

Water treatment potential in relation to phytoplankton dynamics in tropical sewage-fed urban water bodies

Durga Madhab Mahapatra¹, HN Chanakya^{1,2,3*} and TV Ramachandra^{1,2,4}

1-Centre for Sustainable Technologies,

2-Centre for Infrastructure, Sustainable Transport and Urban Planning

3-Centre for Contemporary Studies

4-Energy and Wetlands Research Group, Centre for Ecological Sciences

Indian Institute of Science, Bangalore 560 012, India

durgamadhab@ces.iisc.ernet.in, chanakya@cst.iisc.ernet.in, cestvr@ces.iisc.ernet.in

*Corresponding Author

Abstract

Urban water bodies frequently receive untreated sewage and water levels in such water bodies are maintained by daily inputs of sewage. They function as “variable-zone” anaerobic-aerobic lagoons suffering several macrophyte, biotic and abiotic stresses. We have studied two such lakes in Bangalore (Bellandur-360 ha and Varthur-220 ha) to understand whether such an occurrence could be made beneficial (maintaining water levels as well as treatment). Such hypertrophic water body receives sewage at 180-250mg/L and is discharged at 25-80mg/L COD/BOD in different seasons. In an earlier study we reported macrophyte altering the purification function of the water body. In this paper we studied the impact of phytoplankton dynamics and macrophyte cover on the functions such as organic load removal. Algal community analysis, algal biomass, macrophyte cover, water quality, nutrient status was studied seasonally during 2009-2010. Oxygen deficiency and sometimes anoxia, recorded from surface samples resulted in high quantities of $\text{NH}_4^+\text{-N}$ (30-40mg/L) and phosphate (0.5-4mg/L)-characteristics of anoxic hypertrophic urban lakes. The productiveness favoured high phytoplanktonic community characterized by small cells (<10 μm ; *Chlorella* sp. - highest numbers). The lake could be clearly demarcated into an initial anaerobic zone (40% area), a facultative zone (20%) and an aerobic zone (40%) based on redox values and GIS/bathymetry. During summer the lake is covered by floating macrophytes converting the lake into an anoxic/anaerobic water pool subduing the water purification function as well as aesthetics. When macrophytes are controlled such sewage fed water bodies can be used for treating urban wastewater while also maintaining water sustainability in these semi-arid ecosystems. This paper reports the community dynamics of phytoplankton, their function and competition with macrophytes.

Keywords: Phytoplankton, sewage, urban lakes, treatment, nutrients.

Introduction

Tropical urban water bodies have become prone to increased anthropogenic stress especially due to constant sewage ingress leading to poor water quality. Often the management of these water bodies in urban areas of the developing countries is largely neglected to a major extent. Due to

nutrient enrichment these water bodies are increasingly becoming eutrophied, resulting in very frequent algal blooms and rapid macrophyte growth and with periodic successions. The macrophyte and macrophyte that tolerate these stressed conditions out-compete the native species and reduce endurance to local conditions. In this competitive exclusion principle, the superior competitor species dominates a constant environment and lead to a low community richness and diversity. Contradicting this principle, phytoplankton communities generally consist of a wide variety of species in a believed stable environment, which was described as paradoxical (Hutchinson, 1961). The Hutchinson's dilemma named "Paradox of the Plankton" was explained by non equilibrium conditions due to the fluctuations of the environment (Hutchinson, 1961), related to annual cycles of physical, chemical and biological factors. Most of the water body systems are extremely sensitive to these environmental changes resulting in unstable conditions and discontinuously advantageous habitat features for different species (Reynolds, 1997; Calijuri et al. 2002). Studies about population dynamics and ecological succession have shown that a fluctuating environment results in phytoplankton communities comprising of different species at different seasons (Sommer et al. 1986; Talling, 1987; Giani, 1994; Figueredo and Giani, 2001). Climatic conditions play a major role in the dynamics of stressed aquatic systems. In tropical urban lakes, that are anthropogenically more stressed the oscillations of total radiation and water temperature are relatively smaller, but seasonal patterns of phytoplankton communities are not negligible (Talling, 1987; Grover and Chrzanowski, 2006). These environments also exhibit seasonal changes in climate (especially related to light, temperature and precipitation) that induce modifications in the physico-chemical characteristics of the water and influences the phytoplankton dynamics (Costa and Silva, 1995; Figueredo and Giani, 2001). Sedimentation, grazing, light, CO₂, nutrient concentrations act as forces responsible for the selection of phytoplankton species (Anneville et al. 2004). The final phytoplankton composition results from the balance between gains and losses within the pool of species adapted to survive in that particular environment (Reynolds, 1997; Zohary, 2004). It is therefore interesting to understand how stressed aquatic sewage fed systems respond to reasonably constant sewage composition but significantly varying environmental conditions.

Bellandur and Varthur lake, situated in the south of Bangalore, were built nearly a millennia ago to store natural run off water for drinking and irrigation purposes (Government of Karnataka, 1990). Today large scale developmental activities and unplanned urbanization in the lake catchment area have resulted in reduced catchment yield. Inefficient primary feeder channels feeding the lake have also contributed to fresh water shortfall. However, this shortage has been adequately supplemented by an increased sewage inflow into the lakes causing nutrient enrichment. Bellandur and Varthur lakes have been receiving about 40% of Bangalore city sewage for over 50 years resulting in eutrophication. There are substantial algal blooms, dissolved oxygen depletion, malodor generation and an extensive growth of water hyacinth that covers about 70 to 80% of the lake in the dry season. Sewage brings in large quantities of C, N and P which are trapped or transformed by the system. Despite being stressed these lakes function as facultative lagoons and bring down the COD/BOD and nutrient levels to satisfactory levels. The phytoplankton communities, with dominant species like *Chlorella* in Varthur and *Microcystis* in Bellandur, show seasonal transition in preference to the water quality. Here we have examined the role of seasons, phytoplankton dynamics and macrophyte cover on the functioning of the lake to remove the organic load and render the discharged water capable of being re-used.

Materials and Methods

Study Area

The study area comprises of the two major water bodies - Bellandur lake and Varthur lake which are situated in the south of Greater Bangalore as depicted in Figure 1. Bellandur Lake is the largest lake in the Bangalore city and spreads across an area of 365ha [Figure 1 a)]. Sewage from residential areas near the old Bangalore International Airport, regions around Challaghata and Koramangla is directly fed into the lake through the storm water drains.

Varthur Lake is the second largest fresh water body in Bangalore built by the Ganga Kings over a thousand years ago [Figure 1. b)] for domestic and agricultural uses. It is 5 km downstream of Bellandur lake receiving the discharge from Bellandur lake and an additional sewage from inflows from near by areas. The Varthur lake catchment has seen large scale land use changes after 2000, consequent to the rapid urbanization in the region. The lake receives 595 million liters per day (MLD) of sewage. The sampling locations are shown in the Figure 1. Table 1 shows the characteristics of the studied lakes.

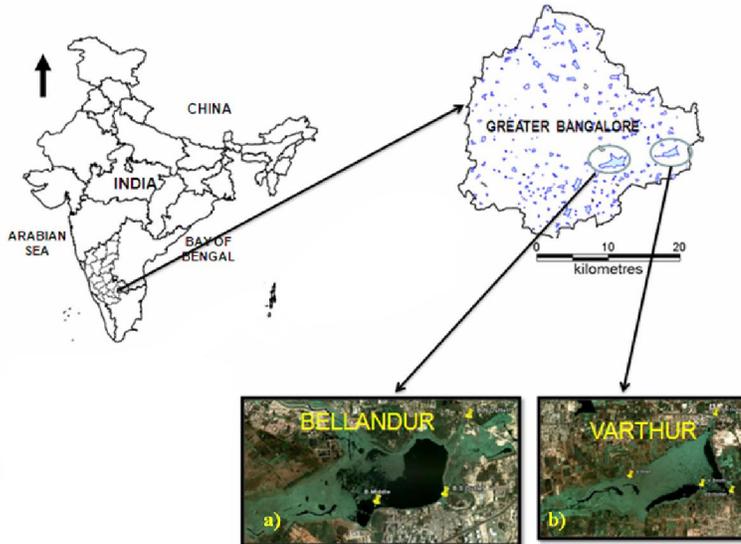


Figure 1. Study Area: Bangalore city, Greater Bangalore; 2 lakes of Bangalore.

Characteristics	Bellandur	Varthur
Location	SE of Bangalore	SE of Bangalore
Coordinates	12.943917° - 12.927959° N 77.638344° - 77.680167° E	12.956683° - 12.941499° N 77.745378° - 77.72805° E
Primary inflows	Sewage from Bangalore	Bellandur
Primary outflows	Varthur lake	To river Pennar
Catchment area (sqkm)	148	166
Max. length (km)	3.6	2
Max. width (km)	1.4	1.1
Surface area (sqkm)	3.6	2.2
Mean depth (m)	2.1	1.1
Surface elevation (m)	921	919
Water colour	Greenish	Greenish (intense)
Odur	Yes	Yes
Macrophyte cover	<i>Eicchornia</i> , <i>Alternanthera</i> , <i>Cyperus</i>	<i>Eicchornia</i> , <i>Alternanthera</i> <i>Typha</i> , <i>Lemna</i>

Table 1. Characteristics of the Study area

Experimental Design

Water samples from 10cm below the surface were collected from the inlet, middle and outlets representing the inflow and the outflows of the lake. Parameters like pH, temperature, electric conductivity were analysed on-site with appropriate probes. Dissolved Oxygen, free Carbon dioxide and other physico-chemical analyses were carried out following standard methods (APHA, 1998). Algal samples from water were collected with the help of Planktonic net in 100 ml polythene bottles and were preserved in 70% alcohol. Algae attached to aquatic plants and stones (biofilms) were also collected in separate containers. With the help of a pipette, samples were mounted on the slide and observed under the microscope for enumeration. Images were captured using Caliper pro software and DIP microscope. Algae were identified till genus level following Taylor et al., 2006 and 2007 and their community structure were observed. The relative abundance of algal communities was examined. The bacterial count and density were analysed by Flow Cytometer (FACS Caliber) and were verified with microscopy. The bacterioplankton population was analysed by first filtering the lake samples with 40 µm and 2.5 µm sieve and then by the FSC (forward scatter) plots. The nutrient content (C and N) of the phytoplankton, bacterioplankton and macrophytes were measured with CHN analyzer (TRUE SPEC CHN, 1.9X, LECO).

Results and Discussions

Phytoplankton abundance, species composition and turn over

Algal abundance and distribution

Algae play a vital role in oxygenating the system that helps lower BOD and oxidizes many substrates. In Bellandur lake during the pre-monsoon period the regions around the inlets were dominated by the members of bacillariophyceae (70 %; *Gomphonema parvalum*). These species are tolerant to organic pollution which can reside in strictly anaerobic conditions. In the middle reaches the cyanophycean members like *Microcystis* sp. dominated (71 %) and the outlets were dominated by the members of chlorophyceae such as *Chlorella* sp. and *Chlorogonium* sp. During the monsoon, the chlorophycean members dominated, however, the post monsoon period saw abundance in the cyanophycean members. The algae in the biofilms collected from the rock surface, plant surface and sediment layers showed greater proportion of filamentous algae (*Oedogonium* sp.) and diatom sp. (*Gomphonema* sp. and *Navicula* sp.). The distribution of the different members of phytoplankton at various sampling locations and seasons are depicted in Figure 3.1.

In case of Varthur Lake during summer *Scenedesmus* sp., *Anabaena* sp. and *Anaycstis* sp. were dominant while enormous *Chlorella* sp. (<10 µm) were observed during the monsoon season (80 %). Micro-algal sampling studies also revealed a greater dominance of diatoms especially *Gomphonema* sp. (10-18 µm) near the inlet reaches during the monsoon taken over by the euglenophycean members like *Euglena* sp. and *Trichellomonas* sp. (>20 µm) in the pre monsoon period. The predominance of euglenoides are indicators of excess accumulation of organic matter. In the post monsoon period the algal bloom of the Bellandur, that is situated at the upper reaches of the Varthur lake, brings in a higher quantity of chlorophycean members which act as

inoculant for Varthur lake. Filamentous alga like *Oedogonium* sp. and *Oscillatoria* sp. (>30µm) dominated in the monsoon and were observed to a large extent near the outlets of the Varthur lake. Comparative analysis of algal populations in the biofilms showed a marked difference in the community structures at various zones of the lake. The rock biofilm consisted of colonies of *Stigeoclonium* sp. Diatom species such as *Gomphonema* sp. and *Nitzschia* sp. were at the inlet and chlorophytes and euglenoides were observed at the outlets. This distribution shed light on our existing understanding of the dependence of the algal assemblage on the environmental variables. Further field investigations revealed that depending upon the wind direction and the extent of growth and movement of the macrophytes together with the nutrient influx, there is periodic transition from an anaerobic-aerobic (in monsoon) to anaerobic (in summer) and aerobic-anaerobic system (winter/pre monsoon). The algal communities identified upto the genus levels (four families) are depicted in Table 2.

Chlorophyceae	Cyanophyceae	Bacillariophyceae	Euglenophyceae
<i>Chlamydomonas</i> sp.	<i>Cylindrospermo</i>	<i>Gomphonema</i> sp.	<i>Phacus</i> sp.
<i>Chlorogonium</i> sp.	- <i>opsis</i> sp.	<i>Navicula</i> sp.	<i>Euglena</i> sp.
<i>Scenedesmus</i> sp.	<i>Arthrospira</i> sp.	<i>Pinnularia</i> sp.	<i>Trachelomonas</i> sp.
<i>Ankistrodermus</i> sp.	<i>Microcystis</i> sp.	<i>Nitzschia</i> sp.	<i>Lepocinclis</i> sp.
<i>Chlorella</i> sp.	<i>Oscillatoria</i> sp.	<i>Synedra</i> sp.	
<i>Oedogonium</i> sp.	<i>Anabaena</i> sp.	<i>Fragillaria</i> sp.	
<i>Stigeoclonium</i> sp.	<i>Merismopedia</i> sp.	<i>Cocconeis</i> sp.	
	<i>Lyngbya</i> sp.	<i>Melosira</i> sp.	

Table 2. Algae communities (identified up to genus level) in the lakes.

In case of algal cells, the inlet regions of Bellandur were consistently showing very low count of the order of 10^2 cells/ml. However, the average cell count in case of middle portion of the lake was 10^6 cells/ml. At the outlets the cell counts decreased to the order of 10^5 cells/ml. In Varthur lake the number of algal cells were less during the monsoon 10^3 cells/ml but during the other periods, the cell count was of the order of 10^5 cells/ml. At the middle reaches and the outlets the algal cell count was of the order of 10^6 cells/ml.

Bactrioplankton abundance and distribution

Three different types of bacteria identified under the microscope were coccoid, rod-shaped, and curved bacteria (Figure 4). In flow cytometric analysis, through normal laser encounter, these three clusters of bacteria were distinguished (Figure 3). In case of Bellandur lake samples, the samples from the inlet regions (Figure 3 A) had less cell density (10^8 cells/ml). However for the middle zone, three different peaks were observed (Figure 3 B). This is an indicator of the filamentous bacteria being a resident near of the facultative zone. In case of the outlet samples one particular type of bacteria i.e. bacillus (Figure 3 C) were observed.

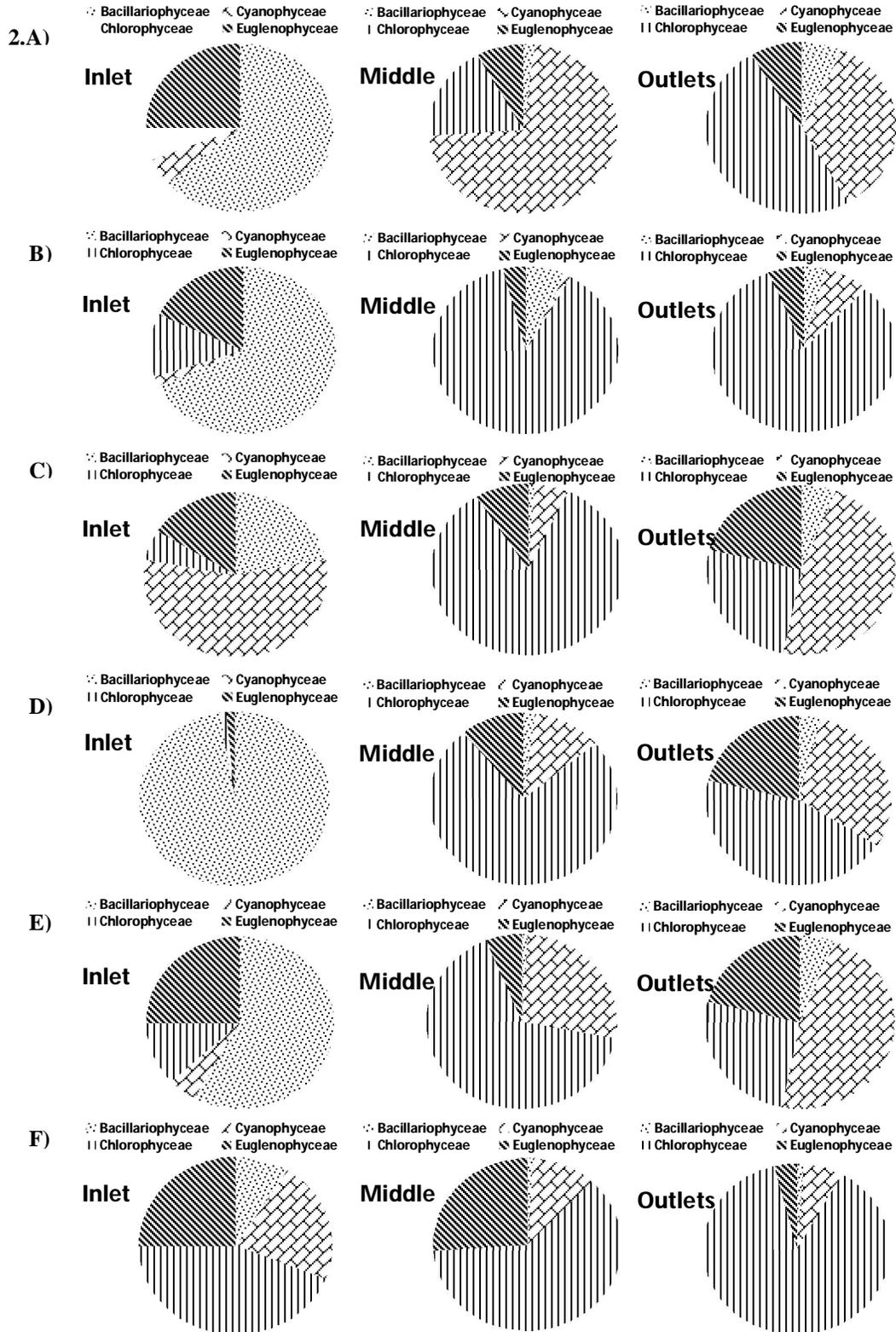


Figure 2. A), B) and C) represents Bellandur lake Algal densities at inlet, middle and outlets in various seasons, and D), E) and F) represents Varthur lake Algal densities at Inlet, middle and Outlets in various seasons where A) and D) - Pre Monsoon B) and E) - Monsoon C) and F) - Post-Monsoon

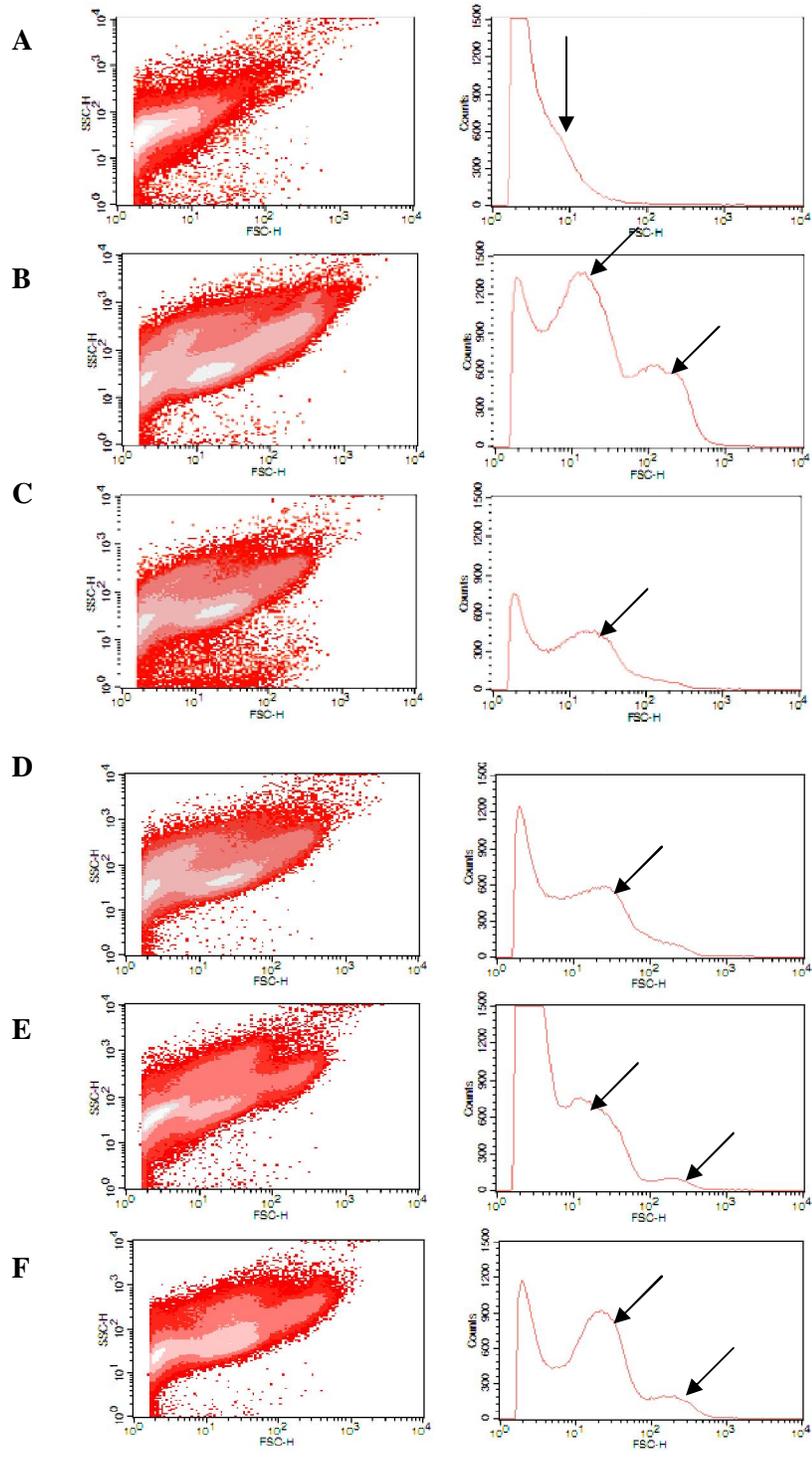


Figure 3. represents Flow cytograms for Bellandur lake (A, B and C) and Varthur lake (D, E and F)

*A and D - Inlet; B and E - Middle and C and F – Outlet

Varthur lake showed a higher bacterial abundance towards the inlets mostly comprised of cocci forms (shown as single peak Figure 3. D; Figure 4. A). The middle regions comprised of two

different groups of bacteria's the coccus and the spirillum (Figure 3. E; Figure 4. B) evident from the two peaks indicated by the arrows (Figure 3. E). The outlets essentially comprised of rod shaped bacteria shown by one prominent peak given in figure 3. F and figure 4. C.

Lake/Sites	Total bacterial cell count /ml	Bacterial cells/ml (<2.5μ)
Bellandur		
Inlet	18909667	1747800
Middle	20711400	3517500
Outlet	8510200	1111700
Varthur		
Inlet	8712400	3021800
Middle	10634200	1705700
Outlet	12962600	1995800

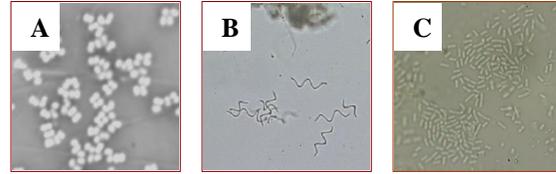


Figure 4. Bacteria A) inlet, B) middle and C) outlet.

Table 3. The bacterial cell count-Flow cytometer

Climatic and physico-chemical variables in water quality

Climatic conditions are important and very specific to places. The average annual rainfall of the study area is 859 mm and temperatures vary from 14°C (December to January) to 33°C (Maximum during March to May) as shown in figure 5. There are two rainy periods, from June to September (South-West Monsoon) and November to December (North-East Monsoon). During the rainy periods, fresh water also enters the lake as runoff. Temperature, pH, and DO profiles (Table 4) suggest that both the lakes are incompletely mixed with variable stagnation zones during the year. Water transparency oscillated in very small amplitude (8 cm–30 cm) during the steady period.

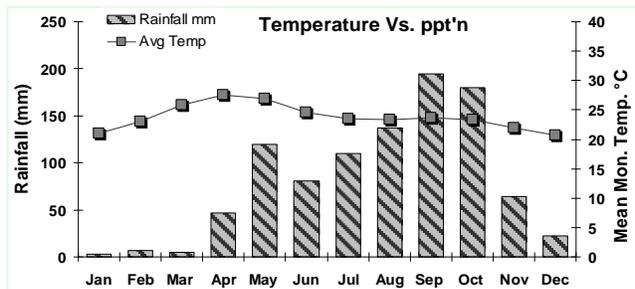


Figure 5. Mean monthly variations in temperature and precipitation in the study site, obtained from IMD site, Bangalore.

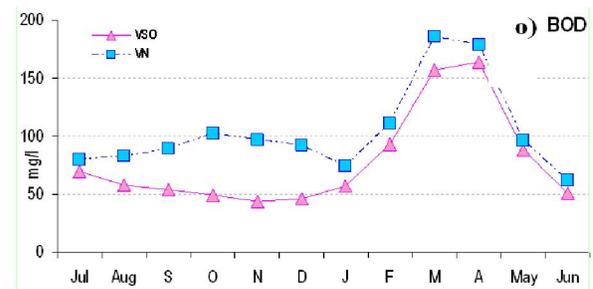


Figure 6. Comparison between the inflow and the outflow (o) concentrations during 2009-10.

The physico-chemical analysis of the lake water shows that higher treatment occurred in Bellandur lake during the monsoon and the post monsoon season, with COD and BOD removal efficiencies of about 70% (filterable) and >50% total COD as illustrated in Table 4. However in case of Varthur lake the COD and BOD removal >50 (filterable) and BOD 38-43 % during the monsoon and post-monsoon period (Table 4 and Figure 6.). This suggests that the two lakes have different dynamics. The ORP values (-245 to -140 mV) indicate anoxic-oxic conditions (Table 4). Where there were higher ORP values, the COD and BOD values were considerably higher indicating higher organic matter decomposition.

Parameters	Bellandur Lake					
	Pre-monsoon		Monsoon		Post-monsoon	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
pH	7.9	8.2	7.4	7.8	7.7	7.8
Temperature (⁰ C)	27.8	27.3	24.1	23.7	24	21
Electrical Conductivity (μ S/cm)	1098	1057	661	735	980	1009
Total Dissolved Solids (mg/l)	868	840	526	592	770	808
Turbidity (NTU)	216.	96.5	71.4	79.2	386	98.9
Dissolved Oxygen (mg/l)	0.0	0.0	0.0	0.0	0.0	0.0
Free CO ₂ (mg/l)	69	21.84	48.4	61.6	64	120
COD (mg/l)	340	153	266	140	253	122
Filtrable COD (mg/l)	182	102	123	93	133	88
BOD (mg/l)	198	74	120	78	170	132
Nitrates (mg/l)	0.05	0.04	0.76	1.63	0.98	0.67
Phosphates (mg/l)	2.10	1.8	3.28	3.36	2.97	3.76
Alkalinity (mg/l)	520	300	360	400	260	300
Total Hardness (mg/l)	196	204	268	232	292	276
Chlorides (mg/l)	84	73	82.36	85.2	86	93
Sodium (mg/l)	54	43.82	39.7	40.4	68	62
Potassium (mg/l)	10.4	9.72	9.1	10	9.8	11.2
ORP (mV)	-180	-150	-96	-165	-245	-220
BOD Removal (Inlet – Outlets)	62.5 %		35 %		22.4 %	
Total COD Removal	45 %		52.5 %		51.7 %	
Filterable COD Removal	44 %		24.5 %		34 %	
Net COD (Tot. –Filt.) Removal	70 %		65 %		65.2 %	

Parameters	Varthur Lake					
	Pre-monsoon		Monsoon		Post-monsoon	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
pH	7.6	7.76	7.85	7.53	7.9	7.5
Temperature (⁰ C)	28.6	26	27.7	29.1	22	23
Electrical Conductivity (μ Scm)	1420	114	910	897	--	--
Total Dissolved Solids (mg/l)	994	792	720	712	768	755
Turbidity (NTU)	325	108	216	102	161	65
Dissolved Oxygen (mg/l)	0.0	0.98	0.54	0.13	0.78	--
Free CO ₂ (mg/l)	55	12.4	40.2	21.8	14.96	8.8
COD (mg/l)	224	192	220	133	188	120
Filtrable COD (mg/l)	146	102	113	86	146	93
BOD (mg/l)	172	135	125	78	130.47	74.9
Nitrates (mg/l)	0.26	0.38	1.39	1.43	0.36	0.6
Phosphates (mg/l)	2.66	3.51	1.72	3.04	1.32	1.72
Alkalinity (mg/l)	400	360	360	380	380	330
Total Hardness (mg/l)	508	272	248	256	264	288
Chlorides (mg/l)	446	149	85.2	90.88	99.4	85.2
Sodium (mg/l)	1100	810	42.43	42.32	220	221
Potassium (mg/l)	80	80	9.72	8.67	41.5	47
ORP (mV)	-145	-210	-13	-8	-49	-178
BOD Removal (Inlet – Outlets)	21 %		37.6 %		42.7 %	
Total COD Removal	14 %		39.5 %		36.2 %	
Filterable COD Removal	30.1 %		23.9 %		36.3 %	
Net COD (Tot. –Filt.) Removal	54.5 %		59.3 %		50.5 %	

Table 4. Physico-chemical characteristics of Bellandur and Varthur lake at inflow and outflow in different seasons

Nutrient status in the lake

In Bellandur and Varthur lakes it was observed that the predominant form of inorganic N present in the dissolved form is ammonia at inlets 37 ppm and 34 ppm respectively. N was found to be the limiting nutrient for the algal bloom. Nitrate and Nitrite concentration constituted an insignificant portion of the dissolved nitrogen pool (2.0%). The nitrate values were near about 1.5 mg/l with very low variations (Table 4). The higher ammonia values were well correlated with the ORP (-250 mV) values which shows the redox status of the lake and thus the prevailing anaerobic conditions. In Varthur lake the ammonia concentrations showed a clear cut gradation from the inflows to the outfalls. The ammonia concentrations were ~35 mg/l near the inlets, 23 mg/l at middle and were ~15 mg/l near the outfalls attributed to progressive N uptake by the microflora with an AmmN removal efficiency of 57 %. Total N content at inlets and outlets were observed to be 55 mg/l and 28 mg/l respectively showing a TN removal efficiency of 50%. Total N influx into Varthur was measured to be 32 tN/day. A significant portion (45%) of it is lost to the environment by denitrification and volatilization processes. However in case of Bellandur the ammonia values were high at inlets as well as outlets. Similar findings were made earlier with $\text{NH}_3\text{N}=31$ mg/l (Chanakya et al. 2006; Chanakya and Sharatchandra, 2008). The Total phosphates values ranged from 7.86 to 9.87 mg/l. The orthophosphates concentrations in Bellandur varied from 1.7 mg/l to 3.84 mg/l from inlets to outlets. However in case of Varthur the orthophosphates concentration varies from 1.2 mg/l to 4.3 mg/l from inlets to outlets. The phosphates values at the outlets are higher than the inlet and may be attributable to additional influx of sewage from non-point and non-inlet sources.

Nutrient content in biomass

In case of wastewater bacteria, the average bio-volume was calculated to be $0.52 \mu\text{m}^3$. The average N value for the bacterial cells was found to be 0.5×10^{-11} mg N/cell. Similar concentrations were found in earlier studies (Munch and Pollard, 1997). This accounts to a total bacterial N accumulation of 0.074 tN on a daily basis. On a dry wt, basis 420-480 mg of algae was recovered for a litre of lake water. The N content in the algae varied from 3.7-6.2 g/100 g dry wt (CHN Analysis). The average N content in algae was found to be 4.95 % which gives algal biomass concentration of 22.27 mgN/l. The alga in the lake accumulates 3.302 tN on a daily basis. Among the macrophytes water hyacinth uptake bulk of these nutrients. The N content per unit area of the dry biomass for macrophytes accounts to 0.54 kg/m^2 . On a daily basis N accumulation by the macrophytes accounts to 2.44 t/d. The detailed study has been discussed by Mahapatra et al, 2010a. Among all these biotic components the algae plays the major role for nutrient accumulation. The macrophyte cover of the lake surface reduces sunlight for phytoplankton during the post monsoon period. The phytoplankton count greatly reduces along with reduced water purification. It has been concluded that without the macrophyte cover the COD/BOD reduction reaches above 50% (Mahapatra et al. 2010b).

Summary and Conclusion

Urban lakes of Bangalore have been subject to appreciable anthropogenic nutrient loads due to high rate of sewage discharge during the last 50 years, which has resulted in predominant changes in physico-chemical conditions and phytoplankton communities of the lake. The study of the physico-chemical parameters and their impacts on the standing crop of phytoplankton indicated that the maximum number of phytoplankton species counted, belonged to class chlorophyceae (*Chlorella* blooms), which is an indicator of eutrophication. The higher ammonia content favoured the growth of these members. It was observed that in anoxic-aerobic conditions the chlorophycean and euglenophycean members dominating the lake. However, the partial anaerobic regions (N limited) were dominated by the cyanophycean members. There was a transition of phytoplanktons with seasons where the chlorophycean members dominated in the monsoon period and the cyanophycean members during the dry periods. Transparency/ turbidity exhibited significant positive relation with the total count of the phytoplanktons. In terms of biomass the algae were found to be the major uptaker of nutrients as N among other biotic members. The major nutrient sink among the biotic component was found to be the lake phytoplankton accumulating N upto 3.3 tN/day. From this study, we conclude that Bellandur and Varthur are undergoing a high nutrient enrichment at the same time they act as nutrient store, by accumulating nutrients mostly as bacterioplankton, phytoplankton and macrophyte biomass. *Chlorella* and *Chlorogonium* were found to be potential candidates for the lake which triumph at such anoxic conditions with optimal nutrient uptake.

References

- Anneville, O., Souissi, S., Gammeter, S. and Straile, D., (2004). Seasonal and inter-annual scales of variability in phytoplankton assemblages: comparison of phytoplankton dynamics in three peri-alpine lakes over a period of 28 years. *Freshw. Biol.* **49**, 98–115.
- APHA (American Public Health Association) AWWA WEF 1995. Standard Methods for Examination of Water and Wastewater, 19th edition. Washington DC.
- Calijuri, M.C., Santos, A.C.A., and Jati, S., (2002). Temporal changes in the phytoplankton community structure in a tropical and eutrophic reservoir (Barra Bonita, SP – Brazil). *J. Plankton Res.* **24**, 617–634.
- Chanakya, H.N., and Sharatchandra. H.C. (2008). Nitrogen pool, flows, impact and sustainability issues of human waste management in the city of Bangalore, *Current Science*, **94** (11), pp.1447-1454.
- Chanakya, H.N., Karthick, B. and Ramachandra, T.V. (2006). Carbon and Nitrogen flows in Bellandur Lake—role of Bellandur lake as a natural wetland treating Bangalore wastewater’, Proceedings of Lake 2006.
- Munch, E and Pollard, P.C. (1997). Measuring bacterial biomass-COD in wastewater containing particulate matter, *Water Research*, **31**(10), 2550-2556.
- Costa, H.H. and Silva, P.R., (1995). Limnological research and training in Sri Lanka: state of the art and future needs. In: Gopal, B., Wetzel, R.G. (Eds.), *Limnology in Developing Countries*. SIL, India, pp. 1–39.
- Figueredo, C.C. and Giani, A., (2001). Seasonal variation in the diversity and species richness of phytoplankton in a tropical eutrophic reservoir. *Hydrobiologia* **445**,165–174.

- Figueredo, C.C., Giani, A. and Bird, D.F., (2007). Does allelopathy contribute to *Cylindrospermopsis raciborskii* (cyanobacteria) bloom occurrence and geographic expansion?. *J. Phycol.* **43**, 256–265.
- Giani, A., (1994). Limnology in Pampulha Reservoir: some general observations with emphasis on the phytoplankton community. In: *Ecology and Human Impact on Lakes and Reservoirs in Minas Gerais*. SEGRAC-Belo Horizonte, pp. 151–164.
- Government of Karnataka, (1990) Karnataka State Gazetteer. Lotus Printers, Bangalore. pp. 970, 16, 215.
- Grover, J.P. and Chrzanowski, T.H., (2006). Seasonal dynamics of phytoplankton in two warm temperate reservoirs: association of taxonomic composition with temperature. *J. Plankton Res.* **28**, 1–17.
- Government of India, India Meteorological Department, Rainfall Statistics, Weather warning, Temperature: //www.imdbangalore.gov.in/ (accessed 13 Nov 2010)
- Hutchinson, G.E., (1961). The paradox of plankton. *Am. Nat.* **95**, 137–146.
- Isvanovics, I., Shafik, H.M., Presing, M. and Juhos, S., (2000). Growth and phosphate uptake kinetics of the cyanobacterium, *Cylindrospermopsis raciborskii* (Cyanophyceae) in throughflow cultures. *Freshw. Biol.* **43**, 257–275.
- Mahapatra, D. M., Chanakya, H. N. and Ramachandra, T. V. (2010a). Role of Macrophytes in a Sewage fed urban lake. *Int. Inst. Of Omics and Applied Biotechnology*, X(Y): xx-xx. (submitted)
- Mahapatra, D. M., Chanakya, H. N. and Ramachandra, T. V. (2010b). Assessment of Treatment capabilities of Varthur Lake, Bangalore, India' *Int. J. of Environment Technology and Management*, X(Y): xx-xx. (in press)
- Reynolds, C.S., (1997). *Vegetation Processes in the Pelagic: A Model for Ecosystem Theory*. Ecology Institute, Germany, p. 371.
- Sommer, U., Gliwicz, M., Lampert, W. and Duncan, A., (1986). The PEG-model of seasonal succession of planktonic events in fresh waters. *Arch. Hydrobiol.* **106**, 433–471.
- Talling, J.F., 1987. The phytoplankton of Lake Victoria (East Africa). *Arch. Hydrobiol.* **25**, 229–256.
- Zohary, T., 2004. Changes to the phytoplankton assemblage of Lake Kinneret after decades of a predictable, repetitive pattern. *Freshw. Biol.* **49**, 1355–1371.