



## LIMNOLOGICAL STUDIES OF MANSAGAR LAKE FOLLOWING RESTORATION

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### ABSTRACT

Limnological studies of Mansagar lake were made both before and after restoration. Data on physico-chemical characteristics of lake water and sediment, algal counts, chlorophyll content, zooplankton counts and microbiology of lake water have been discussed to enumerate outcome of lake restoration.

### INTRODUCTION

The rapid urbanization and industrialization in India was not accompanied by establishment of wastewater treatment facility at similar same pace. This led to pollution of lentic and lotic freshwater ecosystems. Even today, most of the cities, except for metros, have minimal/no wastewater treatment facility. As per recent estimate of CSE (2007, Source; Internet 19.9.2007), about 29,000MLD of domestic wastewater and 15,000MLD of industrial waste is discharged into the country's 12 major river basin. Even after huge expenditure to clean up this mess, they remain dirtier than ever. Similar data for lentic water bodies is not available though these are worst affected due to lesser dilution of pollutants and relatively slower self purification capacity in comparison to lotic system due to standing water. The faster expansion of cities in the catchment of several freshwater bodies polluted them from anthropogenic activities.

Rajasthan state situated in the north-west part of the country is relatively a water deficient state. Man-made water bodies such as lakes and reservoirs are the major source of surface water to meet domestic, industrial and irrigation demands. Many of them have become polluted due to discharge of raw sewage and industrial wastewaters. This is increasing gap between demand and supply of water for various uses. The pollution of water bodies also affected tourism in Udaipur and Jaipur. To deal with this situation, Ministry of Forest & Environment, New Delhi has initiated a revival program for lakes under the banner of "National Lake Conservation Program since 2000.

Mansagar lake, popularly known as Jal Mahal, is the first water body of the Rajasthan state to receive grants for its restoration. Jaipur Development Authority (JDA), Jaipur, was

the nodal agency to implement lake restoration. Limnological studies initiated prior to lake restoration were continued after its restoration to monitor changes in abiotic and biotic components and important findings are reported in this communication.

### STUDY AREA

Mansagar lake is a large manmade lake on the northern fringe of Jaipur city. Mansagar reservoir stretches on the eastern side of the lake. It is a 300m long and 28.5-34.5m wide structure having three sluice gates to regulate outflow in the downstream.

The lake is approximately 130ha in its spread with a maximum depth (>7m) at the dam's outflow point. It has a catchment of 23.5km<sup>2</sup>, about 40% of which falls inside the dense urban area is presently the major source of water (about 90%) in the form of storm water runoff through Nagtalai and Brahmपुरi Nalas in the rainy season while tertiary treated sewage in the dry weather. The denuded and forested hills constitutes remaining 60% watershed. It contributes very little water to lake on account of impediments such as human settlements and hotels in the foot hills on western side and construction of roads on three sides of the lake. Various features (lake spread in 1980 and 2012, point source of pollution, fish kill etc.) in the Mansagar lake are shown in Fig. 1a-f.

The volumes of inflow from the various sources in the lake were as under:

Nagtalai Nala	:	5400 m <sup>3</sup> /d
Brahmpuri Nala	:	24000 m <sup>3</sup> /d

### Inflows from across

Amber road (4 inlets)	:	500 m <sup>3</sup> /d
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Brahmpuri nala is carrying discharge from the walled city

and from the northern 27 MLD sewage treatment plant (STP) and Nagtalai nala from the human settlements and textile printing industries outside the walled city. The sewage of these nalas has been diverted outside the lake via a newly constructed drain terminating near reservoir and its wastewater is discharged in the downstream via a new opening. During rainy season, storm water of urban catchment is still the major source of water in the lake. It flows through these nalas and newly constructed drain. The overflows enter into lake near Mansagar reservoir. However, runoff of first few showers is discarded and discharged via new outlet in the downstream.

After the diversion of nalas, tertiary treated effluent of STP (7.8MLD) is vital to the sustenance of the lake during dry weather.

The lake has its maximum spread just after monsoon and shrinks gradually to its least spread just before the monsoon.

The lake bed was depository of eroded silt materials and settled pollutant materials from the influent nalas. The estimated volume of eroded deposits was about 2.5 MCM. The difference in levels immediately upstream and downstream of the Mansagar dam was about 12 m and most of this was due to siltation.

JDA carried out extensive desilting of lake bed in the year 2001-02 and used sediment to construct three islands in the lake for habitats to both resident and migratory birds. The silt was also used to reclaim land from the lake bed on southern

end of the lake. Jalmahal Resort Ltd. also did desilting of lake bed further (Nov. 2006-June 2007). The excavated silt was used to raise platform of 100 acre land on southern end of lake which also includes submerged area (about 14.15 acre) of lake.

### Climate

Jaipur district falls in the semi arid region. Winter (December to March) is cold after which summer season commences and continues till about the third week of June when the southwest monsoon sets in. The monsoon season is comparatively short and lasts only till mid- September. The period from the second half of September to the end of November is the post-monsoon or retreating monsoon season.

The average annual Rainfall in Jaipur city is 603mm and about 90% of it falls between June to September. The variation of the annual rainfall from year-to-year is very large. On an average there are 34 rainy days in a year.

### CHECK DAM

An earthen check dam having an area of about 5 acre has been constructed on the northeastern side of the lake in 2005 (Fig. 1, 2a). The primary objective of check dam is to arrest flow of eroded soil from hills. It is connected with the main lake through a small underground channel passing through the newly constructed road along north-east bank of lake. The mouth of the channel is closed by wooden logs to arrest entry of floating solid wastes entering in the lake with



Fig. 1a. Satellite picture of Mansagar lake prior to restoration.



Fig. 1b. Mansagar lake in 1979-80 (summer)



Fig 1c Mansagar lake (Dried in June 2007)

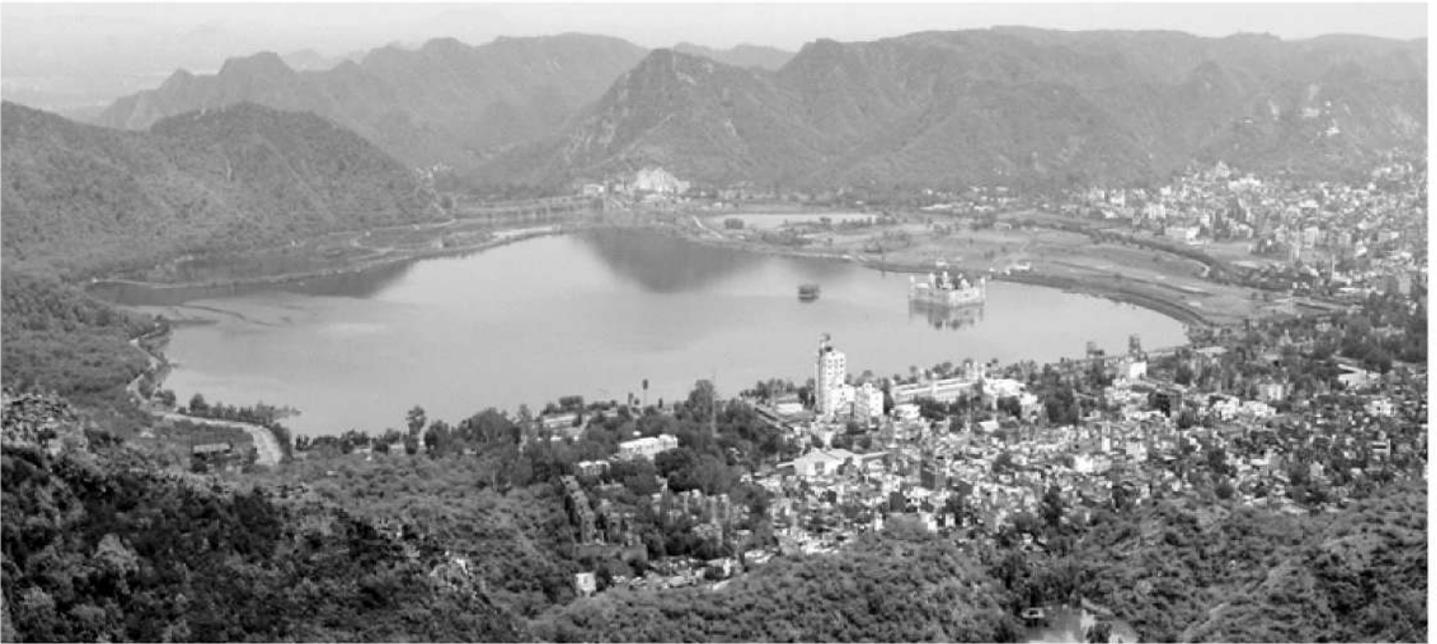


Fig. 1d. Mansagar lake after Restoration (2012 Rainy Season)

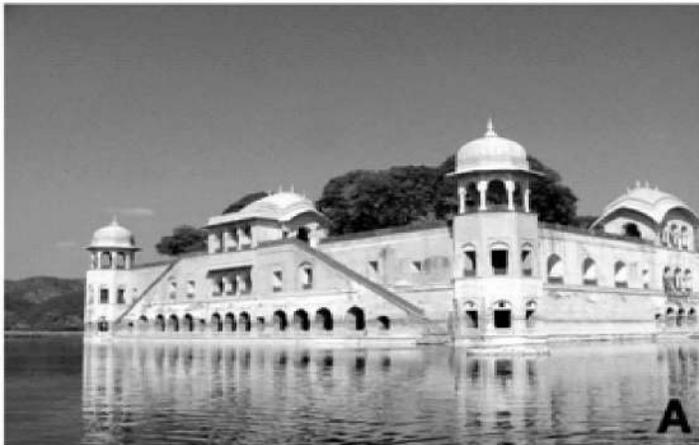


Fig 1e. A. Jalmahal Palace B. Floating solid wastes entering in lake with stormwater



Fig. 1f. Mass mortality of fish in Mansagar lake.

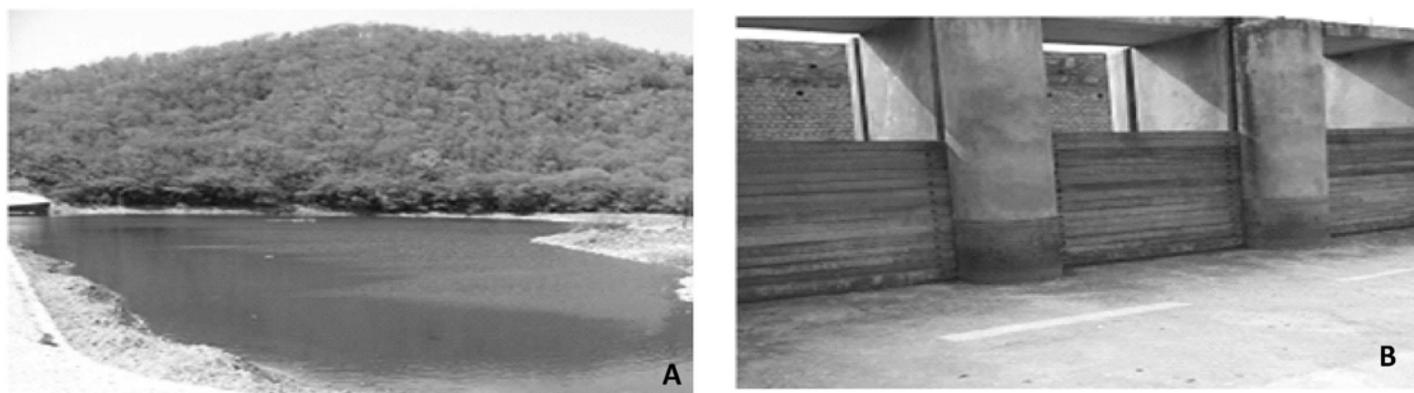


Fig. 2. A. Check dam, 2B. Wodden partition

stormwater (Fig. 2a,b). The water volume contained in this dam is approximately 100,000 m<sup>3</sup>. Presently, check dam serves as a major drinking water source for the wild life in the forest.

## MATERIALS AND METHODS

### PHYSICO-CHEMICAL CHARACTERISTICS OF SEDIMENT

Sediment samples collected from lake bed were dried in the sun, grounded and then sieved through 80 mesh sieve. Physico-chemical characteristics of sediment were analysed following methods described by Trivedy and Goel (1980).

### PHYSICO-CHEMICAL CHARACTERISTICS OF WATER

During first 6 month of study (March 05- August 06), surface samples of water body were collected from 5 sites (S1-S5). Sampling site - 1 (S1) located nearby the outfall of Brahmipuri nallah in lake was receiving sewage of the walled city. Sampling site -2 lying almost opposite to Hotel Trident received wastewater drains from the Gujar basti located behind hotel at the foothill of Nahrgarh hill. Sampling site -3 located on the northern side of Lake was in between S2 and Island-1 adjoining eastern end of the lake. Site-4 closer to Island-2 was also at the eastern face of the lake. Site -5 was on the back of Island -3 on the southern side of lake. This site was nearby entry of Nagtali nala adding untreated sewage and textile dye wastewater in the lake.

In September 2005, 5 more sampling sites were added to the list (viz. S6-S10). Site -6, 7, 9 and 10 were on the southern side of the lake, whereas Site 8 was in the lake centre. Sampling site 10 was at the back of Jalmahal palace while S9 on its northern side. Sub-surface samples (at 1m depth) were also collected from September 2005. Thus, 20 samples {10 each from surface and sub-surface (1m

depth)} of the lake were collected in the cleaned plastic bottles (1000ml) in the morning (between 7.0am-10am during summer and rainy seasons and between 8.0am-11.0 am in winter) from September 2005 – March 2007. Thereafter, only surface water samples were collected from three sites (April 2007- August 2008) located in the north-east direction of the lake where water is in the mixed state because of water currents flow most of the time in the year. Samples were stored in the icebox and transported immediately to the laboratory for analysis. Water temperature, oxygen content and free carbon di oxide content were measured at the lake. Physico-chemical characteristics of water were analysed following methods described by Trivedy and Goel (1980).

### Microbial Flora: 1. Fungi

The study of microbial flora of Mansagar lake was carried out in 2005-2006. Isolation of fungal species was done using different media such as Potato Dextrose Agar, Martin's Rose Bengal agar, Sabouraud's Dextrose Agar and Czapek-Dox media. Antibiotic streptomycin was used to prevent bacterial contamination. Different baits were also used to isolate deep water fungal flora. The baits were; boiled grains of maize, beans, wheat straw, blotting paper, hair, dead insects and decomposing plant litter. The baits were autoclaved and kept in sterilized plastic bottles which were sunk in the lake water for a week using weight. Lake water and baits were inoculated on various sterilized culture media. The inoculated culture plates were stored for 10days in the culture cabinet (12h Light and 12h dark, Temperature = 30°C). The preliminary identification of fungal colonies was done by observing their morphology and then through slide preparation. Uninucleate, binucleate or multinucleate conditions and septation were studied in the fungal species

under the microscope (in 10X × 100X) by putting a drop of immersion oil over the mounted slide. The species were identified using standard keys (Ainsworth 1961, Tandon and Chandra 1976).

## 2. Bacteria

Serial dilutions of the lake water were made. After 24 h of inoculation on nutrient agar medium, colony-forming units (CFU) were counted to calculate bacterial load in the lake water. MPN counts of lake water were made in Lauryl Tryptose broth. IMViC test was made at two occasions for identification and differentiation of enteric bacteria.

## Biological Parameters

The composite sample (5L) consisting of 500ml sample each from 10 sites was collected between March 2006 - March 2007, and thereafter, only from three sites up to August 2008. 500 ml of composite sample was centrifuged at 1500 rpm for 20 minutes and the concentrate was finally make up to a known volume by distilled water and transferred in polyethylene sample bottle for storage. The samples were immediately preserved adding 1 ml of Lugol's solution per 100 ml of solution. The concentration factor was clearly mentioned on sampling bottles which were stored in dark.

## Phytoplankton

Identification of algae was done on the basis of their external appearance, colour, morphological characteristics, size, habit, cellular structure, pigments and reproductive characteristics. The microphotographs of the algae were taken for the record and structures of the algae were compared with that reported in standard flora for a detailed identification of algae (Smith 1950, Pentecost, 1984).

The counting of algae was made in one of the 25 sub-chambers of haemocytometer by placing a drop of well agitated sample on the counting chambers as described by Trivedi and Goel (1980). Ten drops were observed and four sites in each drop were counted.

For estimation of chlorophyll, 100-250 ml of composite sample was centrifuged for 20 minutes at 3000 rpm. The supernatant was discarded and the pellet was transferred to a test tube having 90% acetone (about 5 ml). The mixture was agitated and stored overnight in a refrigerator. The mixture was transferred in to a pestle mortar and grounded adding 0.2 ml MgCO<sub>3</sub> suspension (1%). The crushed sample was then centrifuged and final volume of the extract was made

up to 10 ml adding acetone (90%). The absorbency was noted at 663 and 645 nm and quantity of chlorophyll a, b, and total was calculated by using following formulae:

$$\text{Chlorophyll a} = 12.7 \times (\text{O.D. at 663 nm}) - 2.69 \times (\text{O. D. at 645 nm})$$

$$\text{Chlorophyll b} = 22.9 \times (\text{O.D. at 645 nm}) - 4.68 \times (\text{O. D. at 663 nm})$$

$$\text{Total} = 8.02 \times (\text{O.D. at 663 nm}) + 20.2 \times (\text{O.D. at 645 nm})$$

The chlorophyll concentration (Chl-a mg/m<sup>3</sup>) in the water body was calculated as follow:

$$\text{Chlorophyll a (mg / m}^3\text{)} = \frac{\text{Ca (mg / L)} \times \text{extract volume (L)}}{\text{Volume of sample, m}^3}$$

The algal biomass was calculated by multiplying the chlorophyll- a content (mg/m<sup>3</sup>) by a factor of 67.

## Zooplankton

Centrifuged sample fixed in Lugol's solution for phytoplankton was used for zooplankton study. For identification, organisms were examined under a compound microscope. Their detailed morphology was noted and compared with characteristics and photographs in the monographs (Tonapi 1980, Battish 1992). The counting of micro-invertebrates was made using Sedgewick rafter.

Bolting silk net (of 8 mesh) was also used for collecting zooplankton at one occasion. 20 L of lake water was filtered through the net and the macro-invertebrates lying over the net were removed carefully, fixed in 4% formalin and were observed under microscope for identification made using standard monographs (Tonapi 1980, Battish 1992).

## Benthos

The sediment samples were collected from the shallow regions of lake using a hollow plastic pipe (Diameter = 5"), which was pressed in the mud and the core of the sediment lifted carefully was transferred in the plastic jars, which were transported to the laboratory. The sample was transferred in to a coarse sieve (with a mesh size of 0.5 - 0.6 mm) lying over a fine one (with a mesh width of less than 0.2 mm). The sieves were kept under running tap water, agitating and spreading sediment carefully with a brush. The organism remaining over sieves of different mesh sizes were picked up carefully with forceps and brush. Macro-invertebrates were preserved in 10% formalin while 70 % alcohol was used for organism having calcareous shell or exoskeleton. For identification, organisms were visually examined and/ or under a dissecting / compound microscope.

## Biological Indices

### Shannon-Weaver's Index

It is most widely used index for measuring biological diversity. It has been developed from the information theory (Shannon & Weaver, 1949).

$$D = - \sum P_i \log_e P_i$$

Where D = Diversity Index;  $P_i = n_i/N$  ( $n_i$  = Number of individuals in species; N = Total number of individuals in the Sample).

### Palmer's Algal Genus Index

Table prepared by Palmer (1969) has been used for the calculation of this index. This table has 20 algal genera most tolerant to organic pollution and a number is assigned to each of them depending on their relative tolerance. Algal genera present in a water sample were identified and those present in Palmer list were noted. The numbers scored by each genus were totaled to get the value of algal genus index.

### Diversity index of Boyd

This index also indicates pollution status of a water body (Boyd 1981). The main parameters in the index are number of genera of phytoplankton and their counts in a water body and is calculated as follow.

$$H = S - 1 / \ln N$$

S = No. of genera of phytoplankton

N = Total no. of phytoplankton

Ln = log normal

## RESULTS

### PHYSICO-CHEMICAL PROPERTIES OF LAKE WATER

The data on water qualities of the lake were collected for a period of three years (2005-2008). The lake was reduced to a small pool in April 2007 and was dried almost completely in June 2007 due to release of water in 2006 winter for desilting. The desilting was completed before the onset of monsoon (July 2007). The lake was full (at tank level) in the 2007 monsoon. Aeration of lake bed was commissioned in September 2007. Microbial consortium was also introduced to augment bioremediation. Monthly variations (March 2005-April 2007) are shown in Fig. (3-37) and important findings are described below.

### Turbidity

Secchi disc transparency was measured in noon (12.00 am) when sun rays are almost vertical. Transparency was low (4.2cm) near outfall (S1) but relatively higher at other sites ranging 16.0-17.5cm in March 2005.

### Temperature

#### March 2005 - February 2006

The water temperature increased rapidly during summer (April-June) and was maximum in June (33.2-36.2 °C). Thereafter, it decreased becoming minimum in December (14.0-15.4°C). It varied little in January and February (17.0-19.4°C). In comparison to outfall (S1), temperature of surface samples of lake was little higher (12-37%) during summer while an opposite trend (23-46%) was observed during winter. The sub-surface water temperatures differed little with surface water temperatures.

#### March 2006 – April 2007

The temperature of the water body was found higher during summer (21.7-25.1°C) and rainy season (24.7-28.0°C), and was maximum in August. It decreased in winter (10.0-18.0) and was minimum in January (9.6°C). The water temperature increased after March.

The water temperature at the outfall (12.5-29.0 °C) was almost similar to lake water (S2-S10), except for January (12.5°C) when it was higher than the lake water. Sub-surface water temperatures (9.6 -27.6°C) were almost similar to surface water (9.6-28°C), because of sample collection from a low depth (1.0m).

In the year 2008, temperature values were maximum in the rainy season (23.2-25°C) and minimum in the winter season (15.4-15.7°C), as noted in the year 2006 and 2007.

### pH

#### March 2005 - February 2006

No definite seasonal pattern was observed in the pH values of lake water during the study period. Lake pH remained close to neutral (7.1- 8.0) during study period though it fluctuated at sampling station-5 in acidic (pH = 5.2) to alkaline (pH = 9.0) range because of inflow of textile dye wastewater. Thus, in general, lake water was highly buffered.

A comparison of pH values of lake water (S2-S10) with outfall (S1) revealed little differences. pH values of sub-surface water were similar to surface water.

#### **March 2006 – April 2007**

No definite seasonal pattern was observed for pH. pH values at the outfall were closer to neutral (7.3-7.8), except at few occasions when these were slightly alkaline (pH = 8.0-8.3).

pH values of surface and sub-surface water were similar (8.0 – 8.7) throughout the study period and were usually towards alkaline range. The little fluctuations in pH values suggest that the lake water is highly buffered.

In the year 2008, period for maximum pH values was similar to 2006-07 (summer = 9.1-9.3) but minimum values were noted in winter season (pH = 7.60-7.62). Its values differed little at different sites.

#### **Conductivity**

##### **March 2005 - February 2006**

In general, conductivity values of lake water were higher during summer season (2600-3060 micro mho/cm). Conductivity decreased rapidly during rainy season (1300-2800 micro mho/cm) which was followed by gradual increase in winter (1820- 2400 micro mho/cm). Conductivity of surface (1300-2500 micro mho/cm) and sub-surface samples (1280-2470 micro mho/cm) were almost similar.

##### **March 2006 – April 2007**

The conductivity values at the outfall were usually higher than lake water, especially from March 06 – December 06. Its maximum values (2600-3900 micro mho/cm) were recorded in summer (excessive evaporation of water) and rainy season because of poor rains. The excessive rains decreased EC values (1000- 2790 micro mho/cm) significantly in the post-rainy and winter season because of dilution of dissolved solids.

The release of water from the lake decreased its depth and spread area during 2006 ( winter) -2007 (summer). Lake was reduced to small shallow pool in April 2007 was almost dried in June 2007. The greater evaporation of water increased EC value sharply in April 2007 (4000 micro mho/cm).

EC values of sub-surface water (2000-5000 micro mho/cm) were almost similar to surface water.

In the year 2008, maximum EC values were observed in summer (2100-2230 micro mho/cm) and minimum in the rainy season (1500-1700 micro mho/cm).

#### **Total Suspended Solids (TSS)**

Total suspended solids varied (35-198.5 mg/L) in the post-rainy season (Oct. 2007). Their higher values were observed at site S6, S7, S10 (124-156 mg/L) in the surface water, and at S2, S2, S3, S5 and S7 (130-198.5 mg/L) in the subsurface water.

#### **Total Dissolved Solids (TDS)**

TDS concentrations in the surface water were almost similar in March 2005 (1.2-1.4g/L) and August 2005 (1.10-1.25g/L).

#### **Dissolved Oxygen (DO)**

Dissolved oxygen concentration indicates physical and biological processes prevailing in the waters. Its presence is essential to maintain higher forms of life in the water; and the oxygen balance of the system largely determines effects of wastewater discharges in the water body. Unpolluted surface waters are normally saturated with dissolved oxygen. Low oxygen content is generally associated with heavy contamination by organic matter.

Low oxygen in water is injurious to fauna, particularly fish. The minimum amount of dissolved oxygen required for game fish is 5mg/L while coarse fish may survive at lower concentration (about 2mg/L).

##### **March 2005 - February 2006**

The oxygen concentrations at the outfall (S1) were either nil or very low (0.6-1.35 mg/L) because of microbial degradation of sewage entering at this site (Fig. 3). DO level was higher in April (4.9 mg/L) on account of presence algal bloom and also in the rainy season (2.8-3.6mg/L) due greater mixing of water.

The oxygen concentrations in the lake water (S2-S10) showed seasonal variations, high during summer (5.5-11.3mg/L) and winter (7.3-10.4mg/L) and low in the rainy season (3.5-5.2mg/L) (Fig. 4). Sampling stations 2, 5, 9 and 10 lying closer to point source of pollution had lower DO levels than the other sampling stations (S3, S4, S6, S7, S8).

##### **March 2006 – April 2007**

The dissolved oxygen was nil at the outfall, except at few occasions (1.7-2.6mg/L) (Fig. 3). There were large seasonal variations in DO levels of surface water (Fig. 4), summer

### Outfall: DO

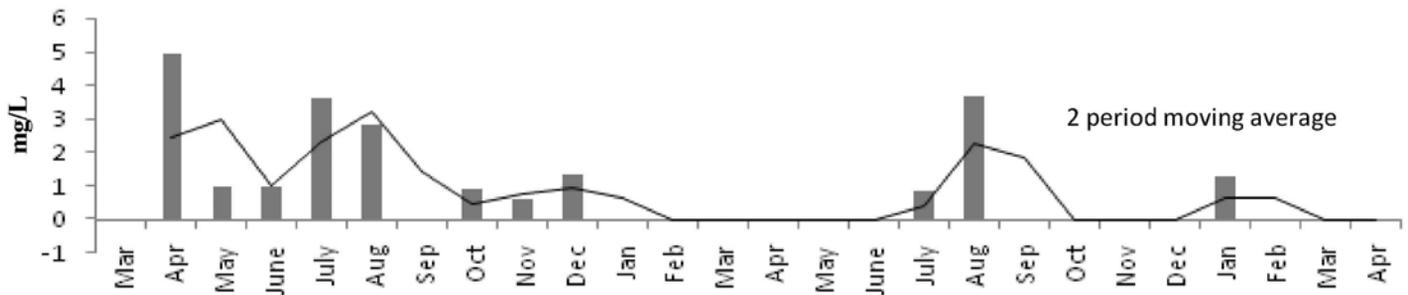


Fig 3 : Monthly variations (March 2005-April2007) in DO levels (mg/L) at the sewage outfall

### Surface Samples: DO

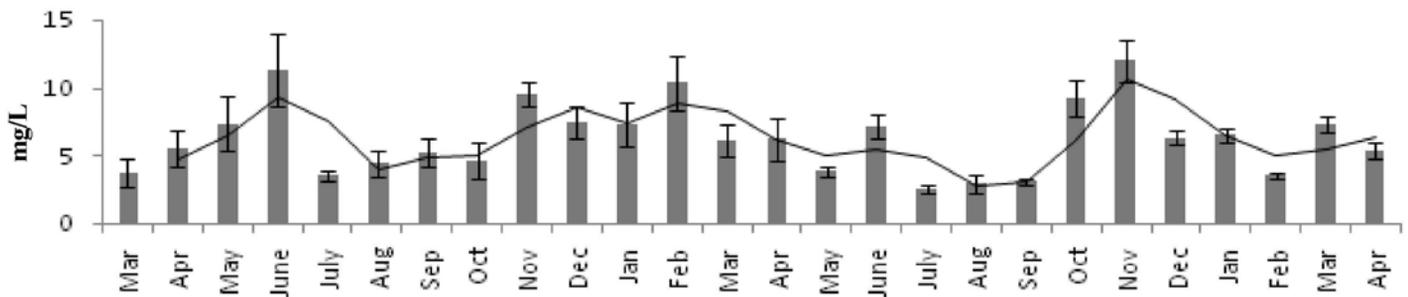


Fig 4 : Monthly variations (March 2005-April2007) in DO levels (mg/L) in the surface water of lake (Mean ± SEM of S2-S10).

(3.8-7.1mg/L), rainy season (2.5-3.1mg/L), post-rainy and post-rainy (3.1 -9.2 mg/L), winter (3.5-12.0mg/L).

#### Free Carbon di oxide

##### March 2005 - February 2006

In general, free CO<sub>2</sub> concentrations found higher in the summer (124-350mg/L) and rainy (70-105mg/L) season decreased markedly in winter (3.5-66 mg/L) at both outfall and lake water (Fig. 5,6). Its values were often higher (13-

97%) at the outfall (S1) in comparison to lake water (S2-S10). Free CO<sub>2</sub> concentrations differed markedly in the lake water (S2-S5) in the warmer months. Free CO<sub>2</sub> concentrations were low in the sub-surface water (2.9-14.5mg/L, Fig. 7).

##### March 2006 – April 2007

Free carbon di oxide concentrations were usually higher at the outfall (11.5-212.0mg/L) in comparison to surface (13-

### Outfall Free: CO<sub>2</sub>

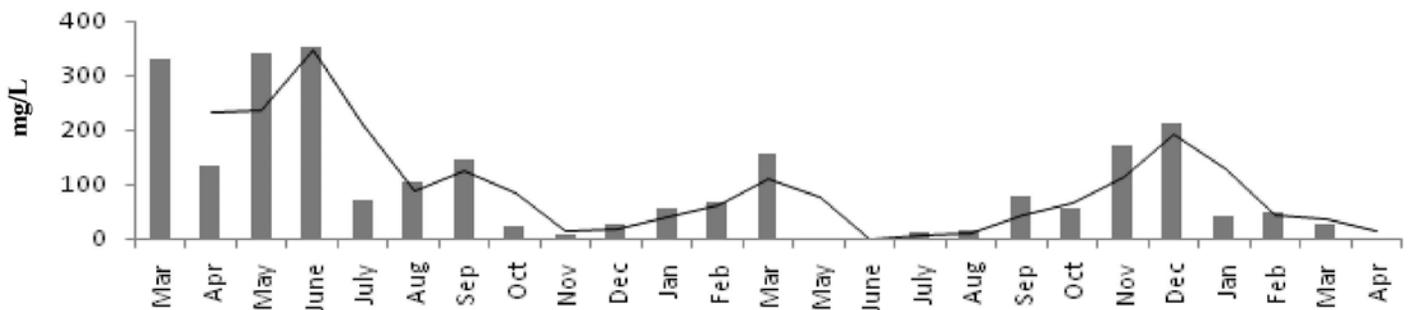


Fig 5: Monthly variations (March 2005-April2007) in free CO<sub>2</sub> levels (mg/L) at the sewage outfall

### Surface Samples: Free CO<sub>2</sub>

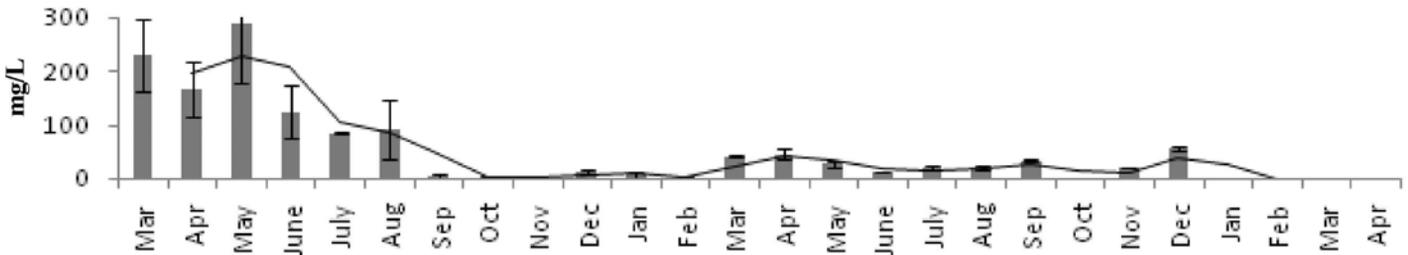


Fig 6 : Monthly variations (March 2005-April2007) in free carbon di oxide levels (mg/L) in the surface water of lake (Mean ± SEM of S2-S10)

### Subsurface Samples: Free CO<sub>2</sub>

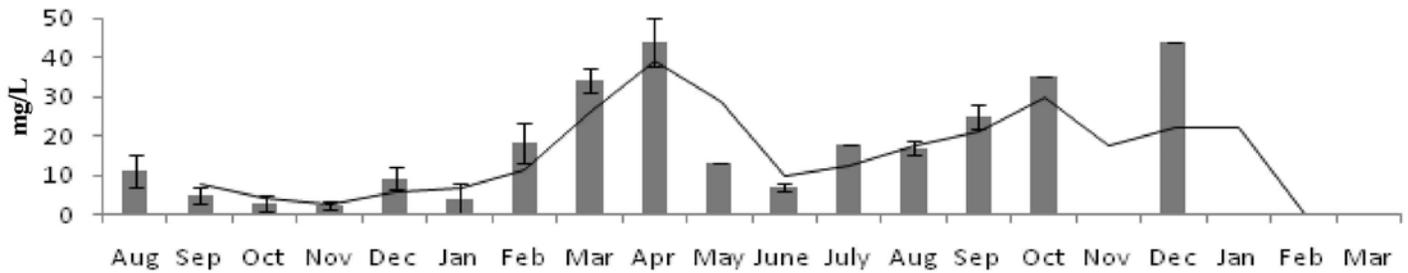


Fig 7: Monthly variations (March 2005-April2007) in free carbon di oxide levels (mg/L) in the sub-surface samples of lake water (Mean ± SEM of S2-S10)

55mg/L) and sub-surface (7 - 44mg/L) samples of the lake (Fig. 5, 6,7).

#### Alkalinity

##### Phenolphthalein alkalinity

##### March 2005 - February 2006

Phenolphthalein alkalinity (PA) at the outfall (60-140 mg/L) was observed in the summer (Fig.8). Its concentrations in the lake water were low in winter (nil – 8mg/L) and fluctuated

markedly during summer (nil – 200 mg/L) and rainy season (nil -200mg/L, Fig. 9).

##### March 2006 – April 2007

Phenolphthalein alkalinity was nil at the outfall, with the exception of June, 06 (325 mg/L) and March 07 (47.5mg/L) (Fig. 8). In contrast, it was usually present in the lake water, being higher in summer (250- 300mg/L, Fig. 9).

### Outfall: PA

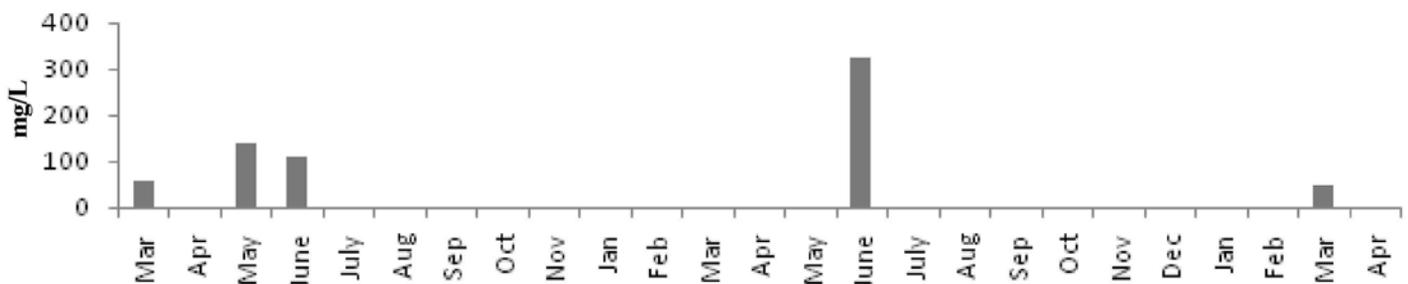


Fig 8: Monthly variations (March 2005-April2007) in PA levels (mg/L) at the sewage outfall

### Surface Samples: PA

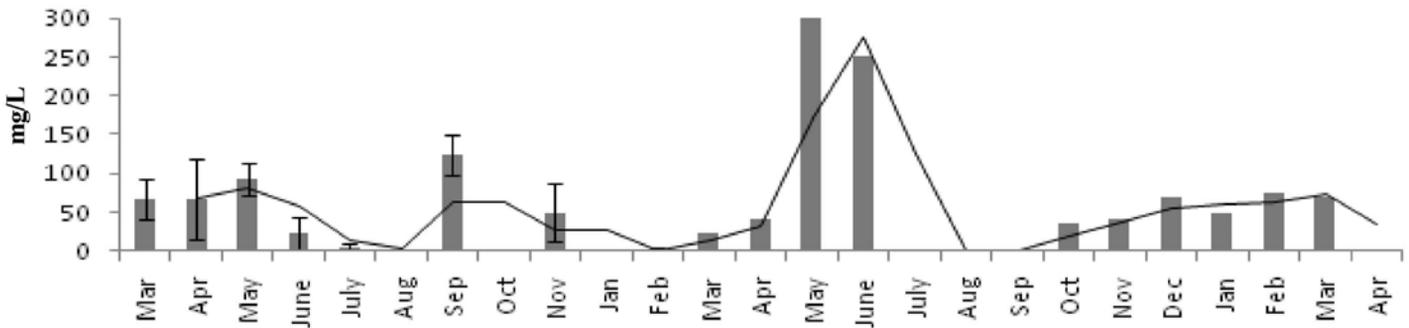


Fig 9: Monthly variations (March 2005-April2007) in PA levels (mg/L) in the surface water of lake (Mean ± SEM of S2-S10)

In the year 2008, the maximum PA values were observed in the rainy season (60 - 110 mg/L) and minimum in the summer season (33.3-53.3 mg/L).

#### Total Alkalinity

##### March 2005 - February 2006

The trend of total alkalinity (TA) parallel with that of free CO<sub>2</sub>, being high in summer (710-1710mg/L) and low during rainy (480-680mg/L) and winter (24-190mg/L) seasons

(Fig.10,11). In comparison to outfall (S1), TA concentrations in the lake water (S2-S5) were usually higher (11-110%), more particularly in the summer season (Fig. 10,11).

##### March 2006 – April 2007

Total alkalinity values were almost two folds higher at the outfall (552 – 2145mg/L) in comparison to lake water (390 – 1550mg/L) (Fig. 10, 11). Its values were higher during summer and rainy seasons and decreased sharply in the post-rainy and winter season at both outfall and lake water.

### Outfall: TA

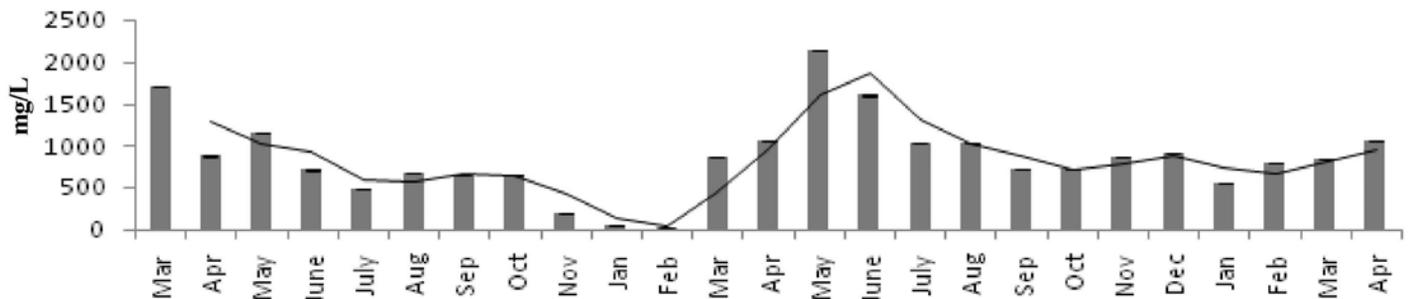


Fig 10: Monthly variations (March 2005-April2007) in TA levels (mg/L) at the sewage outfall

### Surface Samples: TA

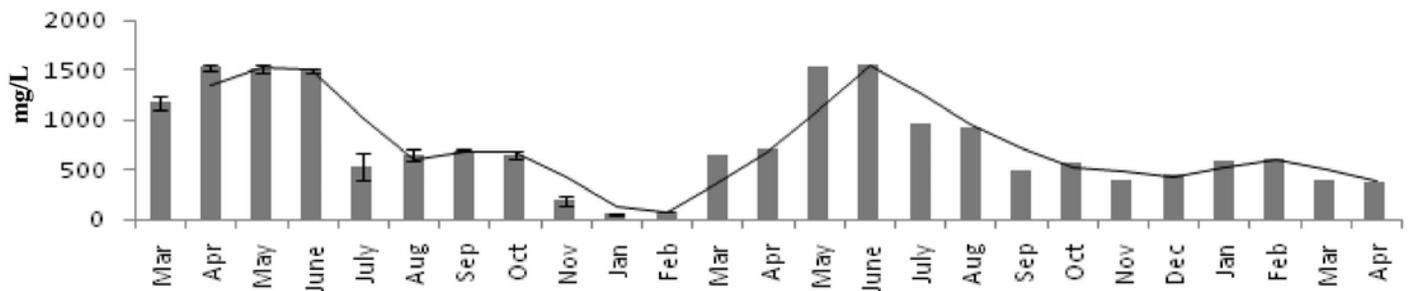


Fig 11: Monthly variations (March 2005-April2007) in TA levels (mg/L) in the surface water of lake (Mean ± SEM of S2-S10)

In the year 2008, trend for TA values were similar to the year 2006 and 2007, being maximum in summer (563.3-806.6 mg/L) and minimum in the rainy season (545-560 mg/L).

**Chlorides**

The discharge of domestic sewage is the most important source of chlorides in the lake. Chloride concentration is therefore, an indicator of sewage pollution. Industrial wastes also contribute chlorides.

**March 2005 - February 2006**

Chloride concentrations were maximum (568-917 mg/L) in the summer season at the outfall (S1). It decreased sharply in the rainy season (136-349 mg/L) (Fig. 12) and thereafter, varied little (318-412 mg/L). Chlorides concentrations in the lake water were almost similar to outfall in the post-rainy and winter season but decreased (50-70%) in summer

(Fig.13). Chloride concentrations varied largely at different sampling stations during summer season possibly on account of greater evaporation in the shallow areas of lake that increased concentration of salts .

**March 2006 – April 2007**

Chloride concentrations at the outfall (310 -1040mg/L) were higher than lake water (330 – 630mg/L) between March 06-November 06, but decreased afterwards (Fig. 12, 13). Its concentrations were maximum during summer and minimum in the rainy season, as also observed in the previous year. The unusual trend noted in winter 07 was rapid increase in chloride concentrations (454-850mg/L) in the lake water possibly on account of increased evaporation of water due to reduction in water depth because of water release. A good rain after sampling in February, 07 however, diluted lake water in March (470mg/L). The chloride concentration increased again in April (850mg/L)

**Outfall: Chloride**

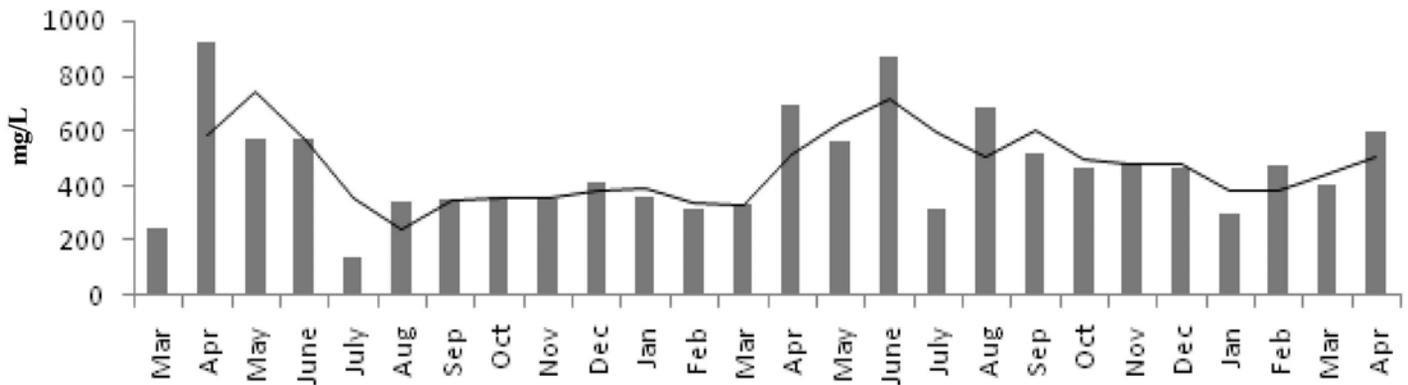


Fig 12: Monthly variations (March 2005-April2007) in chloride levels (mg/L) at the sewage outfall

**Surface Samples: Chloride**

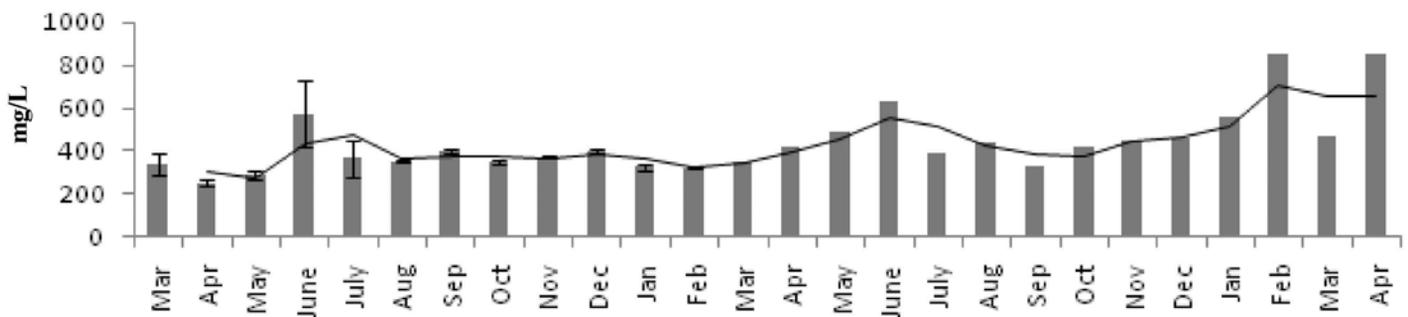


Fig 13: Monthly variations (March 2005-April2007) in chlorides levels (mg/L) in the surface water of lake (Mean ± SEM of S2-S10)

In the year 2008, maximum chloride concentrations were observed in the rainy season (465-485 mg/L) and minimum in the winter season (374-382 mg/L).

### Total hardness

#### March 2005 - February 2006

Total hardness (TH) at the outfall varied between 250-1620mg/L (Fig. 14). Its concentrations were comparatively lower in the lake water (483-646mg/L, Fig. 15). After a

In the year 2008, TH values were maximum (518-700 mg/L) during summer and minimum (432-500 mg/L) in the rainy season.

### Chemical Oxygen Demand (COD)

#### March 2005 - February 2006

COD concentrations fluctuated markedly (227-1051mg/L) at the outfall (S1) in the study period, becoming exceptionally low in October (30mg/L) on account of dilution by massive runoff from catchment following heavy rain (Fig. 16). COD

## Outfall: Total Hardness

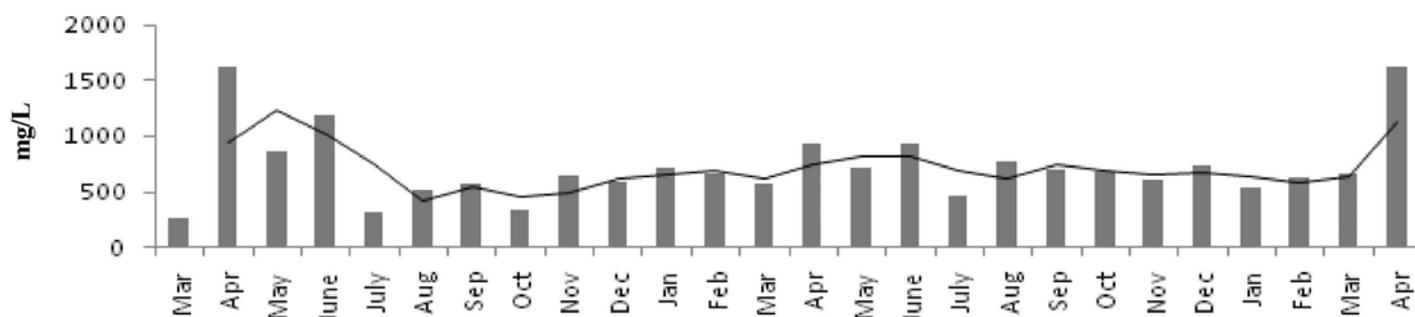


Fig 14: Monthly variations (March 2005-April2007) in TH levels (mg/L) at the sewage outfall

## Surface Samples: Total Hardness

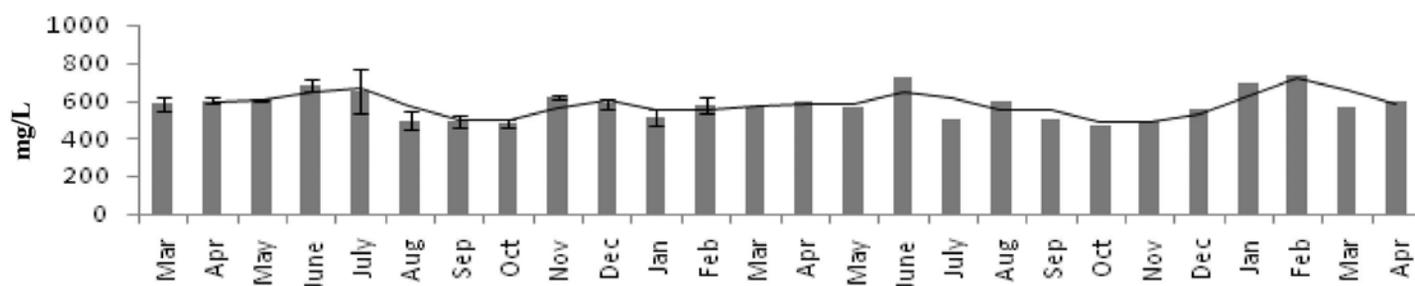


Fig 15: Monthly variations (March 2005-April2007) in total hardness levels (mg/L) in the surface water of lake (Mean  $\pm$  SEM of S2-S10)

marked reduction in the rainy season, it increased gradually in the winter season and was maximum in summer.

#### March 2006 – April 2007

Total Hardness found higher at outfall (708–930mg/L) and in the lake water (568–720mg/L) during summer decreased sharply in the rainy season (Outfall = 453-692mg/L, Lake = 496-600mg/L, Fig. 14,15). Afterwards, TH increased gradually in the winter. The exceptionally higher values of TH were observed in April 2007 at both outfall (1615mg/L) and lake water (1320mg/L).

values differing little (304-391 mg/L) during summer season in the lake water (S2-S10) however fluctuated in rainy, post-rainy (52-324 mg/L) and winter season (184-334mg/L, Fig. 17).

#### March 2006 – April 2007

COD values were higher at the outfall (213–1440mg/L) in comparison to surface (203–384mg/L) and sub-surface (186–333mg/L) samples of the lake (Fig. 16,17, 18). No definite seasonal variation was recorded in COD values of surface

### Outfall: Chemical Oxygen Demand

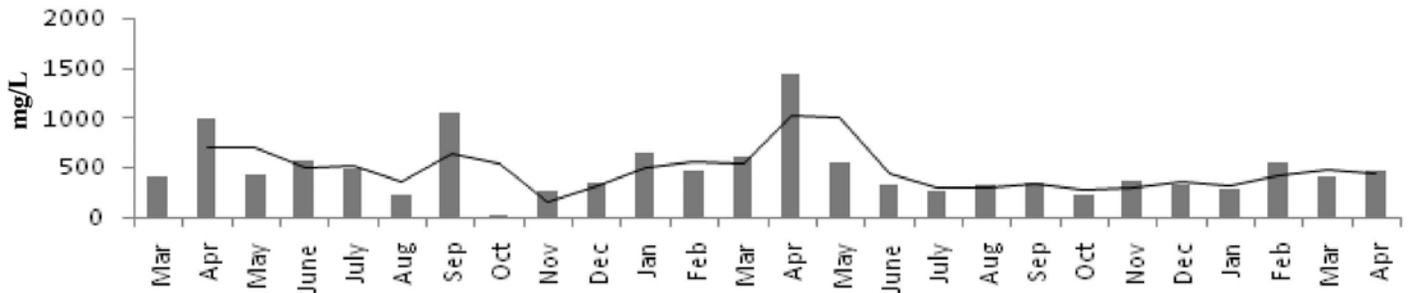


Fig 16: Monthly variations (March 2005-April2007) in COD levels (mg/L) at the sewage outfall

### Surface Samples: Chemical Oxygen Demand

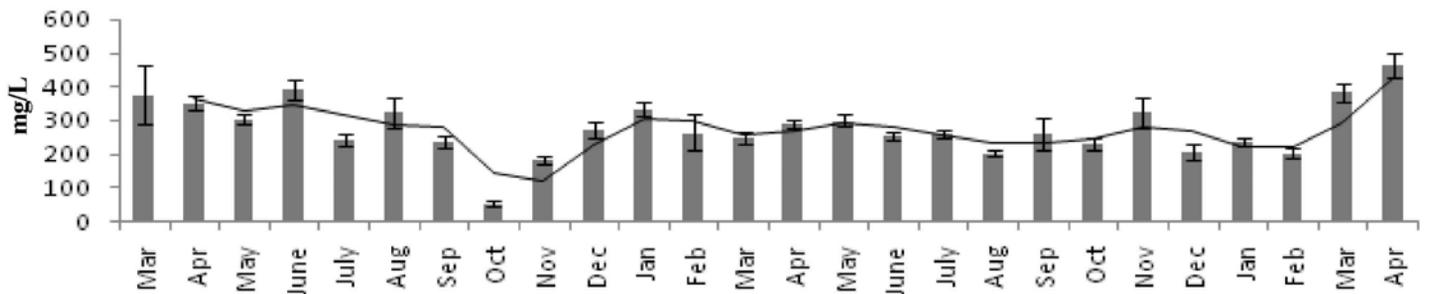


Fig 17: Monthly variations (March 2005-April2007) in COD levels (mg/L) in the surface water of lake (Mean ± SEM of S2-S10)

### Sub-surface Samples: Chemical Oxygen Demand

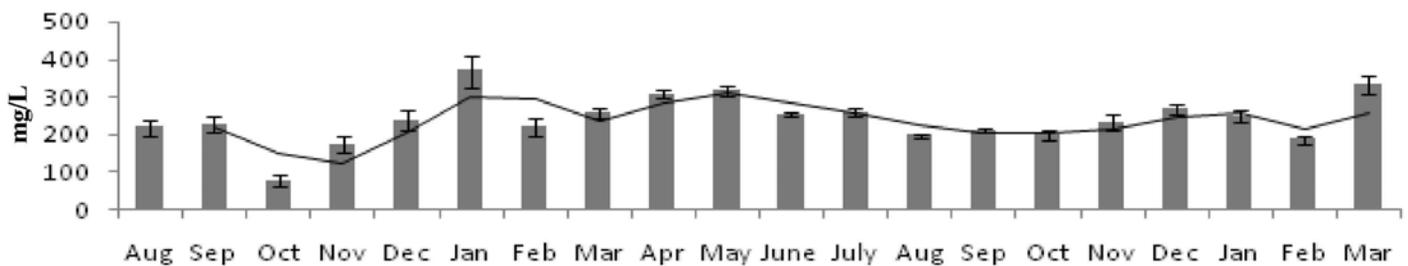


Fig 18: Monthly variations (March 2005-April2007) in COD levels (mg/L) in the sub-surface samples of lake water (Mean ± SEM of S2-S10)

and sub-surface waters of the lake. The exceptionally higher COD value in April 2006 at the outfall was due to greater algal biomass in the water sample.

In the year 2008, maximum COD values were observed in the summer season (138.1-370.3 mg/L), as observed in 2007, and minimum in the winter season (102.3-145.02 mg/L).

### Biological Oxygen Demand (BOD)

#### March 2005 - February 2006

BOD concentrations at the outfall (S1) were higher during summer (202-350mg/L) in comparison to rainy, post-rainy (16-208mg/L) and winter season (132- 205mg/L, Fig. 19). Exceptionally low value in October (16mg/L) was due to dilution by storm water runoff following excessive rains in the catchment. BOD concentrations in the lake water (S2-

S10) were also higher during summer (167-240mg/L) and low (19-149mg/L) in the rainy and post season (Fig. 20). It increased again in winter (81-200mg/L).

BOD values (August – Feb 2006) of sub surface samples (28-200mg/L) were similar to surface samples (Fig. 21).

**March 2006 – April 2007**

BOD concentrations (157 – 589mg/L) at the outfall were higher in comparison to surface (89 - 217mg/L) and sub-surface (92 – 266mg/L) water of the lake (Fig. 19, 20, 21). No definite seasonal pattern was found in BOD values during the study period.

**Outfall: Biological Oxygen Demand**

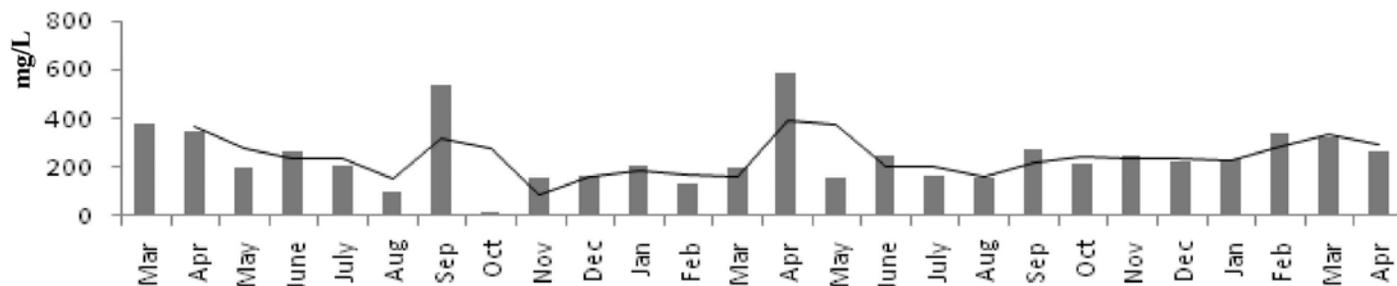


Fig 19: Monthly variations (March 2005-April2007) in BOD levels (mg/L) at the sewage outfall

**Surface Samples: Biological Oxygen Demand**

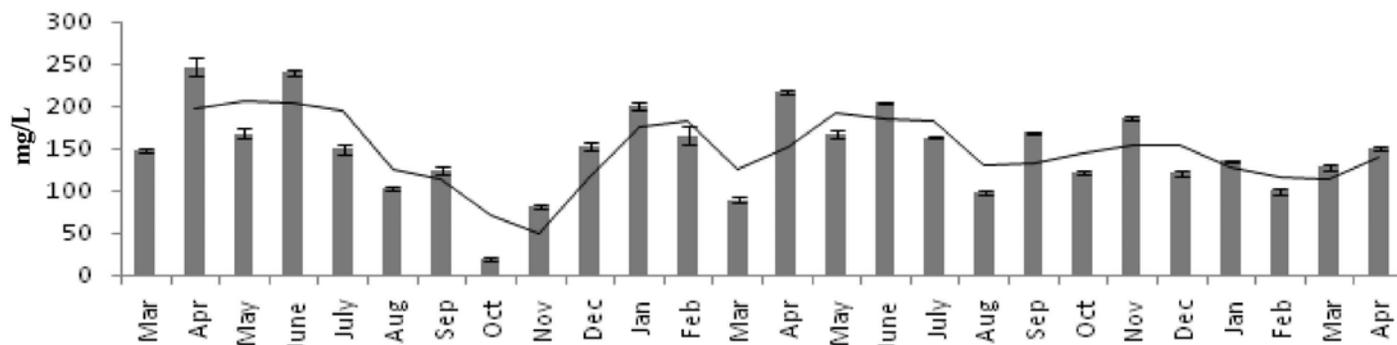


Fig 20: Monthly variations (March 2005-April2007) in BOD levels (mg/L) in the surface water of lake (Mean ± SEM of S2-S10)

**Sub-surface Samples: Biological Oxygen Demand**

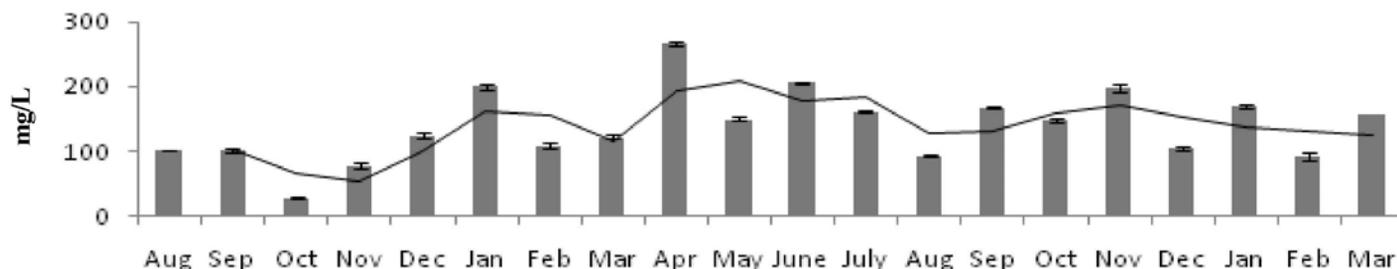


Fig 21: Monthly variations (March 2005-April 2007) in BOD levels (mg/L) in the sub-surface samples of lake water (Mean ± SEM of S2-S10)

## Outfall: Ammonia

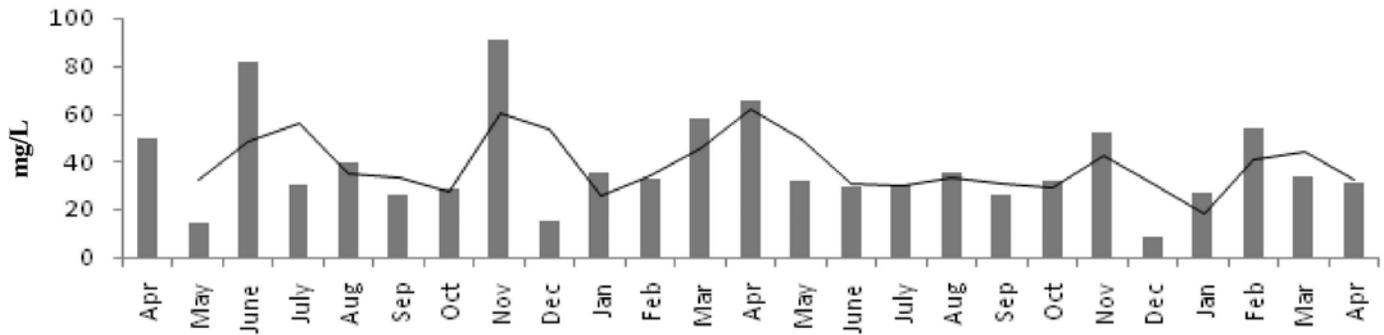


Fig 22: Monthly variations (March 2005-April2007) in free ammonia levels (mg/L) at the sewage outfall

## Surface Samples: Ammonia

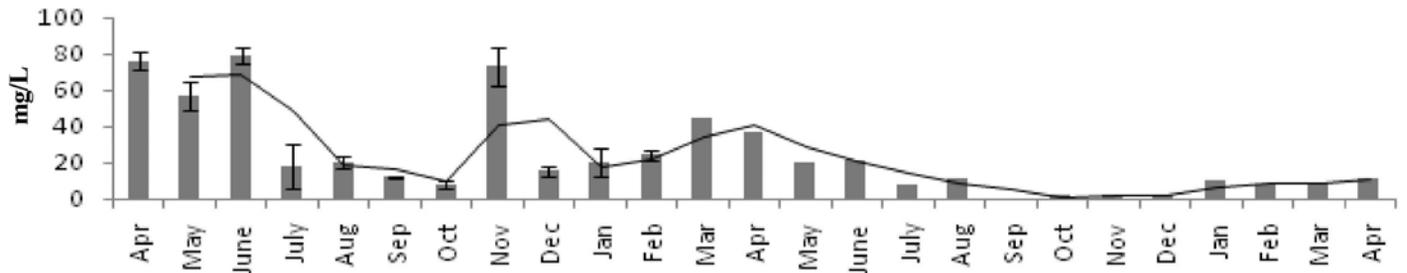


Fig 23: Monthly variations (March 2005-April2007) in free ammonia levels (mg/L) in the surface water of lake (Mean  $\pm$  SEM of S2-S10)

### Ammonia

#### March 2005 - February 2006

NH<sub>3</sub> concentrations at the outfall (S1) fluctuated (15-91 mg/L) during the study period showing no definite seasonal trend (Fig. 22). Its concentrations in the lake water (S2-S10) were high in summer (57-79 mg/L), low in the rainy season (7.8-20 mg/L) and were again high in winter (15-73 mg/L, Fig. 23). In comparison to outfall (site 1), NH<sub>3</sub> concentrations were low (25-50%) in the lake water.

#### March 2006 – April 2007

Ammonia concentrations were high at the outfall (27 - 66 mg/L) with the exception of December 06 (8.4 mg/L, Fig. 22). Ammonia levels fluctuated markedly in the lake water (Fig. 23). These were high (37 – 45 mg/L) in March & April 06, and decreased after wards up to December 07 (1.7-20.7 mg/L). Thereafter, it increased again (7.8-10.6 mg/L) between January -April.

### Oxidisable Nitrogen Forms (NO<sub>x</sub>)

#### March 2005 - February 2006

NO<sub>x</sub> levels were low (<5 mg/l) at both outfall and in the lake

water during the study period (nil in June), except for the month of October (22 mg/L) in the lake water and November (25 mg/L) at the outfall (Fig. 24, 25). It is likely that oxidized nitrogen formed during biological oxidation of NH<sub>3</sub> was possibly used up by phytoplankton in the lake.

#### March 2006 – April 2007

NO<sub>x</sub> concentrations were low (1.4 – 6.4 mg/L) at the outfall (S1) and lake water (1.7-9.5 mg/L, Fig. 24, 25). No distinct seasonal variation was found in NO<sub>x</sub> concentrations, though values were little higher during the rainy season.

### Total Kjeldahl Nitrogen (TKN)

#### March 2005 - February 2006

TKN concentrations at the outfall were found high in summer (55-145 mg/L), low in the rainy season (51-66 mg/L) and again high in winter (47-121 mg/L, Fig. 26). In comparison to outfall, TKN values in the lake water (S2-S10) were low (27-115 mg/L, Fig. 27). TKN values in sub-surface water (24-74 mg/L) were lower (17-44%) than surface water (Fig. 28).

### Outfall: NOx

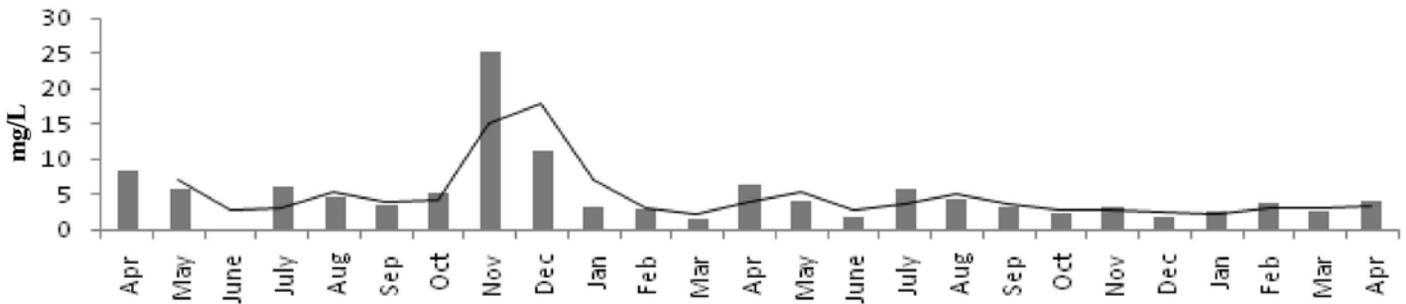


Fig 24: Monthly variations (March 2005-April2007) in NOx levels (mg/L) at the sewage outfall

### Surface Samples: NOx

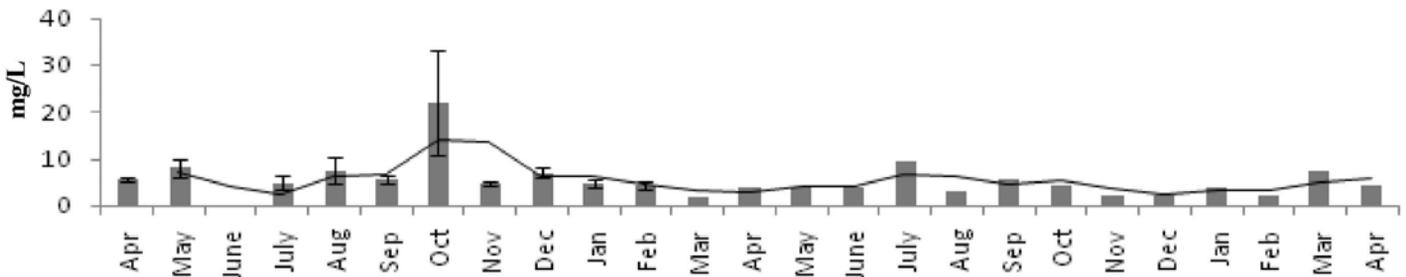


Fig 25: Monthly variations (March 2005-April2007) in NOx levels (mg/L) in the surface water of lake (Mean ± SEM of S2-S10)

#### March 2006 – April 2007

TKN values were higher at the outfall (36 – 76mg/L) in comparison to surface (18 – 71mg/L) and sub-surface (18 – 65mg/L) water of the lake (Fig. 26, 27, 28). An exceptionally higher value (600mg/L) at the outfall was observed due to contamination of sample with the algal bloom. TKN values at the outfall generally decreased after

summer season and thereafter, varied little. Both surface and sub-surface samples also had higher values of TKN during summer and rainy season that decreased sharply in the post-rainy and winter season.

In the year 2008, TKN values were high in the summer (20.9-50.8 mg/L) and low in the winter season (17.9-26.9 mg/L).

### Outfall: TKN

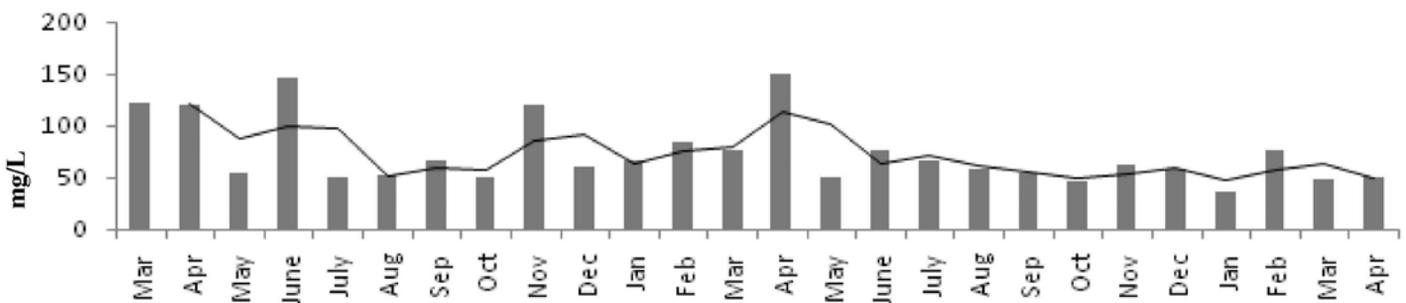


Fig 26: Monthly variations (March 2005-April2007) in TKN levels (mg/L) at the sewage outfall

### Surface Samples: TKN

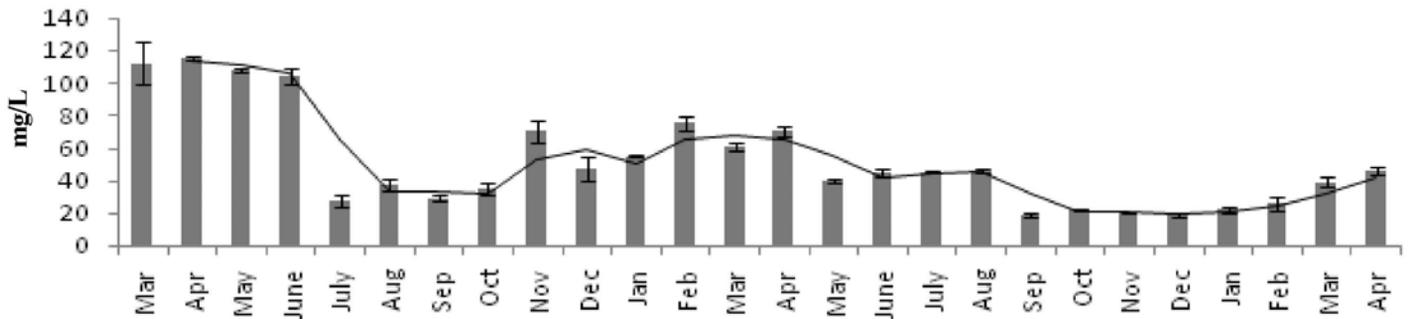


Fig 27: Monthly variations (March 2005-April2007) in TKN levels (mg/L) in the surface water of lake (Mean ± SEM of S2-S10)

### Sub-surface Samples: TKN

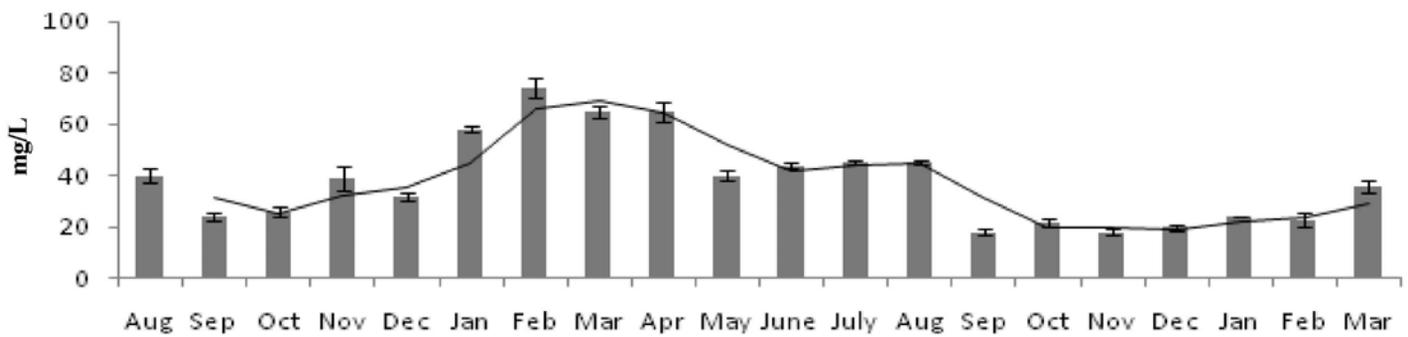


Fig 28: Monthly variations (March 2005-April2007) in TKN levels (mg/L) in the sub-surface samples of lake water (Mean ± SEM of S2-S10)

### Inorganic phosphorus (IP)

#### March 2005 - February 2006

Inorganic phosphorus concentrations fluctuated markedly (0.16-9.9mg/L) during the study period (Fig. 29, 30). These

were higher (30-170%) in the lake water (S2-S10) during rainy season but at the outfall (S1) in the summer and winter seasons (20-90%).

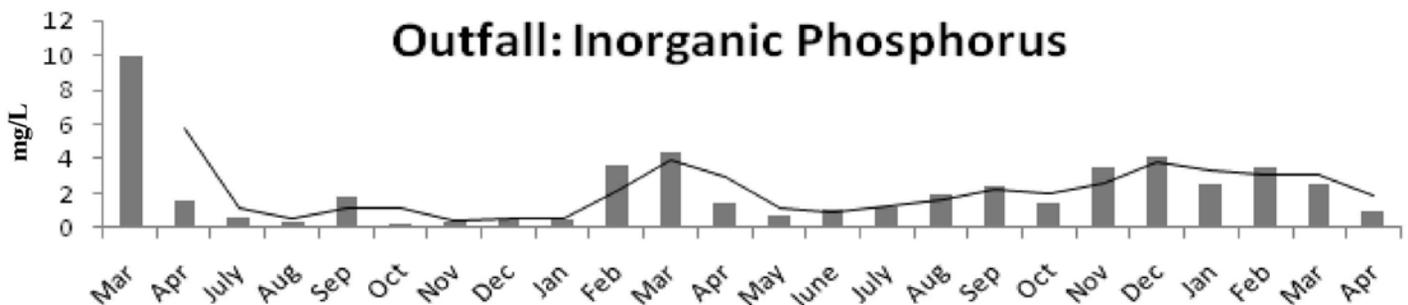


Fig 29: Monthly variations (March 2005-April2007) in IP levels (mg/L) at the sewage outfall

### Surface Samples: Inorganic Phosphorus

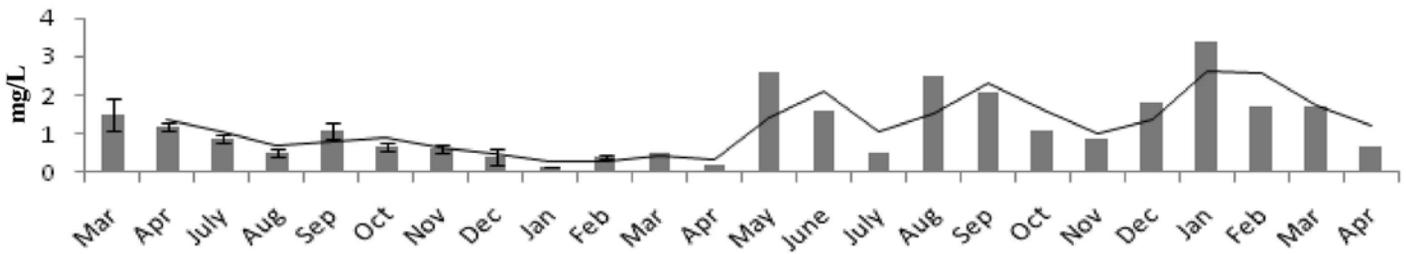


Fig 30: Monthly variations (March 2005-April2007) in IP levels (mg/L) in the surface water of lake (Mean ± SEM of S2-S10)

#### March 2006 – April 2007

In comparison to lake water (0.23-2.59mg/L), IP levels were 3-8 folds higher at the outfall (1.14-4.34mg/L), with the exception of rainy season when values were almost similar to lake water (Fig. 29,30).

In the year 2008, maximum IP concentrations (2.14-2.97 mg/L) were recorded in the winter and minimum in the rainy season (1.47-1.49 mg/L).

#### Total phosphorus (TP)

##### March 2005 - February 2006

TP concentrations were higher in the lake water (10.1-13.8mg/L) in March. These decreased rapidly in summer (5.7-6.9mg/L) and rainy season (0.45-5.12mg/L) but

increased again in winter (3.7-6.7mg/L) (Fig.31, 32). In comparison to outfall (S1), TP concentrations were lower (4-44%) in the surface water of lake (S2-S10) in the summer and winter season, but higher during rainy season. TP concentrations in sub-surface water were almost similar to surface water (Fig. 33).

##### March 2006 – April 2007

Total phosphorus concentrations were higher at the outfall (3.5–9.3mg/L) in comparison to the lake water (2.5-7.4mg/L) (Fig. 31, 32). An exceptionally higher value (40.2mg/L) at the outfall in April 06 was due to presence of suspended sludge mixed with algal bloom. TP concentrations in surface (2.5 – 7.4mg/L) and sub-surface (3.1 – 7.5mg/L) water were

### Outfall: Total Phosphorus

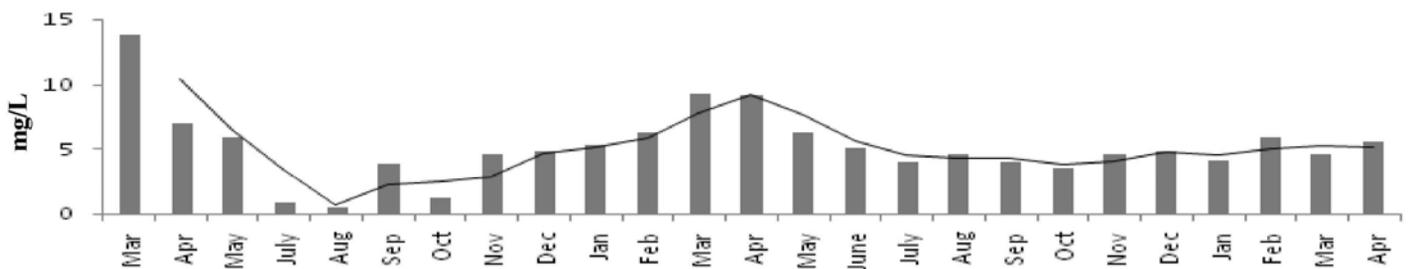


Fig 31: Monthly variations (March 2005-April2007) in TP levels (mg/L) at the sewage outfall

### Surface Samples: Total Phosphorus

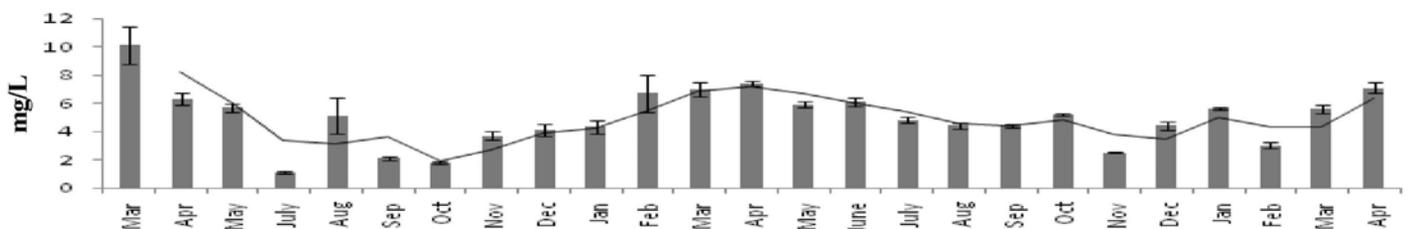


Fig 32: Monthly variations (March 2005-April2007) in TP levels (mg/L) in the surface water of lake (Mean ± SEM of S2-S10)

### Sub-surface Samples: Total Phosphorus

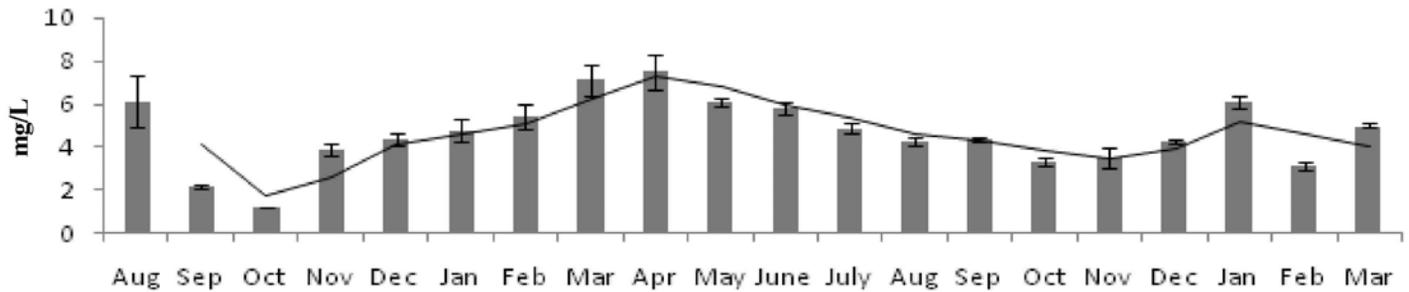


Fig 33: Monthly variations (March 2005-April2007) in TP levels (mg/L) in the sub-surface samples of lake water (Mean ± SEM of S2-S10)

almost similar throughout the study period (Fig. 32, 33). Their higher values were observed in the summer months (5.8-7.5mg/L) in both surface and sub-surface water of the lake which decreased until November (2.5-3.5mg/L), and then increased again.

In the year 2008, TP values were high in the winter season (4.12-4.88 mg/l) and low in the summer season (2.43-3.43 mg/L).

### Sulphate

#### August 2005 - February 2006

Sulphate concentrations in water samples were usually lower in the rainy season (80-137mg/L) in comparison to post-rainy and winter seasons (144-1660mg/L) (Fig. 34,35). This has been attributed to discharge of textile dye wastewater after rainy season. Its values were higher at S5 receiving inflow of textile dye wastewater in the lake.

### Outfall: Sulphate

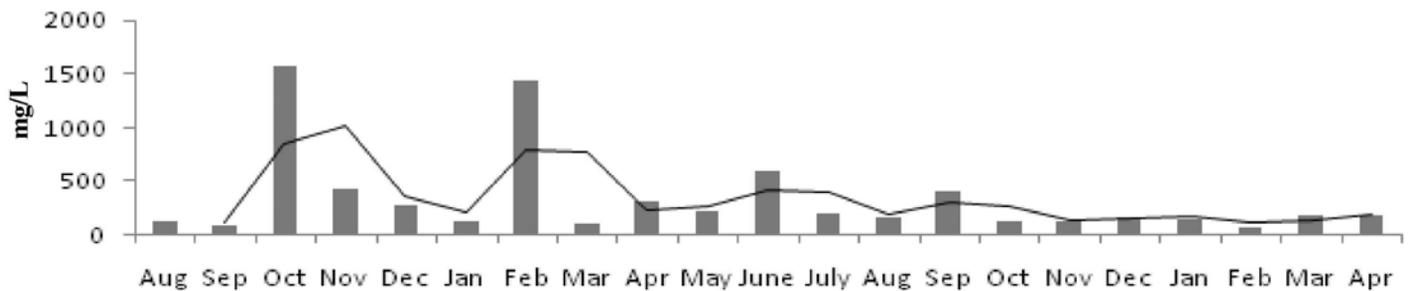


Fig 34: Monthly variations (March 2005-April2007) in sulphate levels (mg/L) at the sewage outfall

### Surface Samples: Sulphate

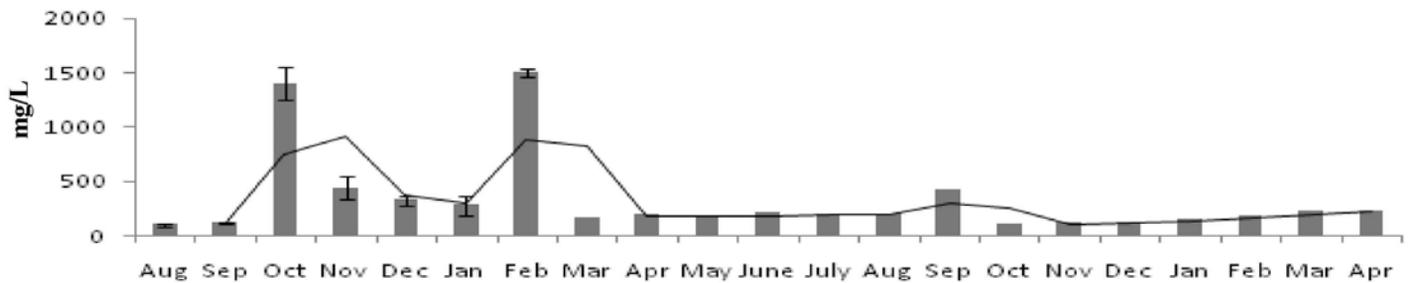


Fig 35: Monthly variations (March 2005-April2007) in sulphate levels (mg/L) in the surface water of lake (Mean ± SEM of S2-S10)

### March 2006 – April 2007

Sulphate concentrations were higher than lake water (100-422mg/L) at the outfall (115-595mg/L) (Fig. 34, 35). An exceptionally very high value (1036mg/L) was noted in a small pool formed during lake silting in summer 2006. It was filled in with sub-surface water released from lake bed during desilting. The sulphate content of lake water also rose following rains. It is likely that metal sulphides present in the lake sediment were oxidized following exposure of loose sediment to atmospheric air, which dissolved readily after onset of rains.

### Hydrogen sulphide

Hydrogen sulphide values were low in the morning (nil-2.02mg/L) and high in the noon (5.4-12.9mg/L) in the lake in July 2005.

### March 2006 – April 2007

Hydrogen sulphide concentrations varied at the outfall (< 1.0 – 14.6mg/L) and were maximum in March and April, 2006 (Fig. 36). Hydrogen sulphide was either absent or present in low quantity (0.6 – 2.6mg/L) in the lake water (Fig. 37) but unusually high value similar to outfall site was noted (9.3mg/L) in November 2006.

### Sodium

#### March 2005 - February 2006

Sodium concentrations found high during summer season (438-525mg/L) decreased in the rainy season (230-303mg/L). It increased again in winter (280-332mg/L). In comparison to outfall (320-525mg/L), sodium concentrations were lower in the lake water (242-438mg/L) during summer but this trend reversed in the rainy and winter season (Outfall = 230-305mg/L; Lake water = 295-332mg/L).

#### March 2006 – April 2007

Sodium concentrations at the outfall (210 – 402mg/L) were usually higher than lake water (255 -370mg/L). No definite seasonal trend was noticed in Na content at outfall. Its values differing little (255-285mg/L) in the composite samples of lake water between March – September 2006 increased (305-370mg/L) in winter and was maximum in April 2007 (535mg/L).

In the year 2008, maximum sodium values were observed in summer (412.5-622 mg/L) and minimum in the rainy season (245-270 mg/L).

### Outfall: H<sub>2</sub>S

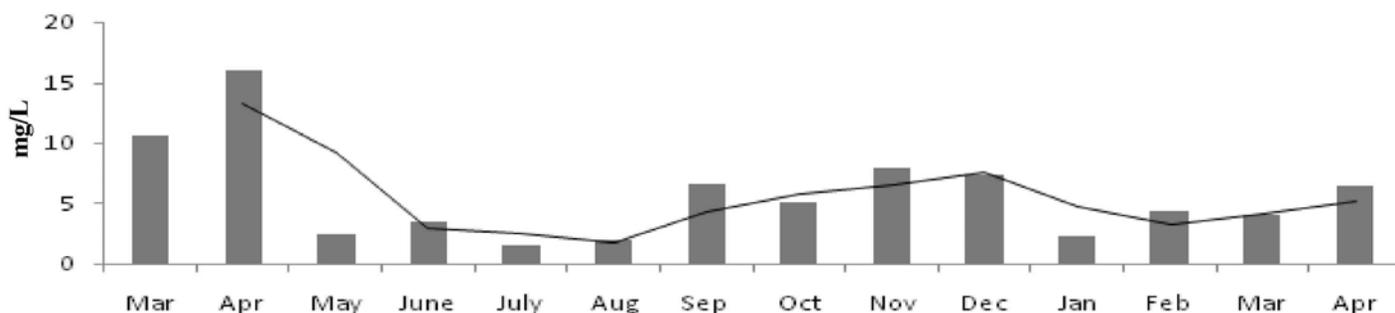


Fig 36: Monthly variations (March 2005-April2007) in dissolved hydrogen sulphide levels (mg/L) at the sewage outfall

### Surface Samples: H<sub>2</sub>S

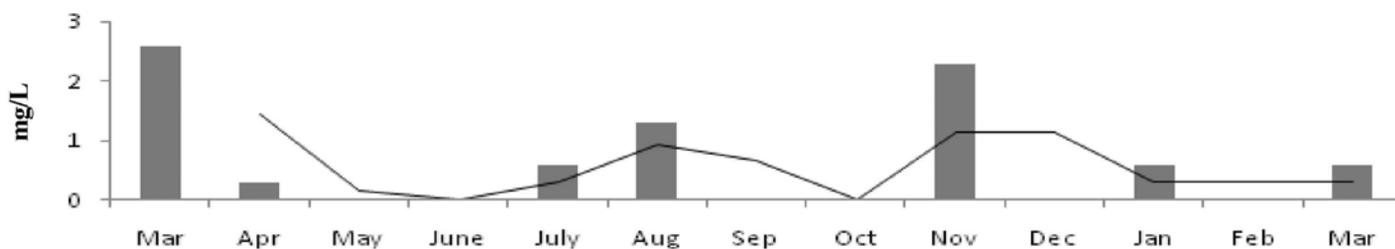


Fig 37: Monthly variations (March 2005-April2007) in dissolved hydrogen sulphide levels (mg/L) in the surface water of lake (Mean ± SEM of S2-S10)

## Potassium

### March 2005 - February 2006

Potassium concentrations at the outfall (S1) were higher (43-61mg/L) in warmer months (April-October) in comparison to winter (32mg/L), except for September (30mg/L) and March (141mg/L). Its values in lake water differed little (31-36mg/L) during the study period, except for April, May and August (48-53mg/L).

### March 2006 – April 2007

Potassium concentrations in the composite lake water samples (32 – 53mg/L) were little higher than the outfall samples (24–43mg/L) during the study period, except April 07 (68mg/L). There was no marked seasonal variation in potassium content, except for a little reduction in values during rainy season in both outfall (30-41mg/L) and lake water (32-42mg/L).

In the year 2008, maximum potassium content was observed in the summer (40-46 mg/L).

## Calcium

### March 2005 - February 2006

Calcium concentrations at the outfall (S1) were high in the summer (77-100mg/L) and low in the rainy season (41-71 mg/L). It increased again in the winter season (65-90mg/L). Calcium values in the lake water (60-82mg/L) had no definite seasonal pattern.

### March 2006 – April 2007

Calcium concentrations in the composite lake samples (27 - 210mg/L) were almost similar to outfall (29–200mg/L) during study period. Between April – August, these were low at the outfall (29 -71mg/L) and lake water (27 – 89mg/L).

In the year 2008, calcium concentrations were high in the rainy season (87-93 mg/L) and low in the winter (70-76 mg/L).

## Physico-chemical Characteristics of Sediment

The lake bed pH was close to neutral (pH=7.2-7.3). The values of EC (1.4-2.7  $\mu$ S/cm) and chloride (9.2-57 mg/100ml) contents fluctuated at different sites. Large variations were also observed in values of organic matter (0.74-2.34%), TKN (94.5-214.0 mg/100 g), IP (12.89-20.04 mg/100 g), TP (205.1-382.8 mg/100 g), Na (115-255 mg/100 g), K (335-415 mg/100 g) and Ca (1480-2780 mg/100 g) contents of the sediment.

## Microbial Flora: Fungi

Using various baits (boiled grains of maize, beans, wheat straw, blotting paper, hair, dead insects and decomposing plant litter), 15 fungal species were isolated in the lake water on PDA (potato, dextrose-agar medium) and Rose Bengal Agar media. These were: *Alternaria sp.*, *Aspergillus terreus*, *Aspergillus flavus*, *Aspergillus fumigatus*, *Aspergillus niger*, *Aspergillus ochraceus*, *Cladosporium cladosporioides*, *Cladosporium sphaerospermum*, *Fusarium oxysporum*, *Mucor sp.*, *Monilia sp.*, *Penicillium chrysogenum*, *Rhizopus nigricans*, *Trichoderma harzianum*, *Trichoderma viridae* and *Verticillium alboatrum*.

## BACTERIA

Standard Plate Counts (April 05) were very high ranging between  $1 \times 10^4$ -  $21 \times 10^{28}$ . Both gram positive and gram negative *Bacilli* were the dominant forms. Most Probable Number (MPN) of coliform bacteria was >2400 even in diluted water samples ( $10^{-3}$ ). IMViC test performed at two occasions confirmed the presence of *Escherichia coli*, *Enterobacter aerogens* and *Klebsiella* in the lake water.

## PRIMARY PRODUCERS

Algae were the chief primary producer in the lake whereas isolated patches of a free floating macrophyte *Spirodela polyrhiza* were observed on the North-West bank of the lake during the rainy season. Emergent macrophytes growing in the shallow northern region of the lake were *Cyperus alopecuroides* and *Paspalum* species.

In the year 2006-08, other emergent macrophytes *Arundo donax*, *Typha angustata*, *Phragmites karka* and *Ipomoea aquatica* were introduced in the littoral region of the lake while *Lemna aequinoctialis* (free floating) and *Ceratophyllum demersum* (submerged) in the check dam.

Nineteen algal species belonging to chlorophyceae (53%; 10 species), cyanophyceae (26%; 5 species) and bacillariophyceae (21%; 4 species) were recorded in the composite sample collected during the study period. The overall species richness fluctuated markedly (7-15 species) in the year 2006 and 2007 but it varied little in the year 2008 (13-15 species). It also varied seasonally attaining maximum richness in the rainy season in 2006, post-rainy in 2007 and winter in 2008.

The seasonal dynamics of the phytoplankton counts was characterized by a unimodal curve with a summer maximum

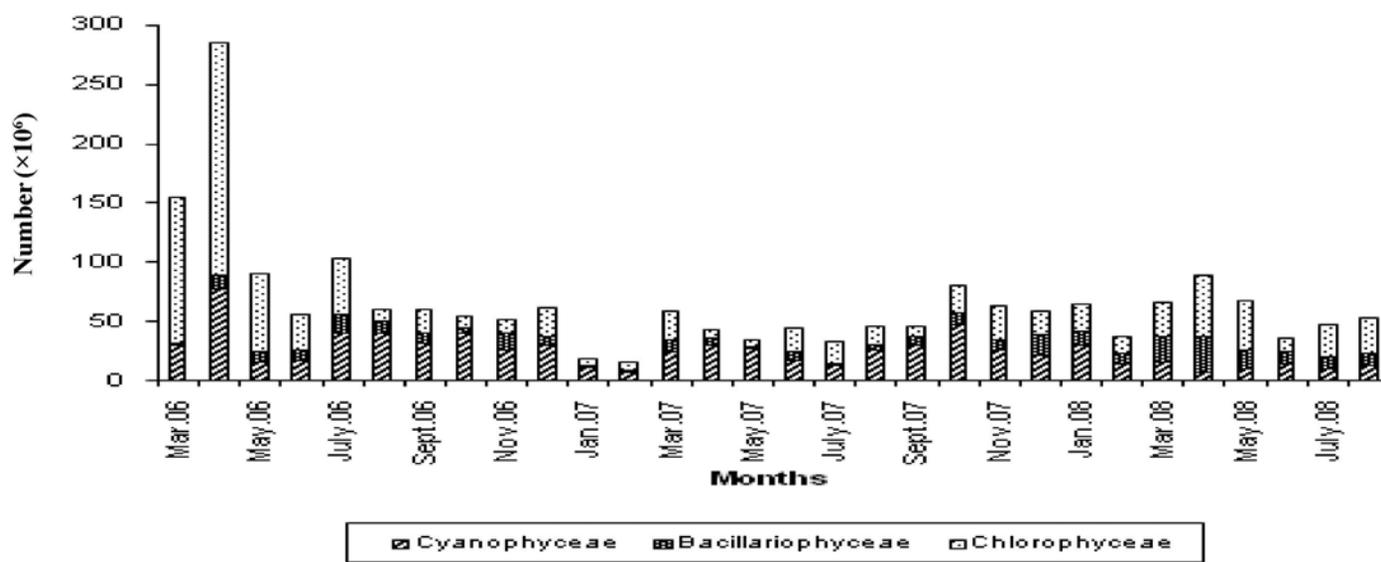


Fig. 38: Monthly variations of phytoplankton counts during the year 2006-2008

in the year 2006 and 2008 but in the early winter in 2007 (Fig. 38). Phytoplankton counts were higher in the year 2006 ( $5.2-28.5 \times 10^7$ ) in comparison to 2007 ( $1.6-8.0 \times 10^7$ ) and 2008 ( $3.5-8.6 \times 10^7$ ).

The counts of cyanophycean taxa found higher in 2006 ( $1.56 - 7.74 \times 10^7$ ) decreased in 2007 ( $6.37 \times 10^6 - 4.76 \times 10^7$ ) and 2008 ( $7.5 \times 10^6 - 3.0 \times 10^7$ ). These were higher during warmer period of the year (April-October). The percentage contribution of cyanophycean taxa to the total algal counts was found higher in 2006 (17.4-75%) and 2007 (37 - 78%) decreased significantly in 2008 (8.4-47%). *Merismopedia* and *Microcystis* were the dominant taxa in 2006, *Spirulina* and *Merismopedia* in 2007 while *Aphanocapsa* and *Spirulina* in 2008.

Total counts of members of Bacillariophyceae were higher in 2008 ( $8.75 \times 10^6 - 3.0 \times 10^7$ ) in comparison to 2006 ( $1.87 \times 10^6 - 1.62 \times 10^7$ ) and 2007 ( $6.25 \times 10^5 - 1.68 \times 10^7$ ). Marked seasonal variations were noted in the population size, being often lower in the winter season of the year 2006 and 2007 but often higher in the year 2008. Thus counts of Bacillariophyceae increased after sewage diversion.

The percentage contribution of members of bacillariophyceae to the algal pool increased with time (2006 = 14.4 - 15.8%, 2007 = 15.8-28.7%, 2008 = 18 - 34%). *Cyclotella* was the only dominant species in the year 2006, while *Cyclotella* and *Navicula* dominated in 2007 and 2008.

Total counts of members of chlorophyceae were maximum ( $9.8 \times 10^6 - 19.7 \times 10^7$ ) in the year 2006, minimum ( $5.0 \times 10^6$

$- 2.8 \times 10^7$ ) in 2007 and moderate ( $1.18 - 5.18 \times 10^7$ ) in the year 2008. The population attained peak in the mild winter in the year 2006 and 2008 but a little earlier in the post-rainy season in the year 2007. The percentage contribution to the total algal pool (2006 = 17.8- 79.3%, 2007 = 14-54%, 2008 = 61%) varied seasonally, and decreased in 2007 and 2008 in comparison to 2006.

*Ankistrodesmus*, *Chlorella*, *Chlorococcum*, *Scenedesmus*, *Coelastrum* and *Oocystis* were the dominant taxa in 2006 whereas *Oocystis*, *Biddulphia*, *Chlorococcum*, *Coelastrum* in 2007, and *Ankistrodesmus*, *Chlorella*, *Oocystis* and *Pediastrum* in 2008.

### BOYD INDEX

Boyd Index attained peak in the rainy season (1.27) in the year 2006, but in winter in 2007 (1.27) and 2008 (1.26). Monthly variations in the index values were higher in 2006 and 2007 in comparison to 2008 (Fig.39).

### Shannon Weaver's Index

Two distinct peaks were observed in the year 2006 (Rainy season = 2.54, winter = 2.40), one in 2007 (winter = 2.51) and again two in 2008 (winter = 2.46, summer = 2.41, Fig. 40).

### Palmer Index

Two identical peaks of Palmer index (29) were observed in the summer and rainy season of the year 2006 and also in 2007 (winter = 30, Rainy season = 27). In the year 2008,

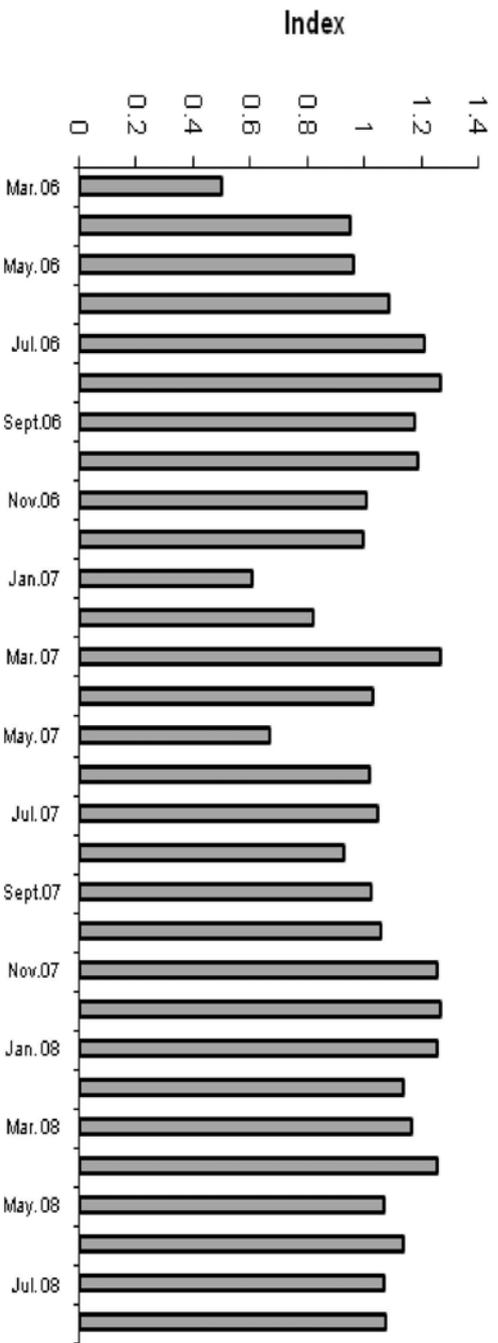


Fig. 39 : Monthly variations of Boyd Index during 2006-08

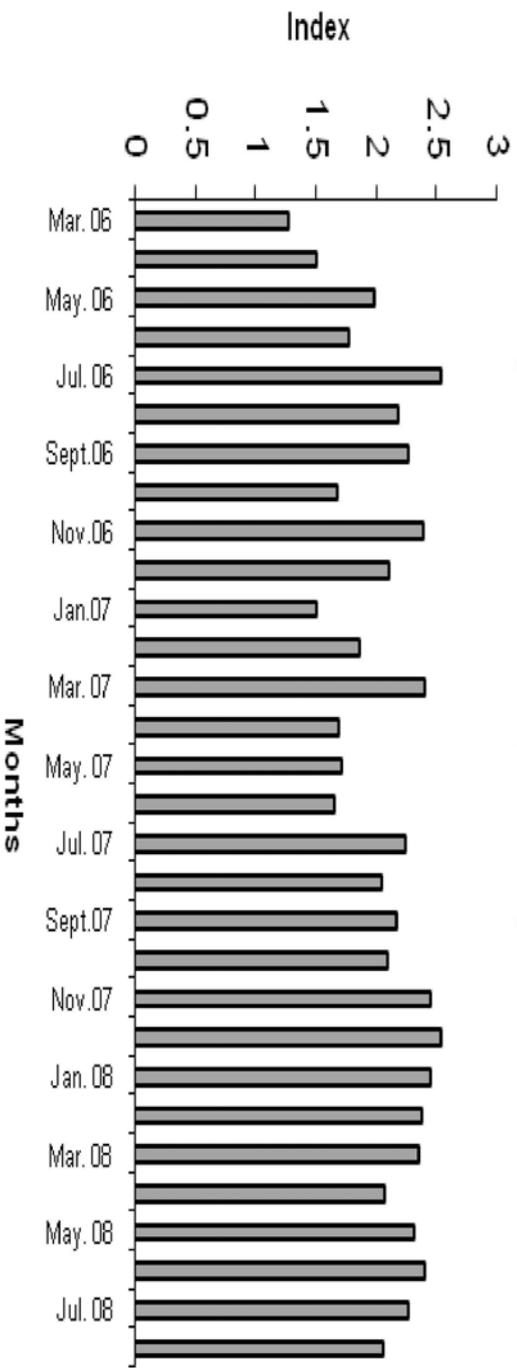


Fig. 40 : Monthly variations of Shannon Weaver's Index during 2006-08

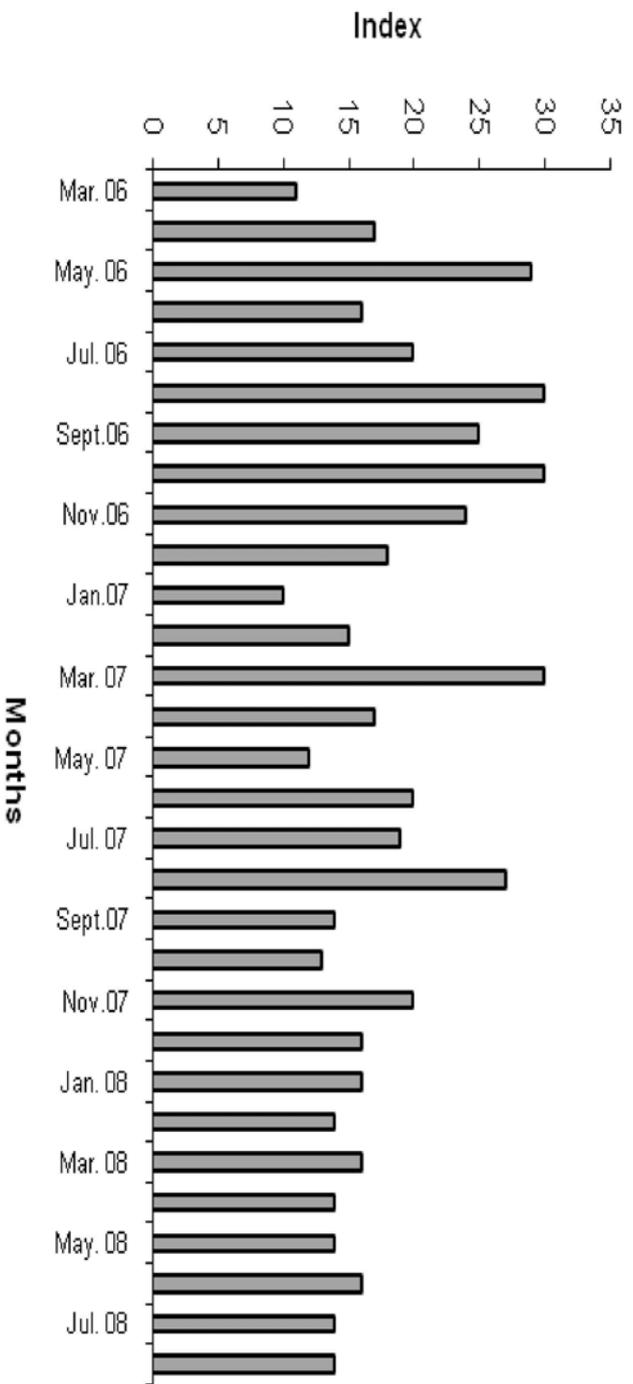


Fig. 41 : Monthly variations of Palmer Index during 2006-08

the values of Palmer Index differed a little throughout the winter, summer and rainy seasons (Fig. 41).

### TOTAL CHLOROPHYLL

Total chlorophyll content was found higher in 2007 (88-585  $\mu\text{g/L}$ ) in comparison to 2006 (59-392  $\mu\text{g/L}$ ) and 2008 (35-164  $\mu\text{g/L}$ ). Peak values were observed in mild winter in the year 2006 and 2007 but in summer in 2008.

Chlorophyll-a content followed trend similar to total chlorophyll (year 2006 = 40-246  $\text{mg/m}^3$ , 2007 = 54 - 428  $\text{mg/m}^3$ , 2008 = 22 - 110  $\text{mg/m}^3$ , Fig. 42). During the present study, the maximum annual average concentration (182  $\text{mg/m}^3$ ) of chlorophyll-a was recorded in the year 2007, moderate (142  $\text{mg/m}^3$ ) in 2006 and minimum (69  $\text{mg/m}^3$ ) in 2008.

### Algal Biomass

Algal biomass followed trend similar to chlorophyll-a (2006

= 2680-16500  $\text{mg/m}^3$ , 2007 = 3640 - 28680  $\text{mg/m}^3$ , 2008 = 1500-7357  $\text{mg/m}^3$ ) (Fig. 43). The maximum annual average algal biomass (12173.6  $\text{mg/m}^3$ ) was recorded in 2007, moderate (9524  $\text{mg/m}^3$ ) in 2006 and minimum (4597.8  $\text{mg/m}^3$ ) in 2008.

### ZOOPLANKTON

Five species of protozoan present in Mansagar lake were; two species each of *Euglena* (*E. acus* and *E. spirogyra*) and *Paramecium* (*Paramecium aurelia* Ehrenberg, *Paramecium caudatum* (Ehrenberg), and *Phacus pleuronectes* (Müller).

Arthropods were *Daphnia similis* (Claus), *Moina* sp., *Brachionus pallas* (Ehrenberg), species of *Corixa* (Water boatman), *Notonecta* (Back-swimmers), Naucoridae (Creeping water bugs), *Mesocyclops leuckarti* Claus) and *Chironomus* sp.

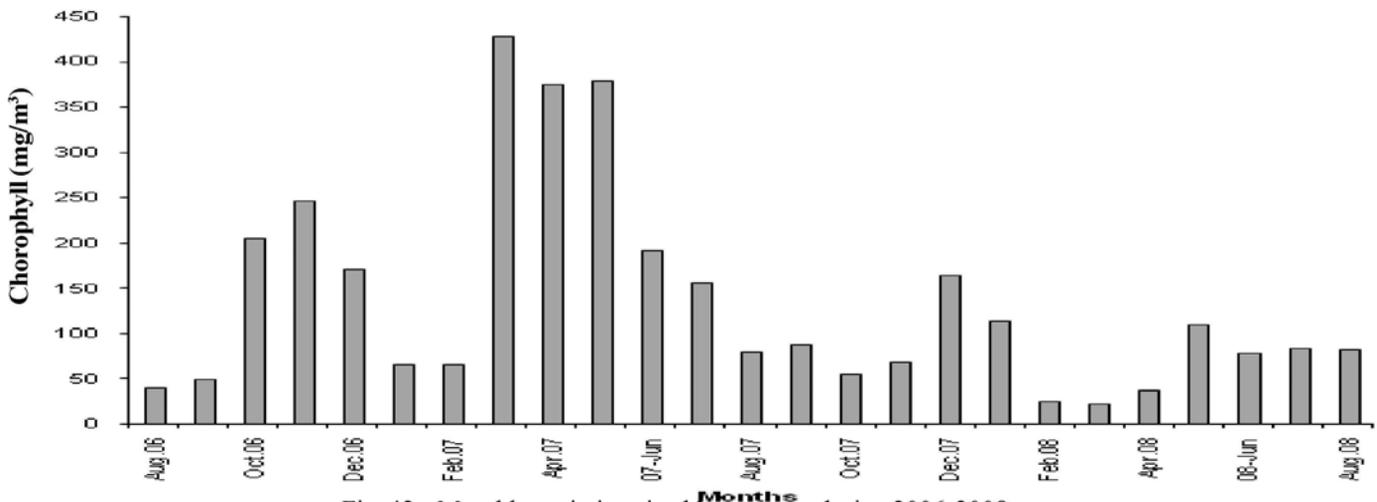


Fig. 42 : Monthly variations in chl. a content during 2006-2008

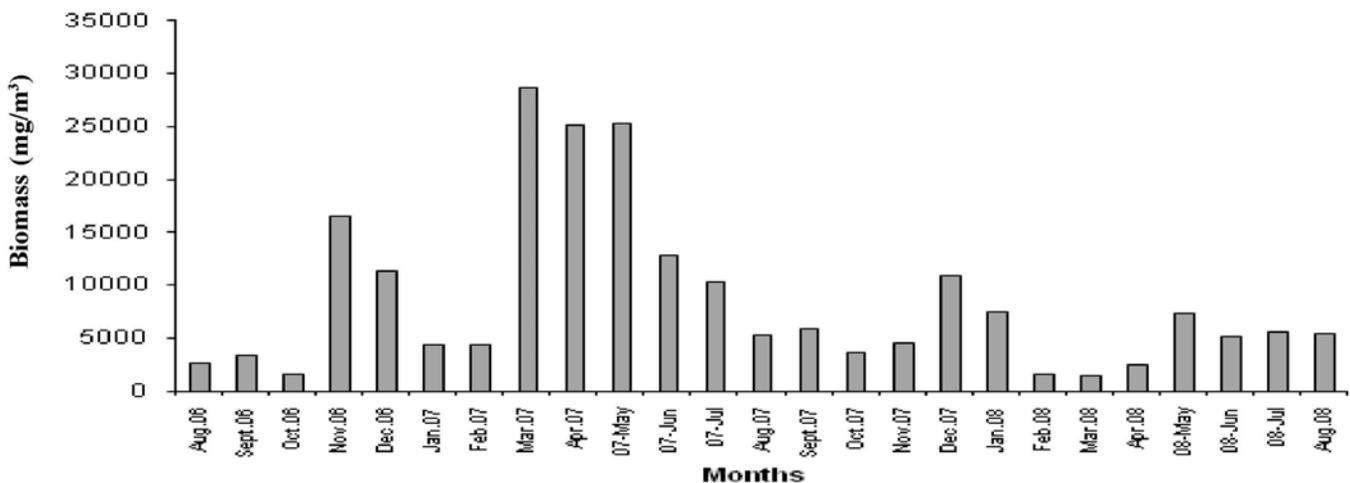


Fig. 43: Monthly variations in algal biomass during 2006-08

## POPULATION DYNAMICS: 1. Micro- Zooplankton

### *Phacus* sp.

*Phacus* population fluctuated greatly during the study period (2006 = 625-6875 x 10<sup>3</sup>/L, 2007 = 500-6875 x 10<sup>3</sup>/L and 2008 = 625-5625 x 10<sup>3</sup>/L). It contributed significantly to the zooplankton population ranging between 25-100% in the year 2006 and 2008, and 47-100% in 2007. No definite seasonal trend was observed.

### *Euglena acus* (Ehrenberg)

Its occurrence was quite irregular and population fluctuated between 625-3125 x 10<sup>3</sup>/L in 2006, 625-6250 x 10<sup>3</sup>/L in 2007, and 625-1250 x 10<sup>3</sup>/L in 2008. Its contribution to zooplankton population was low to moderate (9-52%) in the year 2006 and 2007. In the year 2008, it was observed only at one occasion (January) during the study period (up to August), contributing almost 10% to the zooplankton population.

### *Euglena spirogyra* (Ehrenberg)

It was observed only in the year 2006 (625-1875 x 10<sup>3</sup>/L) and 2007 (625-2500 x 10<sup>3</sup>/L) having large variation in density. It was found absent in 2008. Its percentage contribution to zooplankton population was poor to low (4.5-25%).

### *Paramecium* sp.

The individuals of two species of *Paramecium* were counted simultaneously as they were highly mobile in microscopic field. Their population fluctuated markedly ranging between 625-4375 x 10<sup>3</sup>/L in the year 2006 and 1875-2500 x 10<sup>3</sup>/L in 2008 while in the year 2007 they were observed only at one occasion (December) having a population of 1875 x 10<sup>3</sup>/L. Its percentage contribution to zooplankton population was low – medium in 2006 (23.5-33.3%) and 2007 (December = 20%) but high in 2008 (57-75%).

### *Brachionus* sp.

Its occurrence was highly irregular in the water samples, noted once in 2006 (August) and 2007 (December) but throughout the rainy season in 2008. The increase in period of occurrence including density in the lake coincided with beginning of lake bioremediation (After Sept. 2007), being poor prior to bioremediation (4.54 %) in the year 2006 and high during bioremediation (33.3–100.0 %) in 2008.

### Macro- Zooplankton

In the late winter of year 2007 (February and March), grab samplings of lake water were made using 10L sized bucket

tied with a rope. A known volume of water sample (4L) was filtered through bolting silk and the concentrate was made up to 250ml in volumetric jars. The density of macro-zooplankton (*Daphnia*, *Cyclopes* and *Chironomous* larvae) was counted immediately in the field.

*Daphnia* (19/L) and *Cyclopes* (4/L) density was significantly lower in February in comparison to March (*Daphnia* = 32/L, *Cyclopes* = 50/L) whereas an opposite trend was noted for *Chironomous* larvae (Feb. = 2/L; March = 0.4/L). *Daphnia* contributed maximum (75.1%) to macro-zooplankton population in the February while *Cyclopes* (61%) in the March.

### Nektons

Aquatic insects were also sampled similarly but in October 2006 and February 2007. Nektons were *Corixa* sp. (Water Boatman), *Notonecta* sp. (Back-swimmers) and Naucoridae (Creeping water bugs). Their populations were higher in October (27.7/10L) in comparison to February (2.3/10L). *Notonecta* (25/10L) was the most dominant insect in the lake.

*Corixa* is attracted to light and therefore highly active in air during night. During the rainy season millions of corixids were observed in Mansagar lake and Check dam. They provided excellent food to edible fishes.

### BENTHOS

The benthos had maximum population (417395 organisms / m<sup>2</sup>) in the summer season. Their number decreased markedly in the post-rainy (88.2%) and winter (93.1%) season. The site variations in population size were higher, especially during summer.

Crustacean contributed almost 50% to the total benthic population in summer which increased (60-70%) in the post rainy and winter season. The seasonal variation in crustacean population was higher (20227- 208213 Organisms/m<sup>2</sup>), being maximum in summer. Its population size however, differed little during post-rainy (29239 Organisms / m<sup>2</sup>) and winter (20227 Organisms / m<sup>2</sup>) seasons. The percentage of dead crustacean was almost similar ranging between 16-22% during the study period.

The resting stage of *Daphnia* and *Moina* commonly termed as *Ephippia* were the sole representative of cladocera in the sediment. Their contribution to the total benthic population found maximum in the summer (50%) decreased a little (40%) in the post –rainy season and was minimum in the winter season (26%) (Table 1). *Moina ephippia* contributed

Table 1. Seasonal variations in benthos population (m<sup>2</sup>) of Mansagar lake (2006-07)

Seasons	Crustacean		Total	Cladocera ( <i>Ehipia</i> )		Total	Anostraca <i>Chironomous</i>	Grand Total
	Live	Dead		<i>Daphnia</i>	<i>Moina</i>			
Summer 2006	138185 ± 34223 (12300-563000) (33.1%)	70028 ± 56818 (27900-189800) (16.77%)	208213	12566 ± 7391 (3720-21800) (3.01%)	196616 ± 175942 (13140-511800) (47.1%)	209182	Absent	417395
Post- rainy 2006	18249 ± 6078 (11009-27594) (37.15%)	10990 ± 3391 (6322-16023) (22.37%)	29239	5846 ± 4302 (1853-14454) (11.90%)	13791 ± 7038 (7412-29346) (28.07%)	19637	244 ± 112 (146-436) (0.49%)	49120
Winter 2007	15633 ± 6348 (7159-23477) (54.6%)	4594 ± 7083 (436-20000) (16.04%)	20227	2730 ± 1435 (611-52421) (9.53%)	4821 ± 4389 (1310-6527) (16.84%)	7551	848 ± 830 (131-2621) (2.96%)	28626

Data in parenthesis indicate % of total zooplankton population

maximum to the benthic population (16-47%) throughout the study period.

*Chironomous*, the sole representative of anastraca, was present both as plankton and benthos in the lake. It was found absent during summer, had a very thin population in the post-rainy season (244 Organisms / m<sup>2</sup>) that increased almost 3 folds in the winter (848 organisms / m<sup>2</sup>). Its percentage contribution to the total benthic population was however, meager (<1 -3%).

## DISCUSSION

Freshwater is an important renewable resource necessary for survival of most the terrestrial organisms. Only 2 % of the freshwater on the earth's surface is in a readily-usable form, with more than 90% of it is in lakes and reservoirs. The UN estimates that about 18 % of the world's population had poor access to safe drinking water. Therefore, the conservation of lakes and reservoirs for sustainable use, not only as a drinking water supply, but also for a variety of other uses, is an extremely important challenge facing humanity.

Eutrophication of inland water bodies is a worldwide problem because of ever increasing urbanization, industrialization and intensive agriculture. The eutrophication of urban water bodies is a serious problem in our country since their major source of water is untreated/ primary / secondary treated sewage, industrial wastewater and storm water runoff from urban areas and agricultural fields which render water unfit for domestic and industrial use.

Mansagar lake has been recipients of various kinds of pollutants and nutrients through sewage and industrial effluents, more particularly from textile industries for about 45 years (1962- 2006) which changed its water quality over a period of time.

The analysis of correlation between two water quality parameters revealed that certain water quality parameters had significant positive correlation among themselves; EC with Cl, TH, COD and K; Cl with TA; TH with COD, K and PA; COD with TKN, TP, K, Ca, EC, Cl, and TH; TKN with TP, COD; COD with TKN and Na; Na with TP; K with EC, Ca, Cl, TH, and Ca with Cl, TH, COD and K. A careful analysis of the correlation suggested that the most pertinent markers of sewage and industrial wastes contamination are also intimately related in the Mansagar lake.

The physico-chemical characteristics of water have been used in classification of the water bodies for their level of eutrophication. Moyle (1945), Sorenson (1948) and Philipose (1960) have used alkalinity as a criterion for lake classification while others have used the concentrations of N, P, Ca and other elements for the purpose (Strom 1930, Zafar 1959, Wetzel 1975). Uttomark and Peterwell (1975) have developed a Lake Condition Index (LCI) by using penalty points for characters like dissolved oxygen, transparency, fish kill, and recreational use impairment. Accordingly Mansagar lake comes under the category of highly eutrophic water body (Table 2).

The first scientific record for mass fish mortality in Mansagar lake dates back to year 1978 (Sharma et al. 1978). Since then, it has been a regular feature reported in local news papers. We personally observed mass mortality in 2005, 2008, 2009 and 2015. Higher concentrations of BOD kept low oxygen levels in the lake water (<4mg/L) (Fig. 3, 4, 20, 21). The oxygen stress increased further because of high free carbon di oxide in the sub-surface water (Wurt and Durborow 1992) (Fig. 7). The higher values of total alkalinity increased lake water pH to alkaline that possibly raised concentration of toxic form of ammonia in the water (Fig. 11, 23, Wurt and Durborow 1992). The oxygen stress in combination with high concentration toxic form of ammonia possibly formed dead zones in the lake, as evident by mass fish mortality (Arend et al. 2011).

Table 2. Classification of Mansagar lake, according to different systems

\* Lake condition Index is given in parentheses

Classification system	Mansagar lake
Naumann (1919) and Thienemann (1925)	Eutrophic
Strom (1930)	$\alpha$ -eutrophic
Moyle (1945)	Hard
Sorenson (1948)	-
Olsen (1950)	Mesotrophic
Zafar (1959)	$\alpha$ -eutrophic- $\gamma$ -sub-tropico-absolutae myxophyceae
Wetzel (1975)	Hyper-eutrophic
Uttormark & Prterwall (1975)	Very Eutrophic (20*)

Phytoplankton, an important primary producer, are the basis of the food chain in open water, though some species may be harmful to human and other invertebrates by releasing toxic substances (hepatotoxins or neurotoxins etc.) in to the water. Phytoplankton monitoring is therefore, useful in deciphering physico-chemical and biological conditions of a water body (Ariyadej et al. 2004).

Nineteen algal species belonging to Chlorophyceae (53%; 10 species), Cyanophyceae (26%; 5 species) and Bacillariophyceae (21%; 4 species) were recorded during the study period (March 2006- August 2008). The overall species richness fluctuated markedly (7-15 species) in the year 2006 and 2007 but it varied little in the year 2008 (13-15 species). It also varied seasonally attaining maximum

richness a little earlier in 2006 (rainy season) in comparison to 2007 and 2008 (post-rainy and winter season). Such variations in composition and assemblage of phytoplankton may be related to temporal changes in freshwater ecosystems (Cetin 2000, Calijuri et al. 2002, Chattopadhyay and Banerjee 2007). The diversion of wastewater drains and mechanical aeration of the lake since September 2007 led stability in species richness possibly on account of improvement in water quality. Nikulina (2003) also reported stabilization in plankton community in Neva estuary following improvement in water quality after implementation of mechanical aeration system.

The occurrence of certain pollution tolerant species such as *Microcystis*, *Oscillatoria*, *Chlorella*, *Scenedesmus*, *Ankistrodesmus*, *Fragilaria*, *Euglena* and *Phacus* clearly indicates a high level of organic pollution (Hutchinson 1967, Palmer 1969, Tiwari & Shukla 2007). Philipose (1960) opined that species of *Navicula*, *Oscillatoria* and some Volvocales and chlorococcales occur abundantly in sewage-fed waters. Practically all the algal species found in Mansagar lake are in the list of Shukla and Anjum (1991) identified for the presence of sewage discharge in the river.

The seasonal dynamics of the phytoplankton counts was characterized by a unimodal curve with a summer maximum in the year 2006 and 2008 but in the early winter in 2007 (Fig. 38).

The factors contributing population build up during summer were nutrient richness and favorable temperature for algal growth. The reduction in water depth to less than 0.5m in 2007 possibly led to higher diurnal variations in the warmer months unfavorable to algal growth. In contrast, shallow water depth in the early winter (November 07) possibly resulted in water temperature favorable to algal multiplication. Thus water temperature had a critical role in population build up; low being unfavorable (winter) while moderate (summer and post-rainy season) favored its build up.

Algal blooms were noted at two occasions in 2006, first in the beginning of summer (April) and the second in the post-rainy season (September- October) whereas only in the post-rainy season in 2007 and 2008. Interestingly, bloom formed in the post-rainy season appeared as a thick scum over the water surface. The member of chlorophyceae especially *Chlorella* contributed maximum to bloom formed in April 2006 whereas blooms formed in the post-rainy-season were primarily due to cyanophycean members, mainly by *Spirulina*

in 2006 and *Merismopedia* in 2007. The dominance of cyanophycean members in the bloom is because of their competitive abilities under high nutrient concentrations, low nitrogen-to-phosphorus ratios, low light levels, reduced mixing, and high temperatures (Downing et al. 2001, Paerl and Huisman 2009, Paerl and Paul 2012).

*Microcystis aeruginosa* produces secondary metabolites and endotoxins toxic to aquatic and terrestrial animals visiting water bodies for drinking. Senescence and lyses of blooms release toxins into the surrounding medium. Microcystins cause serious health and environmental problems (Sevilla et al. 2008). Cyanobacteria also synthesize several off-flavor compounds (e.g. methyl isoborneol and geosmin) which impart foul odor in the municipal drinking water systems and aquaculture-raised fishes. This causes large financial losses to both state and regional economies (Crews and Chappell 2007). The drinking of lake water did not cause death of cattles, wild life and waterfowls during the study period, though lake water smelled fishy.

In many temperate lakes, the maxima of phytoplankton abundance and blooms were detected in summer (Maeda et al. 1992), or in spring and summer (Talling and Parker 2002). Chattopadhyay and Banerjee (2007) however, reported three blooms in a year in the shallow Lake Krishnasayer and attributed them to relatively less long-term stability in the surface waters of shallow lakes in comparison to stratified deep lakes, with regard to species composition and seasonal cycles (Bailey –Watts 1982, Scheffer 1998). Mansagar lake also being a shallow lake had more than one algal blooms in a year.

The causes and factors responsible for abundant growth of blue green algae have drawn considerable attention of scientists world over. The enrichment of nitrogen and phosphorus in water favors reproduction of blue green algae. Other important factors for bloom are; temperature and nitrogen and phosphorus ratio in water, the low light demand of blue green algae and their poor consumption by zooplankton filterers. Low ratio (< 20) of dissolved mineral nitrogen and dissolved mineral phosphorus favors water 'bloom' (Varis 1993, Blomqvist et al. 1994). Although N:P ratios were less than 20 from May onwards i.e. during summer, rainy and winter seasons but algal blooms of blue green algae in the form of thick scum developed only in the post-rainy season (September – October) (Table 2) because other optimal conditions such as temperature (24-26°C) and relatively low brightness due to cloudy conditions for most of the time were met only during post-rainy season.

Algal bloom of green algae was however, observed in April 2006 when N:P ratio was very high (177), suggesting higher values of inorganic nitrogen was favorable for reproduction of green algae.

The maximum algal counts observed in the year 2006 decreased markedly in the ensuing year 2007 and 2008 possibly due to reduction in pollution caused by diversion of wastewater drains that also favored higher species diversity almost throughout the year in 2008. Chlorophyceae contributing maximum to the algal counts in 2006 (54-74 %) and 2008 (58-63 %) was shadowed by Cyanophyceae (60-79%) in 2007 possibly due to reduction in water depth

Table 3. N: P ratios of lake water (March 06- March 07)

Months	NH <sub>4</sub> +NO <sub>x</sub>	IP	Ratio (NH <sub>4</sub> +NO <sub>x</sub> /IP)
March.06	44.8+1.7=46.5	0.51	91.17
April.06	37.0+3.9=40.9	0.23	177.8
May 06	5.6+3.9=9.5	2.59	3.66
June 06	20.7+3.9=24.6	1.56	15.77
July 06	7.3+9.5=16.8	0.46	36.5
Sept.06	0+5.6=5.6	2.09	2.67
Oct.06	1.7+4.48=6.18	1.12	5.51
Nov.06	2.2+2.8=5.0	0.86	5.81
Dec.06	2.2+1.12=3.32	1.83	1.81
Jan.07	9.5+3.36=12.86	3.37	3.81
Feb.07	7.3+5.6=12.9	1.71	7.5
Mar.07	9.0+3.36=12.36	1.69	7.3

caused by release of lake water for desilting that favored larger diurnal fluctuations in the water temperature.

The dominance of chlorophyta in high mountain lakes of Alps was correlated to brighter stable weather conditions (Hinder et al. 1999). Chattopadhyay and Banerjee (2007) reported dominance of cyanophyta in freshwater lake during warmer periods while bacillariophyta in winter. However, no consistent trend was noted during the present study. Members of chlorophyceae dominated in algal community in the warm sunny days in 2006 but of cyanophyceae in 2007 and 2008 during this period. In contrast, cyanophyceae dominating algal community in 2006 winter was replaced by chlorophyceae at few occasions in 2007 and 2008. Such differences in dominance of algae may be related to highly eutrophic nature of Mansagar lake. Bacillariophyceae contributing minimum to the algal community in 2006 (2.7-27.5%) and 2007 (1.93-28.7%) however, shared more in 2008 (15.8–33.8%). Such changes in composition of algal groups suggest improvement in the physico-chemical environment of the lake.

The significant positive correlations were observed between algal counts and TKN and TP. Thus increased availability of N and P favored algal multiplication resulting in their higher counts.

Apart from this, the lake sediment was also an important source of nutrients (bottom –up) to supplement phytoplankton growth and abundance under nitrogen- or phosphorus deficient conditions in the lake.

*Ankistrodesmus* and *Chlorella* were the dominant taxon of chlorophyceae in 2006 and 2007 while *Biddulphia* along with *Chlorella* and *Scenedesmus* in 2008.

*Cyclotella* was the only dominant plankton in bacillariophyceae in 2006 was joined by *Navicula* in 2007 and 2008. *Spirulina* and *Merismopedia* were the dominant cynophycean in 2006 and 2007. In 2008, *Cyclotella*, *Navicula*, *Spirulina* and *Merismopedia* were equally presented. Thus, changes have taken place in structural composition of pre-dominant algal species in the lake.

The dominance of any species in polluted water for one season or more constituting about 10% of the total community may be considered as pollution indicator species (Mihnea 1985). Nikulina (2003) designated them as pre-dominant species in the community. The majority of algal species (13 species) in the lake were thus pollution indicator. These dominant forms attained their maximum counts in summers and minimum in winters. In 2006, the counts of a selected taxa such as *Chlorella* (20 folds), *Microcystis* (2 folds) and *Merismopedia* (4 folds) were 2-20 folds higher than those in 2007 and 2008. Also there was a reduction in number of dominant cynophycean species from 4 species in 2006 to 2 species in 2008. *Aphanocapsa* and *Merismopedia* were found absent in 2008. Though number of dominant chlorophycean taxa (4-5) did not differ during the study period but their species composition changed. *Pediastrum* and *Scenedesmus* were observed only in 2008. *Cyclotella* was the only dominant genus of Bacillariophyceae in 2006 was joined by *Navicula* in 2007 and 2008.

It is thus evident that there was a reduction in predominance of cynophycean members in the lake with progress of time. The increase in number of dominant forms of bacillariophyceae and chlorophyceae compensated reduction in cynophycean members, thereby total phytoplankton number remained almost similar during the study period. The reduction in number of dominant species of cynophyceae along with overall reduction in plankton counts of dominant algal forms over a period of time suggest improvement in lake water quality.

The mathematical integration of algal species richness is used for rating pollution status of a water body. Boyd index of 3-2 indicate moderate pollution but values <1 suggest that water is heavily polluted. Boyd index (annual mean) values were found close to one throughout the study period (2006 = 1.04, 2007 = 1.0) and 2008 = 1.15), suggesting that water body is heavily polluted. Monthly variations in Boyd values were found higher in the year 2006 (0.5-1.27), 2007 (0.6 - 1.27) in comparison to the year 2008 (1.08-1.26) suggesting mild recovery of the lake (Fig. 39).

Table 4. Typical chlorophyll- a concentrations in different waters (After Wetzel 1983)

	<i>Oligotrophic</i>	<i>Mesotrophic</i>	<i>Eutrophic</i>
Chl a (mg/m <sup>3</sup> )	1.7 (0.3-4.5)	4.7 (3-11)	14.3 (3-78)
Chl a peaks (mg/m <sup>3</sup> )	4.2 (1.3-10.6)	16.1 (4.9-99.5)	42.6 (9.5-275)

Palmer algal genus index found maximum in the year 2006 ( $22 \pm 6.59$ ) decreased in 2007 ( $17.75 \pm 5.94$ ) and 2008 ( $14.75 \pm 1.03$ ) (Fig. 41). According to Palmer (1969), a score of 20 or more is an indication of organic pollution while a score of 15-19 is taken as probable evidence of high organic pollution. Thus, Mansagar lake had high organic pollution in the 2006 that decreased gradually in the ensuing years on account diversion of wastewater drains.

In contrast to Boyd and Palmer indices, Shannon and Weaver's index was found minimum in 2006 ( $1.97 \pm 0.40$ ) increased gradually in 2007 ( $2.038 \pm 0.34$ ) and 2008 ( $2.296 \pm 0.147$ ) (Fig. 40). According to Wilham and Dorris (1968), a value of above 3 will indicate clean water, whereas value lesser than this will indicate pollution. Accordingly Mansagar lake is polluted one showing sign of recovery with the passage of time.

It is evident that all the three indices arrived at the same conclusion i.e. higher degree of pollution in the year 2006 followed by its reduction in the ensuing year 2007 and 2008.

Chlorophyll- a concentrations indicate trophic status of a water body (Wetzel, 1983) (Table 4). Accordingly Mansagar lake having higher values of Chl. a ( $22.4-428.05 \text{ mg/m}^3$ ) is a eutrophic lake (Fig. 42).

There was significant reduction in chlorophyll-a and algal biomass values in 2008 in comparison to 2007 suggesting improvement in water quality (Fig. 42,43).

The diversion of wastewater drains including mechanical aeration of lake favoring mineralization reduced nutrient availability in the lake. The lake aeration which started in September 2007 possibly also arrested phosphorus desorption from the sediment.

Certain physico-chemical parameters like total alkalinity (Vollenweider 1966), phosphorus (Ohle 1955), nitrogen and phosphorus (Palmer 1980) and chloride (Beeton 1965) have been reported to have a bearing on the trophic status of the waters. In the present study, concentration of nitrogen and phosphorus are always above the eutrophication level, i.e.  $0.3 \text{ mg/L}$  and  $0.015 \text{ mg/L}$  respectively (Palmer 1980).

The higher concentrations of nutrient and organic matter in the sediment were because of highly polluting nature of the overlying water. The high amount of organic matter in the sediments promotes anoxic conditions in the bottom waters.

Zooplankton community depends basically on the type of food available i.e. organic matter and plankton. The blue greens, euglenoids and few members of chlorophyceae are

considered nutritionally inferior and can be consumed by only few specialized members of zooplankton (Wilson et al. 2006, Tillmanns et al. 2008). This decreases efficiency of energy transfer in the aquatic food webs including control over algal blooms.

The species of *Brachionus*, *Cyclopes* and protozoan such as *Amoeba*, *Paramecium*, are considered as pollution tolerant species and indicate accumulation of organic matter (Anderson 1974, Tundisi and Tundisi 1976). Cairns et al. (1979) showed enhancement of protozoan colonization rate in response to sewage. Sarkar et al. (1986) stated that the ciliated protozoan species and their abundance were more in the eutrophic waters. In Mansagar lake also, protozoan such as species of *Brachionus*, *Euglena*, *Paramecium* and *Phacus* were abundant suggesting eutrophic nature of the lake. Macro-zooplanktons in the lake were *Daphnia*, *Cyclopes* and *Moina*. Chironomous larvae were also observed as plankton at few occasions.

Aquatic insect populations comprising of *Notonecta* and *Corixa* were in abundance in the post-rainy season. These are the important food of fish and waterfowls in the lake. These are considered as tolerant to pollution (Tyagi et al. 2006).

Benthic macro-invertebrates inhabit sediment of the water body. They have long life span and sedentary habit, and are found to be sensitive to organic loading, thermal impacts, substrate alterations and toxic pollution. They are therefore, highly popular as pollution indicator (Hallaswill 1986). After three years of extensive studies of benthic macro-invertebrates of the river Yamuna, Central Pollution Control Board, New Delhi along with Dutch expert has established that they are the most suitable for water quality evaluation among the organisms present in aquatic ecosystem. Other workers findings strengthened this view point in the river Hindon (Tyagi et al. 2006).

The macro-benthic community of Mansagar mostly comprised of Chironomus larvae which are known to survive in highly polluted environment (Jeelani et al. 2006). *Tubifex* species was observed but only in the sediment of Check dam. Whereas only dead shells of molluscs were present both in Mansagar lake and check dam, suggesting a marked deterioration in the lake water quality in time scale.

Zooplankton and macro-benthos community of Mansagar Lake are thus indicator of organic pollution caused by sewage contamination.

Table 5. Water quality criteria (Source: CPCB, MoEF, New Delhi)

Designated-Best-Use	Class of water	Criteria
Drinking Water Source without conventional treatment but after disinfection	A	Total Coliforms Organism MPN/100ml shall be 50 or less pH between 6.5 and 8.5 Dissolved Oxygen 6mg/l or more Biochemical Oxygen Demand 5 days 20°C 2mg/l or less
Outdoor bathing (Organised)	B	Total Coliforms Organism MPN/100ml shall be 500 or less pH between 6.5 and 8.5 Dissolved Oxygen 5mg/l or more Biochemical Oxygen Demand 5 days 20°C 3mg/l or less
Drinking water source after conventional treatment and disinfection	C	Total Coliforms Organism MPN/100ml shall be 5000 or less pH between 6 to 9 Dissolved Oxygen 4mg/l or more Biochemical Oxygen Demand 5 days 20°C 3mg/l or less
Propagation of Wild life and Fisheries	D	pH between 6.5 to 8.5 Dissolved Oxygen 4mg/l or more Free Ammonia (as N) 1.2 mg/l or less pH between 6.0 to 8.5
Irrigation, Industrial Cooling, Controlled Waste disposal	E	Electrical Conductivity at 25°C micro mhos/cm Max.2250 Sodium absorption Ratio Max. 26 Boron Max. 2mg/l

Present study has thus demonstrated eutrophic nature of the Mansagar lake. The reduction with time in values of algal counts (particularly cyanobacteria), chlorophyll content, algal biomass and free carbon di oxide, BOD, TKN and TP in the lake water has clearly demonstrated gradual recovery of Mansagar lake following its restoration by the Jaipur Development Authority, Jaipur. The possible explanations for slow recovery are; construction of sedimentation tank within lake near reservoir and no fishing activity. Because of entry of storm water near reservoir (discharge point), suspended solids settle permanently in the sedimentation tank. The degradation of organic matter contaminates lake water throughout year. State Department of Fishery introduced Mangur fish (*Clarius batrachus*) tolerant to organic pollution. This fish is a voracious feeder and therefore, it is a big threat to faunal diversity of the lake. Because of fishing ban by Rajasthan State Fishery Department, Magur density is very high in the lake. The idea of fish banning was possibly to increase food availability (fish) to both resident and migratory birds. Unfortunately, number of migratory birds visiting Mansagar lake decreased markedly after fishing ban. Because of robust size and strength, Mangur fish is not a easy prey for waterfowls. Rather fish may pose threat to waterfowls and this need a detailed study. Fish banning also affected possibility of scavenging of nutrients from the lake. Even after restoration, water quality of Mansagar lake does

not falls even in class E of CPCB i.e. it is not even suitable only for irrigation (Table 5).

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