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Temporal, Spatial and Depth Variation of Nutrients and Chlorophyll Content in an Urban Wetland

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Abstract: The Deepor Beel is a permanent, freshwater lake at the southwest corner of Guwahati in the southern bank of the Brahmaputra River and the Beel serves as the major storm water storage basin for Guwahati city. It is recognized as a Ramsar site (No. 1207) in 2002. The water quality of the Beel is threatened in recent times by excessive fishing activities, hunting of water birds, pollution from pesticides and fertilizers, and infestation by water hyacinth *Eichhornia crassipes*. The present work reports on bimonthly monitoring of macro and micro nutrients including nitrate, phosphate, potassium, boron, copper, iron, zinc at 13 different sites and three different depths of the water column. The impact of the nutrients on chlorophyll (*a*, *b* and *c*) contents of the wetland were also monitored. Each parameter was monitored 202 times in total. The measured values were subjected to analysis of variance test, which indicated important temporal, spatial and depth-wise correlations for the parameters. The ratios of total nitrogen to total phosphorus for the water is mostly <10 and the Trophic State Index is >70.0, both of which point to a phosphorus-enriched state and water approaching eutrophic conditions. The results indicate a serious degradation in quality of the water mostly due to human interferences.

Key words: Wetland, nutrients, chlorophyll, trophic state index, Deepor Beel.

Introduction

Nutrients in lakes serve the same basic functions as nutrients essential for growth. The algae and plant growth helped by the nutrients may be beneficial up to a point, but may easily become a nuisance. The main nutrients of concern are phosphorus and nitrogen. The total input of nutrients varies through time, depending upon land use and other factors. During the summer, nutrient input increases due to fertilization of cropland, lawns, and gardens, but heavy rains during this period decrease the same by several times. High rainfall brings in organic matter in different forms such as leaves, twigs, grass, and other debris and their decomposition releases more nutrients as the rains recede, constituting an important source of nutrient loading. This along with decrease in water volume during the winter increases the concentration of the nutrients. Nutrient concentrations may also vary with depth in a lake. Near the top of the lake, where light stimulates algal growth, total nutrient concentrations may be lower than those deeper in the lake because more of the nutrients will be used up at the surface. Since decomposition of organic matter and release of available nutrients occur to a larger extent near the bottom of a lake, available nutrient concentrations may be higher at depth (Michaud, 1991).

Surface water runoff from agricultural lands brings in (i) particulate-bound nutrients, such as phosphorus and organic nitrogen, and metals applied with some organic wastes, (ii) soluble nutrients and chemicals, such as nitrogen, phosphorus, metals, and many other major and minor nutrients, (iii) sediment-bound nutrients and organic solids, (iv) oxygen-demanding materials, (v) salts, and (vi) bacteria, viruses, and other microorganisms. Wetlands act like filters that purify water in a watershed. Often the water leaving a wetland is much cleaner than

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the water that enters the wetland. When water is retained in a wetland, much of the sediment settles down and remains in the wetland. Thus, the water leaving a wetland is much less turbid. Wetlands trap nutrients attached to the sediment or dissolved in water. Nutrients are either stored in the wetland soil or are used by plants to grow. The contribution of plants in removing nutrients varies with the nature of the effluent and the age of the wetland. In the absence of plants, the gravel substrate provide significant wastewater treatment although most studies report improved nutrient removal where plants are present.

The sources of nutrients include stormwater runoff, carrying fertilizers from cropland as well as organic matter such as leaves, grass, and insects; waste products from farm animals and domestic pets; failing lakeside septic systems; and industrial and municipal wastewater. As the number or size of pollutant sources increases, average nutrient concentrations also increase. Urban runoff contributes to the eutrophication of receiving waters around the world, and while phosphorus is normally the limiting nutrient in fresh water, nitrogen may also be of concern (Heaney et al., 1999; Lee and Bang, 2000; Field et al., 1998; Novotny and Witte, 1997).

The Deepor Beel (26°05′–26°11′ N, 91°35′–91° 43′ E, area 4000 ha, elevation 53 m above MSL) is a permanent, freshwater lake existing in a former channel of the Brahmaputra River in its south bank and in the southwest corner of Guwahati city (Assam, India). It is a large natural wetland having great biological and environmental importance besides being the only major stormwater storage basin for the city. The Beel is endowed with rich floral and faunal diversity. In addition to the huge congregation of residential water birds, the Deepor Beel ecosystem harbours large number of migratory waterfowl each year. The Deepor Beel is a natural wetland of Guwahati city. It is an important habitat for migratory aquatic birds, including globally threatened species like Spotbilled Pelican (*Pelicanus philippensis*), Lesser and Greater Adjutant Stork (*Leptoptilos javanicus* and *dubius*) and Baer's Pochard (*Aythya baeri*). The Beel is known for nymphaea nuts and flower, ornamental fish, medicinal plants and the giant water lilly, *Euryale ferox*. The Deepor Beel has been designated as a Ramsar site (No. 1207) in 2002. Although the original area of the Beel was 4000 ha, due to large scale encroachment and other activities, the area has shrunk considerably and the present area of the actual wetland has been estimated at around 700 ha. The water quality of the Beel is threatened in recent times by excessive fishing activities, hunting of water birds, pollution from pesticides and fertilizers, and infestation by water hyacinth *Eichhornia crassipes*. The present work provides definitive information on spatial, temporal and depth variations of the nutrients nitrate, phosphate, potassium, boron, iron, copper, and zinc along with chlorophyll contents.

Materials and Methods

Site Selection and Sample Collection

The wetland and its surrounding areas were thoroughly surveyed on boats and 13 different sites were selected for collection of water samples with the following GPS coordinates:

Sampling site	*Latitude (N)*	*Longitude (E)*
1	26:06:57.38	91:39:18.61
2	26:07:06.89	91:39:50.62
3	26:06:54.11	91:40:15.02
4	26:07:41.23	91:39:41.00
5	26:07:19.09	91:39:21.46
6	26:07:03.11	91:39:18.79
7	26:07:23.74	91:38:37.28
8	26:07:25.79	91:38:15.43
9	26:07:33.49	91:37:55.56
10	26:06:34.45	91:37:36.30
11	26:06:39.60	91:38:04.16
12	26:06:43.52	91:38:23.21
13	26:06:25.60	91:41:35.41

Samples were collected bimonthly (June, August, October, December, February and April) from each selected site. An outline of the Deepor Beel is given in Figure 1.

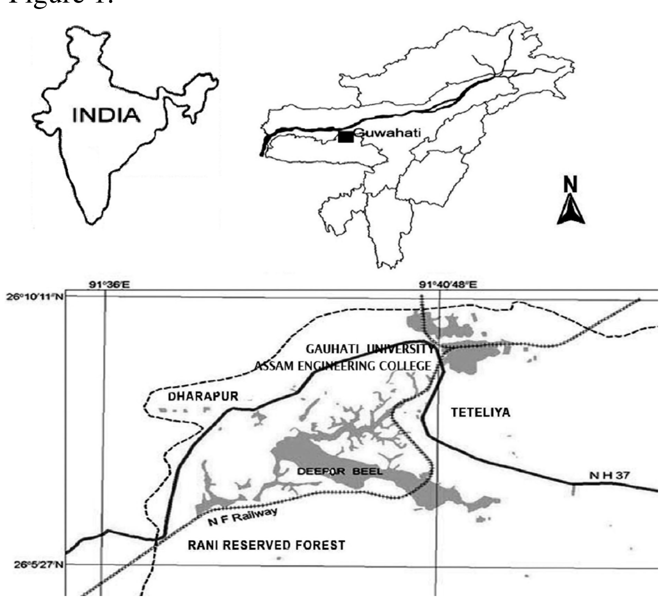

Figure 1: The Deepor Beel wetland system (shaded area) and its surroundings.

Sample Collection and Pre-treatment

Water samples were collected in 1 L polyethylene containers pre-cleaned with 10% reagent grade HNO_3, followed by rinsing three times with deionized water and thoroughly dried in a fume hood.

Water samples were collected at three different depths defined by (a) Surface layer, (b) Euphotic zone, (c) Euphotic Zone × 1.5. Euphotic zone was found with the help of Secchi disk and since light normally penetrates to a depth of 1.5 to 1.7 times the Secchi disk depth, the maximum depth used for sample collection was taken as 1.5 times the Euphotic zone. In some of the sampling stations, however, the water is very shallow and it was not possible to estimate the euphotic zone. In such cases, water samples were collected from surface and bottom layers only. A special water sampler with a heavy bottom was used to collect sample from different depths such that the top cover can be opened and closed from the surface. Standard Methods (APHA, 2005) were followed in collection, storage and analysis of the water samples.

The water samples immediately after collection were acidified to a pH <2.0 by adding 1.5 mL concentrated HNO_3/L or an appropriate volume required to achieve the desired pH. After acidification, the samples were stored in a refrigerator at ~4°C. Since the water samples were mostly turbid with appreciable load of suspended particulates, the samples were digested to find the concentration of both dissolved metals and that associated with the particles. In this work, nitric acid digestion technique (APHA, 2005) was used. For this, a volume of 100 mL each of acid-preserved, well-mixed water samples was taken in a beaker, 5 mL of conc. HNO_3 was added and the mixture was slowly evaporated on a hot plate in a fume-hood to a volume of 10-20 mL of clear solution. The beaker walls were washed with double-distilled water and the volume was remade to 100 mL in a volumetric flask for analysis of the metals.

Potassium was measured with a flame photometer (Elico CL361) after thorough calibration. Fe, Cu and Zn were measured in each water sample with atomic absorption spectrophotometry (Varian SpectrAA-220 AAS). Three-point calibration was done for each metal with certified AAS standards of 1000 mg/L (E. Merck, Germany) and the optimum experimental conditions were as shown below:

	Wavelength (nm)	*Lamp current (mA)*	*Slit width (nm)*	*Optimum working range (μg/mL)*
Fe	248.3	5	0.2	0.06-15.0
Cu	324.8	4	0.5	0.02-3.0
Zn	213.9	5	1.0	0.01-2.0

Nitrate, phosphate, boron and chlorophyll contents were determined by spectrophotometric method (Hitachi 3210 UV-visible spectrophotometer).

Statistical Analysis

Analysis of the variance (ANOV) of the data generated has been done with respect to the concentrations of the metals in the surface and the bottom layers for the different batches of sampling as well as the 13 different sampling sites. For this purpose, the one way ANOVA model (Gelman, 2005) has been used which relies on an additive decomposition of the data into grand mean, main effects, possible interactions, and an error term. This model calculates the degrees of freedom representing the number of effects at that level, minus the number of constraints for each source of variation.

Results and Discussion

Nitrate Levels

The macronutrient nitrate does not show any particular pattern of variation with time, depth and space. For example, in case of the surface layer, the nitrate content is highest during the month of February, which is the driest time of the year. At this time of the year, the water volume recedes to the minimum (for this reason, the middle layer could not be distinguished at several sites as the depth was very small at these sites) while the city's wastewater entering the wetland through the site 13 continues to bring in more and more nitrate leading to accumulation of the macronutrient at most of the sites. The nitrate content of the surface layer at the site 13 during February is 7.90 mg/L while the minimum value of 0.30 mg/L is at site 11, surrounded by luxurious growth of water hyacinth, which might be responsible for taking up a lot of nitrate and decreasing its content in water. The middle and the bottom layers do not show the same trends. A comparison of the nitrate levels of the three layers of water for the month of February (Figure 2) shows different patterns of variation at the 13 sites, which reflect differences in the level of accumulation and uptake by the aquatic plants.

Due to dilution by pre-monsoon rains, nitrate levels come down appreciably during April, but the levels rise conspicuously during June and August as very heavy downpour during these monsoon months results in excessive runoff flow from the surrounding agricultural land and rural households bringing in more input of nitrate. As the rains recede, further input is stopped, but water volume remains high and the nitrate levels more or less stabilize during October (range 0.06 to 0.20 mg/L

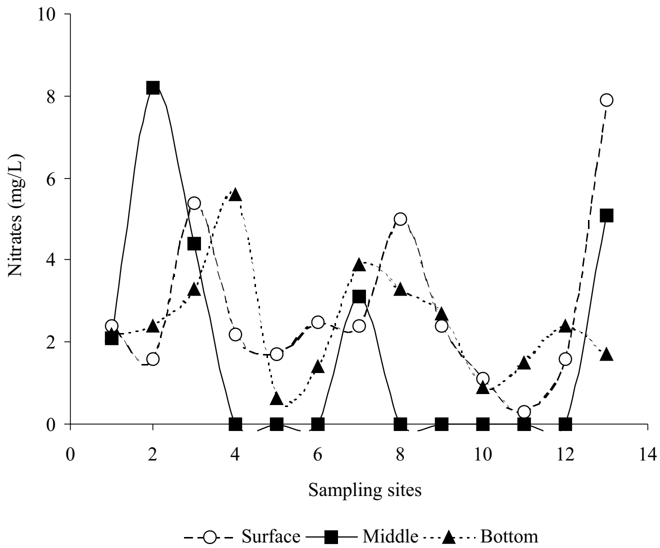

Figure 2: Nitrate levels of the three layers of water for the month of February.

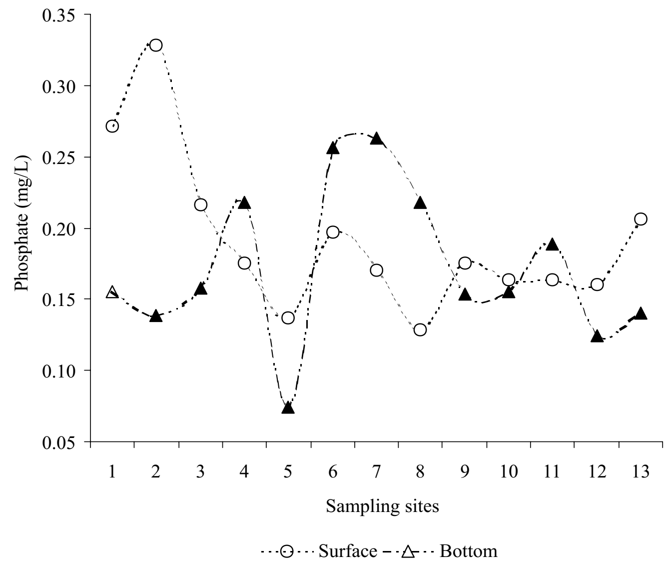

Figure 3: Yearly average phosphate content for all the 13 locations.

for the surface layer) and show a tendency to rise in December (range 0.02 to 0.65 mg/L for the surface layer) attributable to gradual reduction in water volume as the dry season sets in.

The spatial variation of nitrate level is dependent on several interacting factors like distance from the banks, closeness from the input points, human disturbance through fishing and other activities, etc. Taking the averages of the bimonthly measurements, it is seen (Figure 2) that the bottom layer has more nitrate than the surface layer at all the sites excepting the site 13, which receives a continuous inflow of city's wastewater. The natural level of nitrate in surface water is typically low (less than 1 mg/L), but in polluted water, the level can be as high as 30 mg/L or more. Sources of nitrates into the Deepor Beel include runoffs from fertilized cropland, septic effluents, cattle wastes, and industrial discharges.

Phosphate Levels

The macronutrient phosphorous expressed as orthophosphate is in a wide range of values from below detection limit to 0.86 mg/L. The average phosphate values are high during the months of February and April. When the yearly average phosphate content for all the 13 locations is plotted (Figure 3), it is seen that the maximum annual average content is recorded at site 2 (0.33 mg/L) for the surface layer and at sites 4 and 6 (0.26 mg/L) for the bottom layer. The annual average minimum concentration is recorded for the surface layer at sites 5 (0.14 mg/L) and 8 (0.13 mg/L) and for the bottom layer at site 5 (0.07 mg/L). The bottom layer contains more phosphate than the surface layer at the sampling sites 4, 6, 7, 8, and 11, while the reverse is true for the other sites. In these five sites, phosphate has a tendency for accumulating at the bottom layer where the calm, undisturbed conditions of water may be the principal contributing factor.

For all the 202 measurements spread over 13 locations, three depths and six seasons, the highest phosphate concentration of 0.85-0.86 mg/L was found during the month of April for the first three sampling locations (1, 2, 3) at the surface layer, but the concentration decreased rapidly towards the bottom. This is an indication that the large phosphate content at the surface layer is due to fresh inputs arriving at the three locations in the form of washing and laundering at the banks, which are having a significant impact due to decreasing volume of water during this time of the year. Phosphate content is generally high at all locations during April for both the surface layer (0.14 to 0.86 mg/L) and the bottom layer (0.01 to 0.68 mg/L). The values are also high during the month of February (surface layer: 0.19-0.65 mg/L; middle layer: 0.31-0.54 mg/L; bottom layer: 0.17-0.61 mg/L) due to the reduction in water volume in the dry season. Compared to these values, the phosphate content of the Deepor Beel water is very low in the monsoon months and also immediately following rains.

Even at low phosphorus concentration (<1.0 mg/L), significant growth of algae is promoted by phosphorus (Gachter and Imboden, 1985; Xiaoping and Akinori, 2005). If the conditions are appropriate, even a modest increase in phosphorus can set off a whole chain of undesirable events including accelerated plant growth, algae blooms, low dissolved oxygen, and the death of certain fish, invertebrates, and other aquatic animals. The Deepor Beel has been known for manifestation of all these phosphorus-enrichment factors and the low DO content (range: 2.0 to 6.0 mg/L) of water throughout the Beel supplements the phosphorus results. The sources of phosphorus mainly include runoff from fertilized cropland and household vegetable cultivation, septic effluent leaks and discharges, domestic wastewater containing detergents, runoff from animal manure dumps, and phosphate-bearing soil and rocks of the surrounding forests and hills (WQM, 2005).

Potassium

Potassium is required for plant growth mainly for the maintenance of osmotic pressure and cell size, and for aiding photosynthesis, energy production, stomatal opening and carbon dioxide supply, plant turgor and translocation of nutrients. The Deepor Beel water shows a very wide variation in potassium content from 0.2 to 22.3 mg/L for all 202 measurements indicating non-uniformity in potassium distribution. This may be either due to improper mixing or due to large input received from local sources such as agricultural fields. The values are high during the dry months of December to April. During the high monsoon period, uniformity in mixing and large water volume makes the potassium content almost constant throughout the Beel (a comparison for February and August is given in Figure 4).

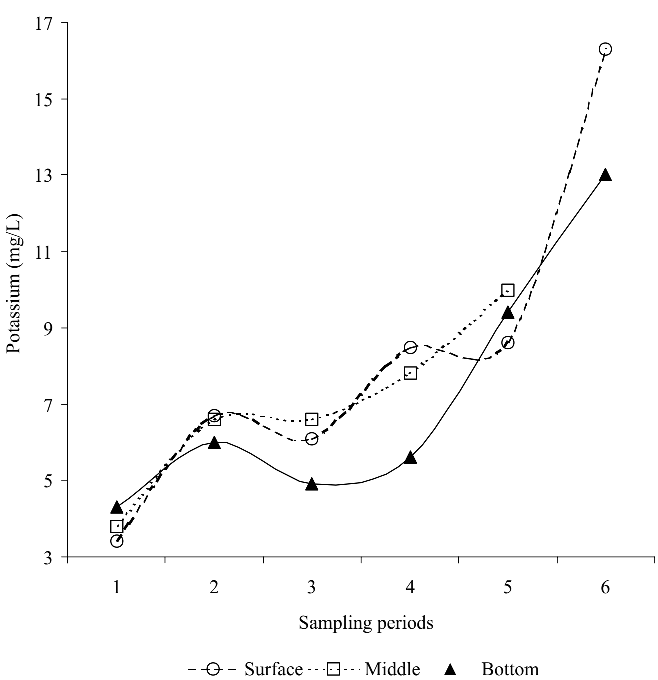

Figure 4: Seasonal variation of potassium contents of the Deepor Beel water.

Potassium exhibits significant variation with depth of the water column. The average K-contents show no tendency to accumulate towards the bottom. There is rich undergrowth of vegetation in the shallow wetland taking up large amount of potassium and thus, depleting its content at the bottom. This is true excepting the sites 1, 2 and 10, where the average concentrations of potassium for the surface and the bottom layers are very similar. The sites 3 and 13 show the highest average potassium content of 9.0 mg/L and 9.7 mg/L at the surface layer and 8.1 mg/L and 8.3 mg/L at the bottom layer. Both the sites, 3 and 13, are located close to the city's municipal effluent discharge point and the high potassium content at these sites could be attributed to the same. Potassium recorded the maximum value of 22.3 mg/L for surface layer at the site 13 during the dry month of April, and the minimum value of 0.2 mg/L for the surface layer at the site 9 during the summer month of June. The average potassium content for all the 13 locations varies from 5.7 to 9.7 mg/L for all the three layers.

Boron

Boron was detected only in a few sites in this work and it was mostly below detection level during the rainy season. The wetland water did not have any detectable amount of boron during the rainy months of June and August when the water volume was the largest. However, as the rains cease, boron level increases and the content is considerable during October (868 µg/L) and December (734 µg/L). As the dry months are approached, water volume recedes and boron content becomes undetectable during February and April, which is due to the aquatic plants taking up the available boron. It is found that for the sites 1, 2 and 3, the surface layer has higher boron concentration than the bottom layer while the reverse is true for the locations 8, 9, 10, 11, 12 and 13. The locations 4, 5, 6 and 7 have almost equal concentration of boron in both the layers. The average values vary from 76 to 226 µg/L for both the surface and the bottom layers. The location 9 has the highest boron concentration of 868 µg/L for the surface layer during October. On the other hand, the bottom layer of locations 1, 2 and 3 has high boron contents of 734, 733 and 733 µg/L respectively also during October.

Concentration of boron in surface water depends on the geochemical nature of the drainage area and inputs from industrial and municipal discharges. Concentration of boron in surface water varies from 0.001 to as much as 360 mg/L (Greenfacts, 2007). Boron accumulates in aquatic and terrestrial plants but does not magnify through the food chain. Concentrations of boron have been shown to range between 26 and 382 mg/kg in submerged aquatic freshwater plants, from 11.3 to 57 mg/kg in freshwater emergent vegetation, and from 2.3 to 94.7 mg/kg dry weight in terrestrial plants. Thus, the aquatic weeds and other plants of the Deepor Beel, which have a luxuriant growth during the rainy season, take up whatever boron is available and when these plants die and decompose, the boron is leached back into water.

Copper

Copper is mostly absent in the Deepor Beel water, but appreciable concentrations are found during February and August (Figure 5). The maximum content was 0.25 mg/L (bottom layer, sample 11, August), 0.23 mg/L (middle layer, sample 2, February) and 0.21 mg/L (bottom layer, sample 9, February). In the 202 measurements, copper content was below detection level in 72.2% of the measurements and no value exceeded the maximum permissible limit. The high values during August indicate appreciable input from the runoff and the metal has shown a tendency to accumulate towards the bottom. The appreciable values during February are obviously due to reduction in water volume and also due to leaching out of the metal from decaying vegetation during the dry season. The levels of Cu for irrigation and livestock watering have been set as 0 to 0.2 mg/L and 0 to 5.0 mg/L respectively with adverse chronic effects expected at 1 to 10 mg/L depending on the livestock (DWAF, 1996). Thus no adverse effects are expected due to Cu-content from use of the Beel water for domestic purpose, irrigation and livestock (Awofolu et al., 2005).

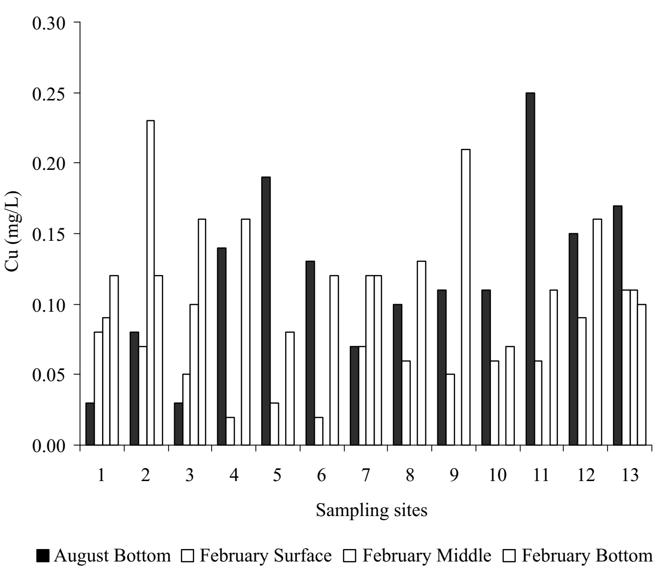

Figure 5: Variation of copper contents with location during the month of August (bottom layer only) and February (all the three layers).

Iron

The Deepor Beel water is rich in iron content. The iron contents spread from a few low values to a large majority of high values, the overall range being from 0.02 to 47.63 mg/L. When average values are computed for each water layer in each batch covering all the sampling points, it is found that the values are the highest for the February batch (11.68, 17.19, 22.08 mg/L for surface, middle and bottom layers). The values have a decreasing trend when the water volume is the largest (August and October). It is found that the average concentration of iron is more at the bottom layer in all locations excepting 5 and 12, showing an almost common tendency to accumulate towards the bottom. Continuous release of the metal into the water column by the bed sediments may also be responsible for it. Considerable spatial variations also exist in iron contents at different sites for the surface and the bottom layers of water.

The temporal variation pattern in iron content for the surface and the bottom layers of water separately is shown in Figure 6 for three of the sampling sites 1, 7 and 13. Iron content is much more during the month of February because of drop in water level. The water column contained much more iron at the bottom layer indicating a clear tendency for iron to accumulate downward.

Zinc

Zinc has been known to be toxic to aquatic organisms such as fish (Awofolu et al., 2005). Zinc contents of the Deepor Beel water are in the range of below detection

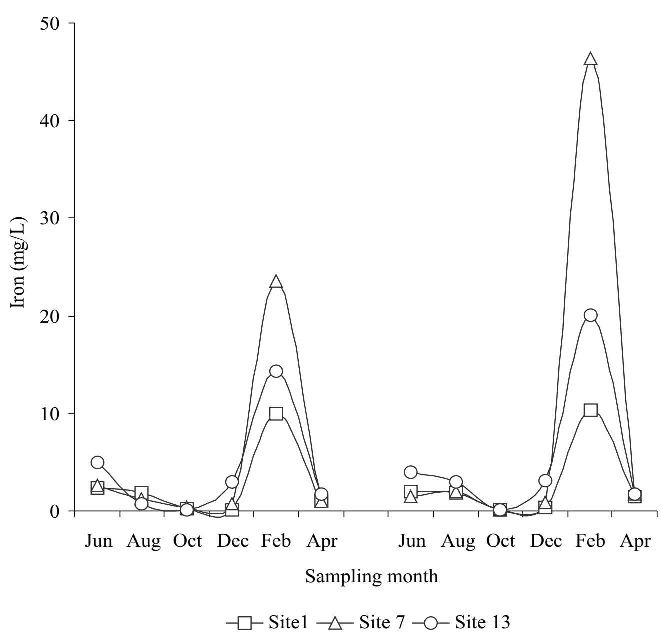

Figure 6: Temporal variation pattern in iron content for the surface and the bottom layers for three of the sampling sites 1, 7 and 13.

level to 3.39 mg/L. Considerable Zn content was recorded at several of the measurements during August and October batches of samples, e.g., 3.39 mg/L (bottom layer, sample 10, October), 2.83 mg/L (bottom layer, sample 8, third batch), 2.65 mg/L (bottom layer, sample 12, third batch), 1.51 mg/L (bottom layer, sample 1, August), 1.48 mg/L (middle layer, sample 3, August). The average Zinc values are usually high during August (0.15, 0.34, 0.28 mg/L), October (0.33, 0.55, 1.02 mg/L), and December (0.37, 0.26, 0.22 mg/L respectively for surface, middle and bottom layers). The average Zn-contents from different measurements for the surface and the bottom layers of the 13 locations are presented in Figure 7. Of the 202 measurements, 18.3% of the data shows Zn below detection limit.

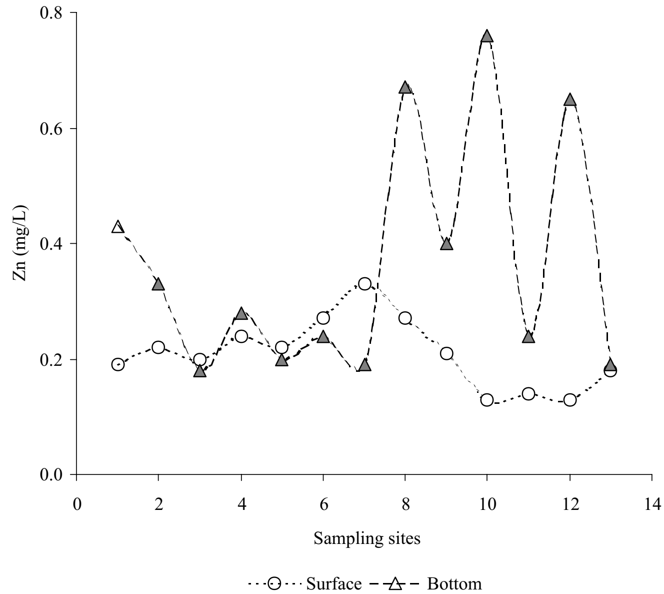

Figure 7: The average Zn-contents for the surface and the bottom layers of the 13 locations.

Chlorophyll Content

Chlorophyll gives a measure of the amount of photosynthesizing plants present in water. Most of these plants are likely to be algae or phytoplankton. Total chlorophyll is a measure of all the green pigments whether they are active (alive) or inactive (dead). 'Chlorophyll-*a*' is considered as a measure of the portion of the pigment that is still active; that is, the portion that is still actively respiring and photosynthesizing at the time of sampling. The Deepor Beel water is found to be very rich in chlorophyll-*b* and *c* rather than in chlorophyll-*a*. This is an indication that the Beel water has a large load of dead plants and algal matter (Michaud, 1991).

Table 1 shows annual mean chlorophyll contents of all the sites along with total chlorophyll contents and the

Table 1: Annual mean chlorophyll contents of all the sites along with total chlorophyll contents and the percentages of chlorophyll-*a* and those of chlorophyll-*b* and *c* combined

Site	*Chlorophyll-a*	*Chlorophyll-b*	*Chlorophyll-c*	*Total*	*% a*	*% b & c*
			Surface Layer			
1	0.31	0.43	0.97	1.71	17.9	82.1
2	0.38	0.56	1.12	2.06	18.5	81.5
3	0.44	0.56	1.11	2.11	20.8	79.2
4	0.47	0.63	1.14	2.24	20.8	79.2
5	0.66	0.93	2.43	4.02	16.3	83.7
6	0.30	0.37	1.02	1.69	17.9	82.1
7	0.39	0.58	1.13	2.11	18.7	81.3
8	0.45	0.61	1.22	2.27	19.6	80.4
9	0.35	0.44	0.85	1.64	21.4	78.6
10	0.42	0.65	1.19	2.25	18.4	81.6
11	0.40	0.50	1.42	2.31	17.2	82.8
12	0.62	0.89	2.28	3.79	16.4	83.6
13	0.55	0.57	1.27	2.39	22.8	77.2
			Bottom Layer			
1	0.42	0.63	1.13	2.18	19.3	80.7
2	0.30	0.79	0.78	1.87	16.1	83.9
3	0.46	0.52	1.06	2.04	22.7	77.3
4	1.93	0.70	1.23	3.85	50.0	50.0
5	0.54	0.49	0.93	1.95	27.6	72.4

(*Contd.*)

(*Contd.*)

Site	*Chlorophyll-a*	*Chlorophyll-b*	*Chlorophyll-c*	*Total*	*% a*	*% b & c*
6	0.56	0.60	1.51	2.67	21.1	78.9
7	0.35	0.55	0.91	1.81	19.3	80.7
8	0.47	0.77	1.18	2.42	19.6	80.4
9	0.43	0.60	1.61	2.64	16.4	83.6
10	0.39	0.44	0.97	1.80	21.7	78.3
11	0.83	0.84	1.69	3.36	24.8	75.2
12	1.48	2.01	3.57	7.06	21.0	79.1
13	0.60	1.13	1.75	3.48	17.2	82.8

percentages of chlorophyll-*a* and those of chlorophyll-*b* and *c* combined. Chlorophyll-*a* content varies from 16.3 to 22.8% in the surface layer, and 16.1 to 50.0% in the bottom layer. Thus, active biomass at the surface is much less (~20%) compared to dead biomass (~80%). The situation is similar for the bottom layer except for the site 4, which is very shallow and has a lot of undergrowth of vegetation making the contributions of active and dead biomass equal at this site. Sunlight, temperature, nutrients, and wind affect algae numbers and, therefore 'chlorophyll-*a*' concentration. Figure 8 presents the variation in chlorophyll-*a* content for the surface and bottom layers of the different sites.

The temporal variation of chlorophyll contents does not follow the same pattern at all the sites. As an example, the variation is shown for three sites, 2, 6 and 10, which are respectively located at the eastern periphery, middle and western periphery of the Deepor Beel (Figure 9). For the site 2, chlorophyll-*a* and total chlorophyll vary from month to month in a similar way for both surface and bottom layers with the important difference that both peak at June and December (highest) in case of the surface layer, but they peak at August (highest) and December in case of the bottom layer. The site 6 shows similar behaviour. At site 10, the temporal variation of chlorophyll shows a different behaviour—both chlorophyll-*a* and total chlorophyll were having maximum values during February, June and December in case of the surface layer, and during April and

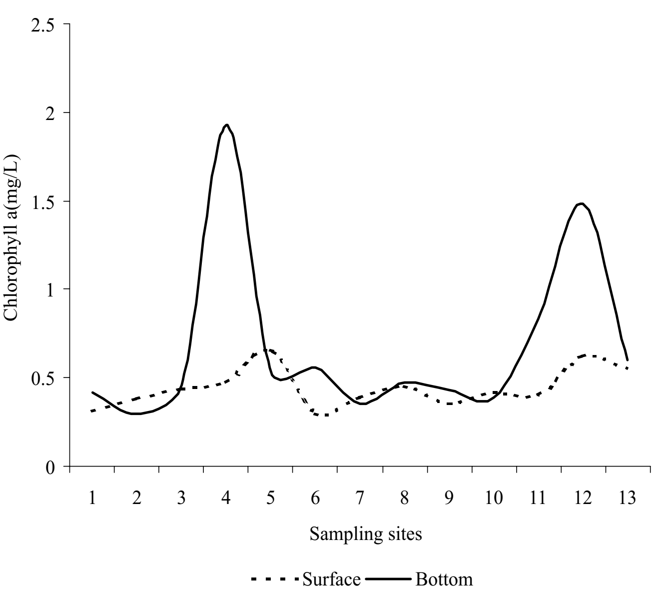

Figure 8: Variation of average chlorophyll-*a* contents for the surface and the bottom layers.

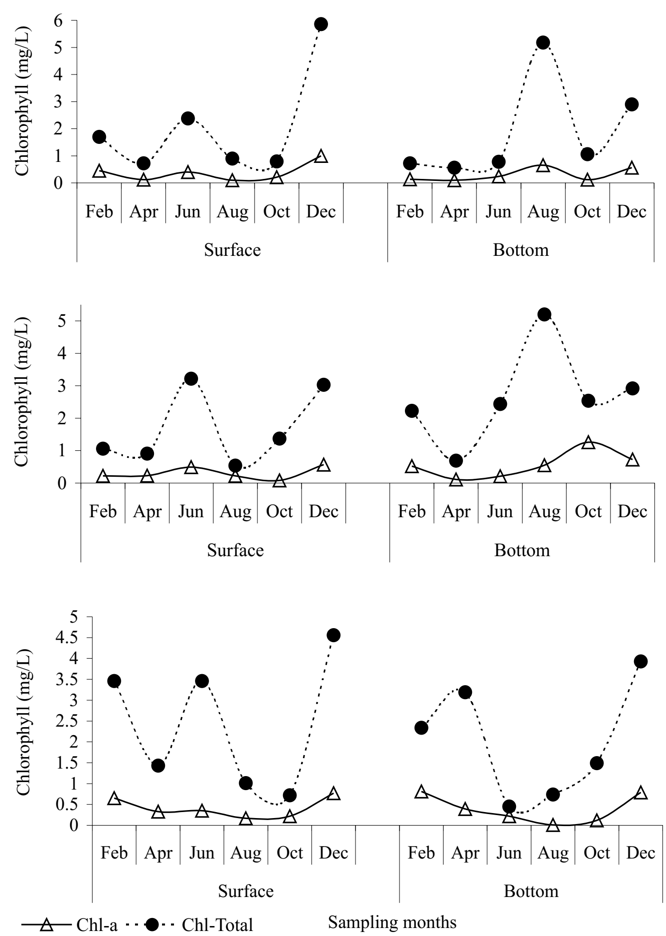

Figure 9: Variation of chlorophyll-*a* and total chlorophyll for the surface and the bottom layers of the sites 2 (top), 6 (middle) and 10 (bottom).

December in case of the bottom layer. The total chlorophyll content shows the general tendency of becoming high towards the dry season when most of the weeds die and decay starts.

Statistical Analysis

The ANOVA data are given in Tables 2, 3 and 4 for (i) time (bimonthly), (ii) depth (surface and bottom layers), and (iii) sampling site (13 sites) as the factors respectively. The mean square for each row is the sum of squares divided by the degrees of freedom. Under the null hypothesis of zero row and column effects, their mean squares would, in expectation, simply equal the mean square of the residuals. The F-ratio for each row is the mean square, divided by the residual mean square. This ratio should be approximately 1.0 if the corresponding effects are zero; otherwise the F-ratio is expected to exceed 1.0. If the F-ratio is less than 1, this is attributed to negative correlations within a group. The *p*-value gives the statistical significance of the F-ratio. For example, if the F-ratio is <1.0 and the *p*-value is statistically not very significant (i.e. it does not differ from 1.0 very much), then the measured values have a 'chance' element which cannot be neglected. In the opposite case of F-ratio significantly higher than 1.0 and the *p*-value significantly different from 1.0, the null hypothesis is incorrect and the measured values within a group have some valid correlation.

When temporal variations are considered, the F-ratio is >1.0 in all the cases (except 'chlorophyll-*a*'). This indicates that variations in these parameters with time are statistically significant and they are likely to follow a definite pattern. This is because the water volume changes with season along with which the concentrations also

Table 2: Analysis of Variance (ANOVA) with time (sampling month) as the factor (A between groups, B within groups, C total)

Dependent parameter	*Source*	*Sum of squares*	*Degrees of freedom*	*Mean square*	*F-ratio*	*p-value*
Potassium	A	1861.3	5	372.26	54.96	0.000
	B	1015.9	150	6.77		
	C	2877.2	155			
Nitrate	A	2.5	5	0.49	21.89	0.000
	B	3.3	147	0.02		
	C	5.8	152			
Phosphate	A	112.9	5	22.58	23.57	0.000
	B	142.7	149	0.96		
	C	255.6	154			
Boron	A	3.7	5	0.73	89.53	0.000
	B	1.2	150	0.01		
	C	4.9	155			
Iron	A	4859.2	5	971.84	28.37	0.000
	B	5034.9	147	34.25		
	C	9894.1	152			
Copper	A	0.2	5	0.04	26.81	0.000
	B	0.2	150	0.00		
	C	0.4	155			
Zinc	A	7.3	5	1.45	9.75	0.000
	B	22.4	150	0.15		
	C	29.6	155			
Chlorophyll-*a*	A	2.4	5	0.48	0.91	0.475
	B	79.3	150	0.53		
	C	81.7	155			
Chlorophyll-*b*	A	4.3	5	0.85	1.38	0.236
	B	92.8	150	0.62		
	C	97.0	155			
Chlorophyll-*c*	A	43.5	5	8.70	6.40	0.000
	B	204.0	150	1.36		
	C	247.5	155			

Table 3: Analysis of Variance (ANOVA) with depth of the water column as the factor (A between groups, B within groups, C total)

Dependent parameter	*Source*	*Sum of squares*	*Degrees of freedom*	*Mean square*	*F-ratio*	*p-value*
Potassium	A	46.4	1	46.42	2.525	0.114
	B	2830.8	154	18.38		
	C	2877.2	155			
Nitrate	A	0.0	1	0.03	0.801	0.372
	B	5.7	151	0.04		
	C	5.8	152			
Phosphate	A	1.9	1	1.87	1.128	0.290
	B	253.7	153	1.66		
	C	255.6	154			
Boron	A	0.0	1	0.00	0.077	0.781
	B	4.9	154	0.03		
	C	4.9	155			
Iron	A	187.9	1	187.87	2.923	0.089
	B	9706.2	151	64.28		
	C	9894.1	152			
Copper	A	0.0	1	0.03	10.558	0.001
	B	0.4	154	0.00		
	C	0.4	155			
Zinc	A	0.7	1	0.72	3.844	0.052
	B	28.9	154	0.19		
	C	29.6	155			
Chlorophyll-*a*	A	2.2	1	2.15	4.167	0.043
	B	79.5	154	0.52		
	C	81.7	155			
Chlorophyll-*b*	A	1.3	1	1.26	2.026	0.157
	B	95.8	154	0.62		
	C	97.0	155			
Chlorophyll-*c*	A	0.1	1	0.06	0.036	0.850
	B	247.5	154	1.61		
	C	247.5	155			

change. This result is supported by $p = 0$ for all parameters except 'chlorophyll-*a*' and 'chlorophyll-*b*', which have p = 0.475 and 0.236 respectively. F-ratio is <1.0 for 'chlorophyll-*a*' (0.911) and >1.0 for 'chlorophyll-*b*' (1.38). Thus, the concentrations of 'chlorophyll-*a*' and 'chlorophyll-*b*' in the Deepor Beel water are more or less static with time while all other parameters have considerable seasonal influence being dependent on the inputs reaching the Beel.

The depth analysis shows F-ratio >1.0 in case of potassium, phosphate, iron, copper, zinc, 'chlorophyll-*a*' and 'chlorophyll-*b*' corresponding to which the $p \sim 0$ (Table 3). These parameters have a positive correlation with depth of the water column and the variations are statistically significant. Combined interpretation of F-ratio and p-value for all the other parameters does not support any correlation with depth and therefore, it may be inferred that the parameter nitrate, boron and 'chlorophyll-*c*' have no tendency either to accumulate or decline in concentration with depth.

No statistically significant correlation is observed when the spatial analysis of the data is carried out considering the sampling sites as the variable factor. F-ratio is marginally >1.0 in the case of phosphate, 'chlorophyll-*a*' and 'chlorophyll-*b*' (Table 4) but the corresponding p-value is non-zero. The given parameters do not bear any type of significant correlation with the sampling sites. This is equivalent to considering each sampling site of the Deepor Beel as an independent monitoring site without a strong relationship with the other sites. This may be due to differences in (i) turbulence level, (ii) human disturbances, (iii) number and density of aquatic plant species, and (iv) depth of the water column.

Table 4: Analysis of Variance (ANOVA) with the sampling sites as the factor (A between groups, B within groups, C total)

Dependent parameter	*Source*	*Sum of squares*	*Degrees of freedom*	*Mean square*	*F-ratio*	*p-value*
Potassium	A	51.3	12	4.27	0.216	0.998
	B	2825.9	143	19.76		
	C	2877.2	155			
Nitrate	A	0.4	12	0.03	0.785	0.665
	B	5.4	140	0.04		
	C	5.8	152			
Phosphate	A	24.9	12	2.07	1.276	0.239
	B	230.7	142	1.63		
	C	255.6	154			
Boron	A	0.0	12	0.00	0.117	1.000
	B	4.9	143	0.03		
	C	4.9	155			
Iron	A	549.5	12	45.79	0.686	0.763
	B	9344.6	140	66.75		
	C	9894.1	152			
Copper	A	0.0	12	0.00	0.105	1.000
	B	0.4	143	0.00		
	C	0.4	155			
Zinc	A	0.8	12	0.07	0.348	0.978
	B	28.8	143	0.20		
	C	29.6	155			
Chlorophyll-*a*	A	10.3	12	0.86	1.728	0.067
	B	71.3	143	0.50		
	C	81.7	155			
Chlorophyll-*b*	A	9.1	12	0.76	1.229	0.269
	B	87.9	143	0.62		
	C	97.0	155			
Chlorophyll-*c*	A	15.2	12	1.27	0.781	0.669
	B	232.3	143	1.62		
	C	247.5	155			

Nitrogen-Phosphorus Ratio and Trophic State Index

Total nitrogen (TN) and total phosphorus (TP) are the primary crop nutrients that can impact the environment. When applied in excess of crop needs, nutrients run off into surface waters resulting in excessive aquatic plant growth and toxicity to certain fish species. TN/TP ratio is considered important in establishing N and P reduction targets in the environment (Sigua and Steward, 2000). This ratio is one of the important components in calculating the Trophic State Index (TSI) of lakes. Several studies have shown that a TN/TP ratio of <10:1 favours algal blooms, especially growth of bluegreen algae, which are capable of fixing atmospheric N (Schindler, 1974; Chiandini and Vighi, 1974; Sigua et al., 2000; Sakamoto, 1966). The TN/TP ratios computed on the basis of average nitrogen and phosphorus contents at each site are given in Table 5.

Table 5: TN/TP ratios and TSI values for the different sampling sites of the Deepor Beel

Sampling site	*TN/TP ratio*		*TSI*	
	Surface layer	*Bottom layer*	*Surface layer*	*Bottom layer*
1	3.18	5.95	84.58	77.28
2	1.93	5.86	87.24	75.28
3	5.58	7.37	81.59	77.28
4	3.89	8.26	78.60	81.59
5	5.52	17.93	75.61	65.32
6	3.81	2.50	80.60	84.58
7	4.55	3.98	78.27	84.58
8	10.82	6.60	74.29	84.58
9	5.73	7.23	79.60	76.28
10	3.62	4.24	77.28	77.28
11	3.27	8.04	77.28	79.93
12	5.53	9.65	77.28	73.29
13	12.51	13.27	80.93	75.28

TN/TP ratio is <10:1 for all the sites excepting sites 8 and 13 for the surface layer, and 5 and 13 for the bottom layer. Thus, the Deepor Beel can be classified as nitrogen limited ecosystem with much more phosphorus than is found in a natural wetland. This is the reason for excessive growth of blue green algae and other vegetation leading to near-eutrophic state of the water.

Total phosphorus concentration determines a lake's trophic status. The Trophic State Index (TSI) has been devised to integrate different but related measures of lake productivity or potential productivity, into a single number that ranges from 0 to 100 and is computed from the modified Carlson's equation (Maki et al., 1984; Carlson, 1977; Miliˇcevi´c, 1984)

$$TSI = 10\,[6 - (\log (48/TP)/\log 2)]$$

where TP represents annual mean total phosphorus content at a site. The trophic level of an ecosystem is generally evaluated from the contents of total N, chlorophyll-*a*, transparency and biological parameters. Since phosphorus is a limiting factor for growth, the above equation based on the mean annual content of total phosphorus gives a good account of the trophic level of a wetland. With respect to the trophic level, the wetlands are termed as "good" (TSI = 0 to 59), 'fair" (TSI = 60 to 69), and "poor" (TSI = 70 to 100). The Deepor Beel, having TSI > 70 at all the sites of the surface and the bottom layers (with one exception) has therefore reached the 'poor' category. Wetlands are also classified as oligotrophic (TSI ≤ 40), mezotrophic (TSI = 40 to 60) and eutrophic (TSI = 60 to 100) and on this basis, the Deepor Beel can be described as eutrophic.

Conclusion

The Deepor Beel, close to the city of Guwahati, is in a very poor state as far as water quality is concerned. The water contains both macro and micro pollutants beyond permissible limits and is not suitable for different uses. The water is rich in phosphorous content and is mainly responsible for the degradation of quality of water in the Beel. The high phosphorous content is also responsible for declining dissolved oxygen content and correspondingly, aquatic life is affected. The causes for degradation of the water quality may be linked to inflow of a large amount of municipal wastewater, inflow from nearby crop fields and discharge of effluents by the small and medium industries in the surroundings.

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