas, in ZII first component axis alone explained 42.97% of variance with eigenvalues of 9.88 while, in ZIII first component axis described 45.82% of variance with eigenvalues of 10.54. Monthly density of various classes of phytoplankton and diversity of phytoplankton community were found to be significantly upgraded by an increment in DO in ZI in pre-monsoon while in ZIII in early pre-monsoon as well as late post-monsoon. An enhancement in density and diversity of phytoplankton was also witnessed during winter and most of post-monsoon with an increase in pH, HCO_3^- and conductivity in ZI and ZIII. Dominance in phytoplankton community was increased in monsoon with a sharp rise in water temperature, turbidity and BOD in all sampling stations. In ZII, monthly density of Bacillariophyceae, Chlorophyceae and Chrysophyceae were found to be significantly upgraded by an increase in pH, HCO_3^-, conductivity and TH in winter and most of pre-monsoon. Further, monthly density of Dinophyceae was found to

Table 6. Pearson's correlation coefficient between phytoplankton diversity indices and physicochemical variables

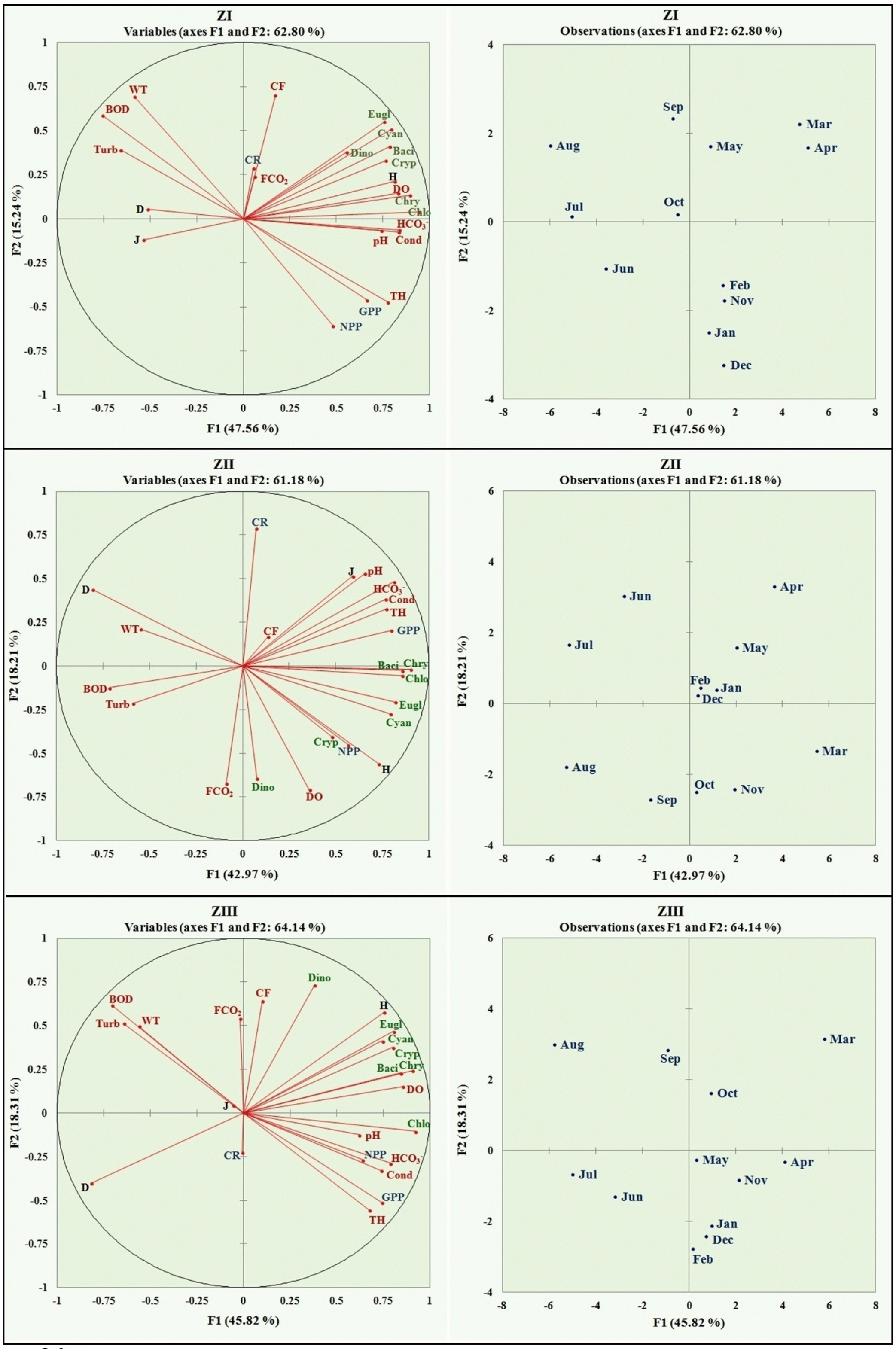
Index	Sites	WT	pH	Cond	Turb	CF	DO	BOD	FCO_2	HCO_3^-	TH	NPP	GPP	CR
H	ZI	-0.39	0.33	0.64	-0.46	0.09	0.75	-0.41	0.20	0.53	0.52	0.35	0.17	-0.27
	ZII	-0.29	0.20	0.22	-0.23	0.16	0.57	-0.26	0.26	0.29	0.23	0.48	0.38	-0.23
	ZIII	-0.21	0.37	0.32	-0.25	0.30	0.78	-0.17	0.28	0.37	0.21	0.40	0.20	-0.31
J	ZI	0.09	-0.45	-0.38	0.46	0.02	-0.47	0.30	-0.20	-0.17	-0.29	-0.29	-0.44	-0.07
	ZII	-0.09	0.57	0.70	-0.29	0.38	-0.03	-0.36	-0.37	0.67	0.50	-0.06	0.33	0.41
	ZIII	0.07	-0.01	0.06	0.31	0.29	-0.19	0.07	-0.08	0.26	0.00	-0.21	-0.10	0.16
D	ZI	0.42	-0.11	-0.58	0.21	0.13	-0.54	0.40	-0.17	-0.42	-0.54	-0.19	0.10	0.32
	ZII	0.32	-0.28	-0.42	0.24	-0.18	-0.60	0.36	-0.24	-0.40	-0.36	-0.46	-0.41	0.18
	ZIII	0.43	-0.34	-0.46	0.20	-0.45	-0.75	0.41	-0.35	-0.54	-0.42	-0.59	-0.39	0.33
1-D	ZI	-0.42	0.11	0.58	-0.21	-0.13	0.54	-0.40	0.17	0.42	0.54	0.19	-0.10	-0.32
	ZII	-0.32	0.28	0.42	-0.24	0.18	0.60	-0.36	0.24	0.40	0.36	0.46	0.41	-0.18
	ZIII	-0.43	0.34	0.46	-0.20	0.45	0.75	-0.41	0.35	0.54	0.42	0.59	0.39	-0.33
Ma	ZI	-0.21	0.39	0.57	-0.50	-0.05	0.68	-0.35	0.28	0.30	0.43	0.32	0.26	-0.15
	ZII	-0.12	-0.38	-0.47	0.10	-0.23	0.46	0.14	0.50	-0.41	-0.30	0.40	-0.05	-0.56
	ZIII	-0.14	0.19	0.10	-0.28	0.06	0.63	-0.07	0.29	-0.01	0.07	0.37	0.09	-0.39
Mc	ZI	-0.37	0.02	0.51	-0.14	-0.18	0.44	-0.33	0.15	0.33	0.49	0.14	-0.18	-0.34
	ZII	-0.31	0.26	0.40	-0.21	0.20	0.61	-0.34	0.26	0.38	0.34	0.44	0.38	-0.19
	ZIII	-0.29	0.30	0.30	-0.12	0.38	0.72	-0.18	0.38	0.31	0.23	0.42	0.12	-0.43
McE	ZI	0.06	-0.43	-0.29	0.47	-0.13	-0.44	0.22	-0.14	-0.19	-0.18	-0.30	-0.46	-0.08
	ZII	-0.13	0.54	0.74	-0.27	0.35	0.08	-0.39	-0.28	0.65	0.53	-0.01	0.32	0.34
	ZIII	-0.02	-0.06	0.05	0.34	0.33	-0.18	0.02	0.01	0.18	0.03	-0.13	-0.13	0.03

Table value of r ' at df_{10} = 0.58, at 5% confidence and significant values are shown in bold numerals

be moderately upgraded by an increase in DO and FCO_2 in post-monsoon only in ZII. Dominance of phytoplankton community was enhanced with a decrement in diversity in all sampling stations (Figure 3).

DISCUSSION

During this investigation, physicochemical attributes of the Chathe River has shown marginal differences among different sampling stations despite of their distinction in watershed and riverbed properties. Even station ZIII was also not recognized to be too distinct from station ZI despite of the presence of a dam upstream in regard of physicochemical attributes and phytoplankton assemblage due to the additive effect of several factors at a time that nullified temporary seasonal outbreaks of a few variables and thus maintained homeostasis of the ecosystem. Various physicochemical attributes of the river was found to be at prescribed ranges viz., WT (<32ºC), pH (6.5-9.0), conductivity (0.1-2mS cm), DO (>5 mg L^{-1}), BOD (3-20 mg L^{-1}), FCO_2 (<15 mg L^{-1}), HCO_3^- (20-400 mg L^{-1}) and TH (20-300 mg L^{-1}) as per the guidelines published by several workers (BIS 2012, Boyd 2003). Though highest DO in sampling stations of the Chathe River was recorded in the range of 16.27-17.07 mg L^{-1} but, normally peak value of DO in any waterbed for achieving maximum saturation at 0ºC is 14.6 mg L^{-1}. This could be explained as in hilly or mountain rivers where pollution level is too low, it may reach to as high as even 300% supersaturating level during daytime, when photosynthetic effects are prominent (CPCB 2006). Range of turbidity in the river was found higher than prescribed guidelines (<100 NTU), yet the range isn't alarming, since higher turbidity was found seasonal and only noticed in monsoon due to a surge in waterway caused by heavy precipitation. Increase or decrease in the value of any physicochemical variable tends to influence other variable directly or indirectly in the waterway. An increase of 10°C in water



Index
WT: *Water temperature,* ***pH:*** *Hydrogen ion potential,* ***Cond:*** *Conductivity,* ***Turb:*** *Turbidity,* ***CF:*** *Curren flow,* ***DO:*** *Dissolved oxygen,* ***BOD:*** *Biochemical oxygen demand,* ***FCO_2:*** *Free Carbon dioxide,* ***HCO_3^-:*** *Bicarbonate alkalinity,* ***TH:*** *Total hardness,* ***NPP:*** *Net primary productivity,* ***GPP:*** *Gross primary productivity,* ***CR:*** *Community respiration,* ***H:*** *Shannon-Wiener's diversity,* ***J:*** *Pielou's evenness,* ***D:*** *Simpson's dominance,* ***Cyan:*** *Cyanophyceae,* ***Chry:*** *Chrysophyceae,* ***Baci:*** *Bacillariophyceae,* ***Cryp:*** *Cryptophyceae* ***Dino:*** *Dinophyceae,* ***Eugl:*** *Euglenophyceae,* ***Chlo:*** *Chlorophyceae*

Figure 3. PCA between phytoplankton assemblage and physicochemical parameters

temperature accelerates the metabolic and reproductive abilities of aquatic organisms, which in turn may increase oxygen demand and gradually lead to oxygen deficit in the river. Higher water temperature may increase the solubility of toxicants and declines the solubility of oxygen in water. Expanded agricultural waste-watershed, disintegration of stream-bank or rock-bed, animal farm spill-over and flood of traffic and sewage effluents in the season of higher precipitation increases turbidity in the river. Increase in suspended solids in the river retains warmth to increase the surface water temperature and also prevent sunlight from reaching to the phytoplankton in mid-surface or bottom of the river. It diminishes photosynthesis and increment in respiration to result in BOD and increase in dissolved CO_2, which in turn decrease pH of the river. Phytoplankton productivity was observed to be reduced during monsoon, due to a significant decrease in the density of phytoplankton, dissolved supplements, conductivity and DO in the river (Saravanakumar et al. 2008).

Phytoplankton represented by algal community is the major producer of organic matter in any aquatic ecosystem and their density as well as diversity depends on numerous physical and chemical factors of the waterway. Being primary producer, phytoplankton are the first group to respond towards changes in nutrient abundance in freshwater ecosystem and so could be acknowledged as most important bioindicator in the waterway. During this investigation, utmost phytoplankton density and diversity indices were noticed in pre-monsoon and least during monsoon. Maximum abundance of density and diversity of phytoplankton in pre-monsoon was due to moderate water temperature with adequate thermal stratification, higher DO, low turbidity, ideal prey-predator interaction and maximum nutrient mixing through moderate wind velocity. Further, a modest increase in density and diversity of phytoplankton was also recorded during post-monsoon due to shallow profundity, ideal intensity as well as duration of light and sufficient dissolved supplement in the waterway (Sugunan 2000). On the contrary, a sharp reduction of phytoplankton density and diversity in monsoon was witnessed because of extreme water temperature, shady sky, higher turbidity, strong stream-flow, differential light intensity and elevated grazing pressure (Giripunje et al. 2013). During winter, abundance of phytoplankton assemblage was noticed to be insignificant due to shallow profundity and feeble warm stratification of the waterway but not critically poor, since the lowest temperature hardly dips below 16ºC in the Chathe River. Increment in water temperature or available nutrients or even a blend of both are reported to be the principal driving force for enhancing abundance of Chlorophyceae (Richardson et al. 2000). On the other hand, Bacillariophyceae were noticed to be the most abundant taxa due to its wide range of tolerance to the fluctuation in various environmental factors in the waterway. It has been reported that, phytoplankton assemblage can adapt to contaminated water to some extent and modifies in accordance to the odds of the condition by adjusting species composition (Stevenson 1997). As a consequence, diversity of the community gets replaced by the dominance of only a few selective species. However, phytoplankton productivity in the Chathe River wasn't witnessed to be critically aligned with density and diversity of phytoplankton assemblage, rather productivity was significantly influenced by water temperature, duration of light intensity and turbidity in the riverbed.

CONCLUSION

During this investigation, water quality in all sampling stations of the Chathe River was recognised to be decent throughout the study year. Various physicochemical attributes of the river were witnessed to be within the prescribed limit (BIS 2012), yet moderate decline in water quality was noticed during monsoon due to an increase in turbidity. In the midst of winter, extensive water withdrawal and shallow profundity as well due to least precipitation was found to be the principal factor responsible for reduction in phytoplankton assemblage; yet station ZI was found to portray relatively better diversity than rest of the stations due to its adequate profundity and decent stream-flow structures. Despite the fact that productivity was not precisely aligned with phytoplankton assemblage, yet these variables were seen to be as per the occasional fluctuations in ecological parameters. Moreover water temperature, conductivity, pH, bicarbonate alkalinity and DO were found to be the principal determinant to enhance phytoplankton density and diversity in the river.

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