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Spatial variation in hydrological characteristics of Chilika – A coastal lagoon of India

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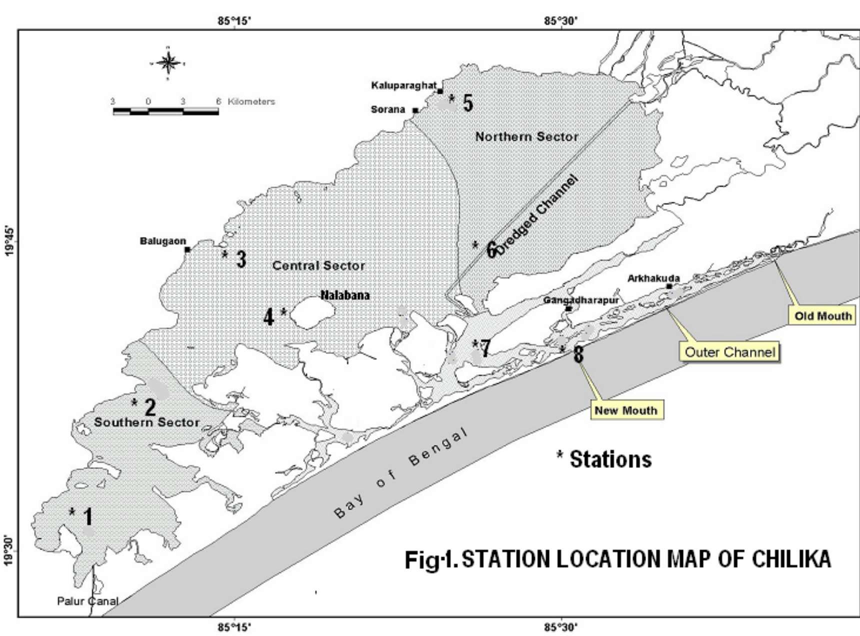
Abstract: The distribution of hydrological characteristics like temperature, pH, salinity, conductivity, DO, BOD, alkalinity, nutrients (NO_2-N, NO_3-N, PO_4-P, SiO_4-Si) along with depth, transparency and turbidity were studied in Chilika, the largest brackish water lagoon in Asia. The results exhibited pronounced spatial variation and distribution pattern, indicating large variations, possibly due to seasonal changes. The photosynthesis of weeds caused the lake water slightly alkaline due to uptake of CO_2 from water column and on the other hand, the formation of humic acid because of decaying of weeds in northern sector lowers the pH of the lake water. The low salinity in northern sector related to influx of more floodwater, which was not very much affected in southern sector. Addition and removal of fresh water, seawater intrusion and mixing bring out the change in salinity of the lagoon. The low DO and high BOD values were associated with the area near to large fishing jetties, where organic decomposition was more. Nitrite exhibited higher concentrations during May due to its release into the water column from the decomposed freshwater weeds. High nitrate during July and August were related to agricultural runoff through floodwater. Silicate concentration showed a well-defined pattern with higher during monsoon months, which was slightly removed at high salinities areas.

Key words: Water quality, pollution, monthly variation, Chilika lake, India

Introduction

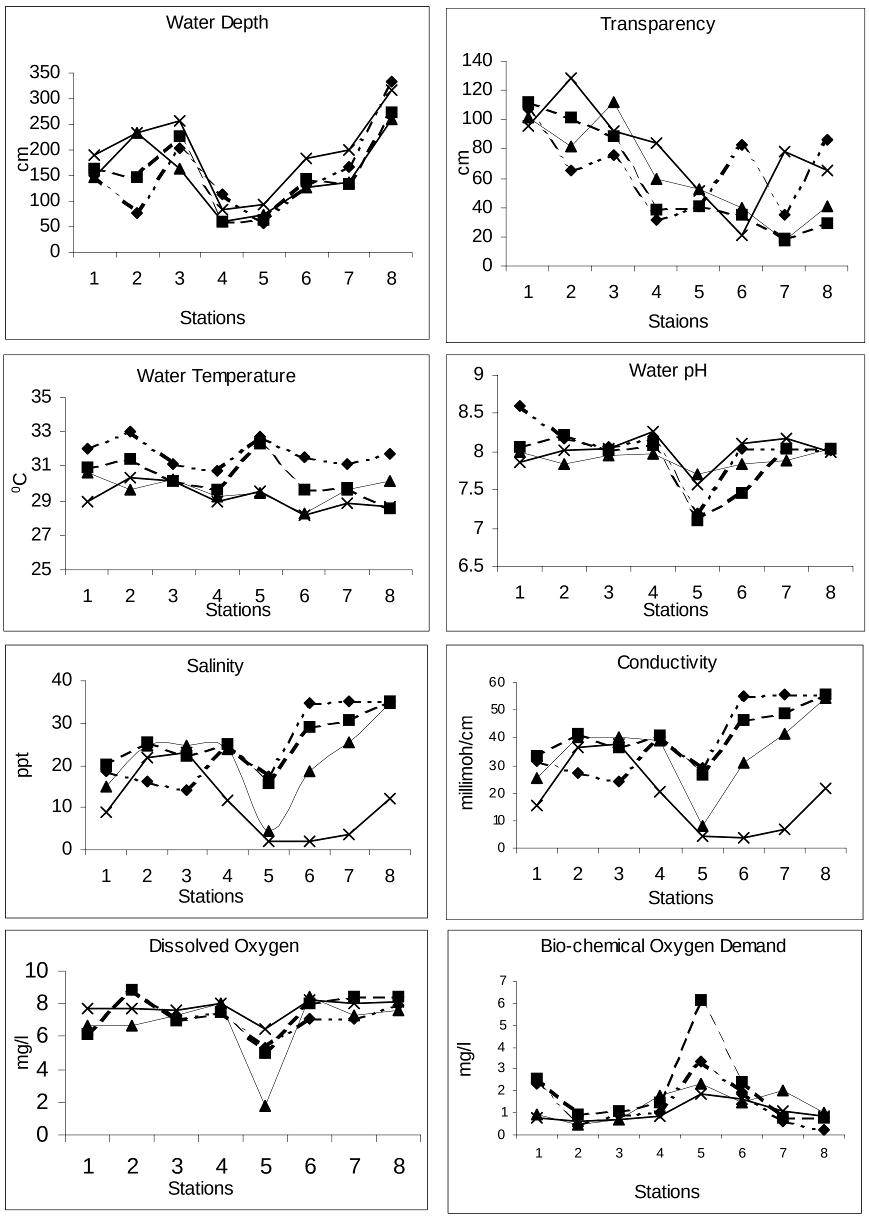
Coastal wetlands are highly productive eco-systems. Some of the detrimental factors responsible for the degradation of wetland eco-system are deforestation, modern agriculture practices, industrial growth and urbanization in its catchment areas and over-exploitation of wetland resources. The fertilizers and pesticides run-off from agricultural lands, domestic sewage, industrial waste etc, affect the water quality of the wetland adversely. The washout of the agricultural crop fields, containing the fertilizer and pesticides, inputs of the industrial waste, domestic sewage, containing detergents and cosmetics, fertilizers, medicines and waste foods of the shrimp culture, affect the water quality of the lake seriously. The above factors, sometimes, lead to the eutrophication on the water bodies. Dense beds of submerged hydrophytes, macro-algae and luxuriant growth of emergent and floating macrophytes in the lake pose a challenge to the lake management. Decomposition of macrophytes leads to deplete dissolved oxygen from lake water, which exerts serious impact on faunal diversity, fishing resources and water quality. Due to the anthropogenic pressure, peoples over-exploited the lake resources beyond the carrying capacity, which ultimately adversely affect the lake eco-system. In view of the spatial and temporal variations in the hydrological characteristics of lake water, regular monitoring programs are required for reliable estimates of the water quality. Hence, spatial and temporal variation of nutrients (NO_2-N, NO_3-N, PO_4-P, SiO_4-Si.) in relation to some physico-chemical parameters like depth, transparency, pH,



Fig·1. STATION LOCATION MAP OF CHILIKA

salinity, dissolved oxygen (DO), biochemical oxygen demand (BOD) and turbidity of Chilika water were carried out for a period of four months, in order to evaluate the chemical processes and anthropogenic activities responsible for degradation of the lake water environment.

Fig. 2. Variation of water quality parameters in Chilika lagoon



Study Area

Geographical setting

Chilika lake ($19^{0}28'$ to $19^{0}54'$N; $85^{0}06'$ to $85^{0}35'$E) situated in the humid tropical setting on the east coast of India, connecting to the Bay of Bengal (Fig.1). This is the largest brackish water wetland complex in Asia, declared as "Wetland of international importance" under IUCN (International Union for Conservation of Nature and Natural Resources) sponsored Ramsar Convention in 1974. Its water-spread area extends to about 1165 km^2 during the monsoon and shrinks to about 906 km^2 during summer.

Climate

The climate of Chilika is similar to that of coastal Orissa. Three principal seasons like summer, monsoon and winter are experienced in this area. The summer season is from March to June, Monsoon from July to October and winter from November to February. Chilika lake experience a dry, Sub-humid, tropical monsoon climate (Subramanian & Uma Devi 1983). The lagoon experiences southwest and northeast monsoons during June to September and November to December respectively. During December and January cold wave conditions prevail for a couple of weeks due to Western disturbances in North India. About 74% of the annual rainfall is received during the monsoon. It rains about 1,450 mm per year at Chilika (mean annual average rainfall), and the rainfall over the area varies from 1,200 - 1,600 mm, increasing towards the northeast. The wind speed is high during the month of March to July and speed is low during the winter season. The wind speed mostly from North to North Easterly direction and during monsoon month it is mostly southerly and southwesterly direction due to influence of the Southwest monsoon and the average wind speed varies between 4.5 and 18.3 kmph (Panigrahi *et al.*, 2007). However, the coastal areas experience higher average wind speeds up to 25 kmph. Chilika is also subjected to cyclonic activity during May - December. Such storms have a strong effect on

Table 1. Physico-chemical parameters of Chilika lake water

		May				June			
Parameters	**Unit**	**Min**	**Max**	**Average**	**Std. Dev**	**Min**	**Max**	**Average**	**Std. Dev**
Water Depth	cm	57	332	153.5	86.15	59	273	151.0	73.31
Transparecy	cm	31	107	65.5	27.46	19	112	58.1	36.63
Air Temp.	^{0}C	31.2	35.4	33.2	1.42	29.7	32.7	31.5	1.12
Water Temp.	^{0}C	30.7	33.0	31.7	0.80	28.6	32.3	30.3	1.16
Water pH		7.20	8.60	8.04	0.39	7.03	8.22	7.63	0.52
Salinity	ppt	14.2	35.2	24.5	9.24	15.7	35.3	25.5	6.19
Conductivity	mS/cm	24.4	55.8	39.8	13.69	26.6	55.8	41.3	9.22
DO	mg/l	5.30	8.84	7.13	1.07	4.95	8.86	7.41	1.33
Alkalinity	ppm	68	138	112.5	20.72	96	280	129.25	61.33
Turbidity	NTU	1.0	56	20.4	19.01	1.0	138	42.1	45.34
BOD	mg/l	0.23	3.37	1.37	1.08	0.76	6.18	2.02	1.82
Chl-a	8g/l	0.44	43.51	7.66	14.59	3.06	14.64	6.66	3.92
NO_2-N	8mol/l	0.648	3.333	1.424	0.98	0.043	0.500	0.239	0.17
NO_3-N	8mol/l	0.648	1.156	0.703	0.37	0.145	1.774	0.569	0.54
PO_4-P	8mol/l	0.222	0.667	0.383	0.15	0.095	0.853	0.345	0.29
SiO_4-Si	ppm	0.476	2.833	1.958	0.90	0.357	1.595	0.762	0.46
		July				**August**			
Parameters	**Unit**	**Min**	**Max**	**Average**	**Std. Dev**	**Min**	**Max**	**Average**	**Std. Dev**
Water Depth	cm	59	261	150.1	70.12	84	317	194.9	78.05
Transparecy	cm	18	112	63.4	32.59	21	128	76.9	32.06
Air Temp.	^{0}C	28.2	31.4	30.6	1.03	27.8	32.3	30.1	1.67
Water Temp.	^{0}C	28.3	30.6	29.7	0.69	28.2	30.3	29.2	0.72
Water pH		7.70	8.03	7.90	0.11	7.58	8.27	8.01	0.21
Salinity	ppt	4.3	34.6	21.4	8.95	2.0	23	10.7	8.31
Conductivity	mS/cm	8	54.7	35.1	13.84	3.9	37.7	18.3	13.40
DO	ppm	1.78	8.45	6.73	2.09	6.50	8.26	7.74	0.56
Alkalinity	ppm	56	188	107.5	37.79	56	104	80.5	17.43
Turbidity	NTU	1.0	292	51.3	98.18	3.0	99	20.9	31.79
BOD	mg/l	0.4508	2.36	1.34	0.69	0.6	1.9	1.04	0.47
Chl-a	8g/l	1.87	5.04	3.20	1.08	3.99	7.54	5.40	1.26
NO_2-N	8mol/l	0.400	4.889	1.092	1.54	0.105	0.579	0.286	0.19
NO_3-N	8mol/l	0.294	3.816	1.675	1.35	0.384	5.321	1.647	1.63
PO_4-P	8mol/l	0.359	0.897	0.656	0.16	0.090	0.852	0.258	0.27
SiO_4-Si	mg/l	0.366	1.634	0.780	0.47	1.025	3.125	2.265	0.71

the coastal areas and have caused changes in the number and position of opening to the sea in the past. In the lake system, as the tidal effect appears negligible, wind acts as a dominant force.

Drainage pattern

The drainage area of Chilika lagoon is 3560 km^2. Fifty-two numbers of rivers and rivulets drain into the lagoon. Important rivers like Daya, Bhargavi, Nuna, Makara, Mandakini, Kansari and Salia and small streams from the hills located on the western side of the lagoon (part of Eastern Ghats), which bring freshwater into the lagoon mostly during monsoon period. The Mahanadi river system drain into the lagoon in northern side and the deltaic area is submerged during rainy season.

Anthropogenic scenario of the lagoon

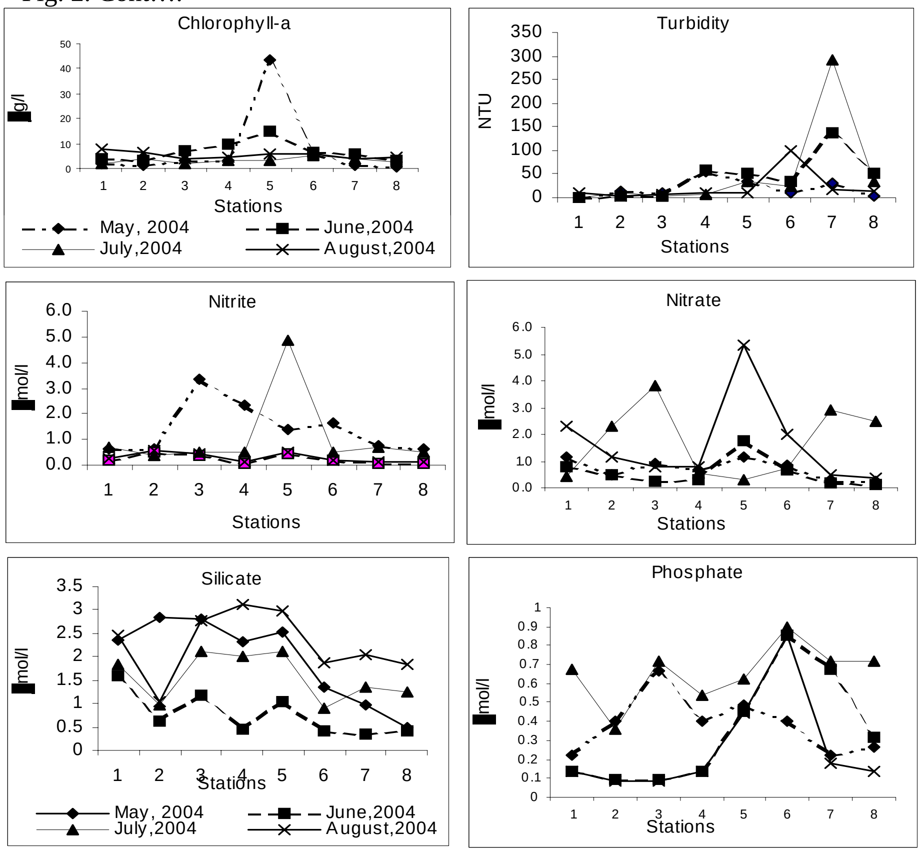
A number of problems like siltation, extensive growth of invasive weed species, eutrophication problems, decrease in salinity gradients, changes in water quality, depletion of fishery resources, chocking of river mouth and inlets, extensive prawn gharries, operation of excess number of mechanized boats, obstruction of migratory routs of economic species in the creeks etc, are observed.

Materials and methods

In order to monitor the water quality and estimate the contamination, hydrological investigation of the Chilika lagoon from 8 stations (2 stations from each sector) was selected (Fig. 2). Field visits were made monthly during May 2004 to August 2004 with help of mechanized boats.

Air and water temperature, pH, conductivity and turbidity were measured immediately, using a portable kit (Model No-WQC-22A). For estimation of dissolved oxygen in the water samples pretreatment was done by Winkler's solution. Half liter of lake water was filtered through GF/C filter paper, using a hand pump for chlorophyll analysis. Secchi depth was measured with a white and black 25 cm diameter, where Secchi disk, as the average depth at which the disk was no longer visible upon lowering and raising it in the water column on the shaded side of the boat.

Fig. 2. Cont….



The parameters like nutrients (NO_2-N, NO_3-N, PO_4-P, SiO_4-Si) and alkalinity were analyzed within 48 hours of the collection and BOD were analysis by Winkler's method, after keeping the samples at 20^0C in BOD incubator for 5 days. GF/C filtered papers were digested in 90% acetone for chlorophyll analysis. Mohr-Kundson argentometric titration method was adopted to determine the chlorinity and salinity of the water sample. Other parameters, such as NO_2-N, NO_3-N, PO_4-P, SiO_4-Si, and TSS were analyzed following the standard guidelines and procedures (APHA, 1998). Each analysis was done in triplicate and the mean value was taken. DO and BOD were measured using Winkler's method and the BOD was calculated from the difference of DO concentration after 5 days of incubation at 20^oC and appropriate dilution was done for high BOD samples. Cellulose nitrate membrane filters of pore sized 0.45µm was used for determination of TSS. Nutrient parameters such as NO_3-N, NO_2-N, PO_4-P and SiO_4-Si, were analyzed spectrophotometerically. The analytical data quality was ensured through careful standardization procedural blank measurements, spiked and duplicate samples.

Results and discussion

The range, average and standard deviation of hydrological characteristics of Chilika lake water collected from 8 different stations during May to August, were presented in Table The monthly variations of air and water temperature, pH, salinity, conductivity, dissolved oxygen, alkalinity, turbidity, biochemical oxygen demand, chlorophyll, and nutrients like nitrate, nitrite, phosphate and silicate were carried out and shown in Fig. 2. The spatial and monthly variations of hydrological parameter are discussed below.

The atmospheric temperature varied from 31.2 to 35.4^{0}C, 29.7 to 32.7^{0}C, 28.2 to 31.4^{0}C and 27.8 to 32.3^{0}C during May, June, July and August, respectively (Table 1). The highest average temperature (35.4^{0}C) recorded during May, which was considered as the hottest month of the present study period. The lowest average atmospheric temperature (30.1^{0}C) recorded during August. The spatial variation of air temperature did not show any significant change (Fig. 2). The variation in air temperature among the stations was mostly followed by the time of collection and variation among the different stations mainly due to seasonal change.

The water temperature among 8 different stations of Chilika lagoon varied from 30.7 to 33.0^{0}C, 28.6 to 32.3^{0}C, 28.3 to 30.6^{0}C and 28.2 to 30.3^{0}C during May, June, July, and August respectively. There was a decreasing trend of average water temperature from May to August (Table 1). The highest water temperature (33.0^{0}C) recorded at a station 2 during May and lowest water temperature (28.2^{0}C) recorded at station 6 during August. The trend of variation of water temperature in different stations was almost followed the atmospheric temperature. Like air temperature, water temperature did not show any significant variation among the stations (Fig. 2).

The water depth of 8 stations lagoon varied from 57 to 332 cm, 59 to 273 cm, 59 to 261 cm and 84 to 317 cm with an average of 154, 151, 161 and 195 cm during May, June, July, and August, respectively (Table 1). The lowest average recorded during May and the highest average water depth during August, which is mainly due to influx of more fresh water through river discharge. The station 4 and 5 of northern sector was showing lower water depths (Fig. 2). The low depths related to northern sector were mainly due to high siltation through major river systems of northern boundary.

Transparency plays a vital role in the growth and development of aquatic flora and fauna. The water transparency varied from 31 to 107 cm, 19 to 112 cm, 18 to 112 cm and 21 to 128 cm during May, June, July, and August respectively (Table 1). The average water transparency was lowest (58 cm) June was related to the formation of high phytoplankton blooms, which restricted sunlight penetration into the water column and re-suspension of suspended solid through churning of water column due to southerly wind action. In general, the lower values of transparency were observed at station 4 and 5 of northern sector, which were related (Fig. 2) to high silt load through river discharges.

The pH in the water body is considered to be the most important factor in brackish water lake system. The distribution and decomposition of hydrophytes in the lake also depends on the pH of the water. The pH of Chilika water varied from 7.20 to 8.60, 7.03 to 8.22, 7.83 to 8.03 and 7.58 to 8.27 with an average of 8.04, 7.63, 7.83 and 8.01 during May, June, July and August, respectively (Table 1). In general, the higher pH of the lagoon was related with larger amount of submerged weeds present in the water column. The photosynthesis of weeds may cause the lake water in the slightly higher alkaline due to uptake of CO_2 from the water column. The lower pH value at station 5 during May and June was related to decay of weeds in northern sector and formation of humic acids. (Nayak *et al.* ,2004), Panda *et al.* 1989; Subha Rao *et al.*, 1981).

Salinity is considered as the most important factor like pH in brackish water lagoon. Its influence on biodiversity of the lagoon is also amazing the distribution of vegetation and fish fauna. The distribution of plant communities like phytoplankton, algae and macrophytes is influenced by the salinity gradient. Similarly, the fauna and the distribution of zoo-biota in a lake eco-system depend on concentration of salinity. The salinity of 8 different stations of Chilika lagoon ranged between 14.2 to 35.2 ppt (parts per thousands) 15.7 to 35.3 ppt, 4.3 to 34.6 ppt and 2 to 23 ppt during May, June, July and August, respectively (Table 1). The highest average of salinity (25.5 ppt) was found during June and the lowest average salinity (10.7ppt) was observed during August. There is a slightly increase in average salinity from May to June and further decreased from July onwards. There was a drastically decrease in average salinity during August, which clearly indicated that influx of more floodwater through river. The salinity of station 6, 7 and 8 was showing lower values during August, indicating fluxing of more floodwater through lead channel. The southern sector stations (2 & 3) were having higher salinity values in comparison to other stations during August, which indicated that the flood was not very much affected to the southern sector. Addition or removal of freshwater, seawater intrusion and mixing, generally, bring out the change in the salinity of lagoon. The salinity profile of the study area revealed different pictures owing to change in freshwater input and seawater intrusion. A large spatial variation of salinity among the station was marked.

The conductivity (millimoh/cm) of Chilika water varied from 15.1 to 55.8, 26.6 to 55.8, 25.4 to 54.7 and 3.92 to 37.7 during May, June, July, August, respectively (Table 1). The distribution of conductivity in Chilika water was very much similar with salinity distribution. The average conductive of Chilika water was highest during June and the lowest during August.

The photosynthesis activities of phytoplankton and submerged macrophytes and wave due to wind control the dissolved oxygen concentration in the lake water. DO is also indicating the health of the eco-system. The DO (mg/l) of Chilika water was ranged from 5.30 to 8.84, 4.95 to 8.86 1.78 to 8.45 and 6.50 to 8.26 during May to August, respectively. The lowest DO value was always associated with station 5 near Kalupadaghat, which may be related with anthropogenic activities as well as decomposition of freshwater weeds.

Alkalinity (ppm) of 8 different stations in Chilika water ranged from 68 to 138, 96 to 280, 92 to 94 and 56 to 104 during May to August, respectively (Table 1). The average alkalinity was highest during June and the lowest during August. The Alkalinity at station 5 during June was considerable high (280ppm), mainly due to anthropogenic activities near Kalupadaghat and higher value of alkalinity at station 8 was due to high salinity.

Turbidity NTU (Nephlen Turbido Unit) of Chilika water was ranged from 1 to 16 1 to 13, 1 to 192 and 3 to 99 during May, June, July, and August, respectably (Table 1). The average turbidity was maximum during July and minimum during May. The stations 1 to 3 were showing lower values of turbidity, because of less influx of floodwater into these stations. The turbidity of stations 4 and 5 was comparatively higher during May, mainly due to low depth and churning action of water by southerly wind, which re-suspended fine sediments from the bottom. Lower turbidities were related to southern sector due to less affected by floodwater.

BOD (mg/l) was observed 0.23 to 3.37 in May, 0.76 to 6.18 in June, 0.45 to 2.36 in July and 0.60 to 1.90 during August. The average BOD concentration was 1.4, 2.0, 1.3 and 1.0 during May, June, July, and August, respectably. In general, the high BOD was found at station 5 followed by station 1, which are near to Kalupadaghat and Balugaon ghatt, respectively. The organic decomposition of waste material by fishing activities at ghatt areas may be responsible for the high BOD concentration. Since the BOD concentration at station 5 was observed to be high (6.18mg/l) during June, which may not support aquatic lives. The high BOD value was found at the stations, where the decomposition of the weeds occurs, which is an indicative of assimilation of organic weed and occurrences of more micro-organisms due to death of huge amount of surface vegetation. The degrading organisms consume a lot of oxygen, which is a common feature of eutrophic ecosystem. In southern sector, the stations 2 and 3 have comparatively less BOD, which agreed with finding of other researchers (Nayak *et al.,* 2004).

Chlorophyll-a is the most commonly occurring natural pigment in photosynthesis cells, which constitutes (1 to 2%) of the dry matter in plankton algae. The total amount of algae biomass in a water body can be calculated by the estimation of chlorophyll-a. In general, the chlorophyll content correlates with the primary productivity. Chlorophyll-a concentration revealed wide variation among the stations for all sampling periods i.e. 0.44 to 43.5 mg/l in May, 3.06 to 14.64 mg/l in June, 1.90 to 5 mg/l in June and 3.99 to 7.54 mg/l in August. During May and June, the station 5 (near Kalupadaghat) showed remarkable high chlorophyll content. However, during July and August, almost all stations showed identical chlorophyll content.

Nitrite-nitrogen concentration of lake water varied from 0.65 to 3.33 μmol/l in May, 0.043 to 0.500 μmol/l in June, 0.40 to 4.89 μmol/l in July and 0.105 to 0.579 μmol/l in August. The nitrite concentration at station 5 was remarkable high (4.888 μmol/l) during July, which may be due to contribution from local anthropogenic fishing activities at Kalupadaghat. However, the concentration of nitrite during May was higher than other months in all stations, excepting at station 5. This may be due to the release of nitrite from the decomposition of fresh waterweeds during May. No remarkable variation of NO_2-N, excepting during May, was found in southern sector.

Nitrate concentration varied from 0.652 to 1.16 μmol/l during May, 0.145 to 1.774 μmol/l during June, 0.384 to 5.321 μmol/l during July and 0.105 to 0.579 μmol/l during August. The stations 2, 3, 7 and 8 showed higher nitrate concentration during July. However, other stations showed higher during August. Like nitrite, nitrate also showed higher concentration at stations 5 and 3 (Balugaon Ghat), which was related to anthropogenic activities. The higher nitrate during July and August are related to agriculture run-off through floodwater (Panda *et al*., 1989), land drainage and precipitation.

The phosphate concentration was ranged from 0.222 to 0.667 μmol/l, 0.095 to 0.853 μmol/l, 0.359 to 0.897 μmol/l and 0.090 to 0.667 μmol/l during May, June, July and August, respectively (Table 1 to 4). The average highest concentration of PO_4-P was found during July and the average lowest during August. Ryther & Yentsch (1957) reported a value of 2.8 μmol/l as the upper limit of PO_4-P concentration of unpolluted water. Ketchun (1967) observed that 2.55 μmol/l of PO_4-P is the maximum limit of its concentration, which can be accepted as the danger signal of evaluating the eutrophication of lake. In the present study, the concentration of PO_4-P was below the pollution limit for aquatic lives.

The silicate concentration varied from 0.476 to 2.889 ppm, 0.357 to 1.595 ppm, 0.366 to 1.634 ppm and 1.025 to 3.125 ppm during May, June, July and August, respectively. The silicate concentrations were found higher value in the stations of northern sector due to high silt coming through the floodwater. The lower values were found at stations 7 and 8 due to presence of large amount of suspended solids in association with sea salts, which is favorable for a biological removal of silicate through adsorption (Desouse, 1999, Liss & Spencer, 1970, Bien *et al*., 1958). Consequently, removal of silicate through uptake by diatoms was well marked at station 2.

Conclusion

The present piece of work is confined to a limited period i.e. May to August months (Part of pre monsoon and monsoon) which is difficult to draw specific conclusion. However a well defined spatial and monthly heterogeneity in distribution of different water quality parameter was observed. freshwater influx and agricultural runoff through the major river systems, cyclic growth and decomposition of microphytes, role of photosynthesis and formation of algal blooms, re-suspension of suspended solid through churning action are playing the key role for the distribution of water quality parameter of the lake system. The decomposition of freshwater weeds in northern sector leads to formation of humic acid, which is responsible for lower water pH during summer months.

The influx of fresh water is playing a critical role for salinity change as well as nutrient input in the lagoon. The anthropogenic activities in the northern catchment areas (specially fishing jetties) as well as decomposition of weeds are largely responsible for increasing microbial activities (BOD), release of nutrient from the organic decomposition of weeds and lowering of DO during summer months in northern part of the ecosystem. This study will be help full for the restoration and economic vitality of the lagoon through integrated approach. The approach should be catchment area treatment, removal of microphytes from the northern sector, de-siltation quick fluxing of silt carried by river water, awareness of fishing communities to prevent pollution in fishing jetties and overall sustainability resource development and management.

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