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Annexure 1

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Influence of Catchment Land Cover Dynamics on the Physical, Chemical and Biological Integrity of Wetlands

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Abstract

Land use and land cover (LULC) changes in the wetland catchments are the direct and indirect consequence of human actions to secure essential resources. These changes encompass the greatest environmental concerns of human populations today, including loss of biodiversity, pollution of water and soil, and changes in the climate. Monitoring and mitigating the negative consequences of LULC while sustaining the production of essential resources has therefore become a major priority today. This communication investigates the effect of land-cover and water quality on distribution of diatoms in selected wetlands of Bangalore. In this respect, water quality (chemical and biological) was assessed along with LULC of respective wetland catchments. Spatial analysis has been done using remote sensing data and geographic information system (GIS). Diatoms, the major primary producers of aquatic ecosystem, respond quickly to environmental perturbations aid as bioindicators. The results showed gradients in physical, chemical and biological parameters across wetlands with different LULC. The diatom community results, when compared to chemical analyses, proved useful in providing an indication of the quality of waters. Pollution tolerant taxa such as *Nitzschia palea* dominated at sites with heavy inflow of sewage while, *Cymbella* sp. and *Gomphonema* sp. present abundantly at less pollution sites. Across the land-cover types, wetlands catchment comprising more of built-up area reflected higher nutrient and ionic levels, whereas wetlands with high vegetation cover showed oligotrophic water quality conditions. Species belonging to the genera *Gomphonema, Cyclotella, Nitzschia* and *Achnanthidium* expressed clear ecological preferences. This study emphasizes the need for conservation efforts at catchment level for conservation of wetlands biota.

Keywords: Land use land cover (LULC), landscape, landscape dynamics, wetlands. Diatoms, Water quality

Introduction

Wetlands being one of the productive ecosystems play a significant role in the ecological sustainability of the region, providing the link between land and water resources (Ramachandra, 2008). The quality and hydrologic regime of the water resource is directly dependent on the integrity of its watershed. In recent years, the rapid urbanization coupled with the unplanned anthropogenic activities has altered the wetland ecosystem severely across globe (Vitousek *et al.,* 1997; Grimmond, 2007). Changes in land use and land cover (LULC) in the wetland catchments influence the water yield in the catchment. Apart from LULC changes, the inflow of untreated domestic sewage, industrial effluents, dumping of solid wastes and rampant encroachments of catchment has threatened the sustenance of urban wetlands. This is evident from the nutrient enrichment and consequent profuse growth of macrophytes, impairing the functional abilities of the wetlands. Reduced treatment capabilities of the wetlands have led to the decline of native biodiversity affecting the livelihood of wetland dependent population. Decline in the services and goods of wetland ecosystems have influenced the social, cultural and ecological spaces as well as of water management. This necessitates regular monitoring of wetlands to mitigate the impacts through appropriate management strategies. LULC analysis is done using remote sensing data acquired through the space-borne sensors. Factors related to water quality are the most important pressure driving heterogeneity of biotic components at an intermediate spatial and temporal scale.

Algae, the primary producers are linked with the changes in various physical (landscape) and chemical (nutrients) variables and indeed have been used as bioindicators of water quality. Among several groups, diatom-based pollution monitoring has proved to be rapid, efficient and cost-effective technique has been implemented worldwide to monitor rivers, streams and lakes (Taylor *et al.,* 2007; Juttner *et al.,* 2010; Karthick *et al.,* 2011). Diatoms are the species-rich group of photosynthetic eukaryotes, with enormous ecological significance and great potential for environmental application. During the last two decades, diatoms have gained considerable popularity throughout the world as a tool to provide an integrated reflection of water quality (Atazadeh *et al.,* 2007). The sensitivity and tolerance of diatoms to specific physical and chemical variables such as pH, electrical conductivity, nitrates, phosphates and biological oxygen demand (BOD) and inherent ecological patterns has been investigated across countries (Sabater et al., 2007; Taylor et al., 2007; Jüttner et al., 2009; Alakananda et al., 2011).

Diatom community structure respond to the LULC changes in the catchment (Cooper, 1995), nutrient concentration (Potapova and Charles, 2002), riparian disturbance (Hill et al., 2000) and decreasing species richness, evenness and diversity from agriculture / forest areas to urban area (Bere and Tundisi, 2011). Walsh and Wepener (2009) report the dominance of *Nitzschia* sp. in the catchment with high intensity agriculture, while *Navicula* sp. was dominant at low intensity agriculture regions. However, studies on water chemistry of wetlands with the catchment LULC conditions and its impacts on diatom assemblages in urban scenario is scarce and needs to be investigated to evolve location specific catchment restoration measures and to mitigate the impact of anthropogenic activities in the fragile ecosystem's catchment.

Wetlands play a prominent role of meeting the domestic and irrigation needs of the region apart from being habitats for wide variety of flora and fauna. Bangalore, with a population of 9.5 million (as per 2011 census) has been rapidly urbanizing during the last three decades. Recent studies reveal that there has been 63.2% increase in built-up area with 78% loss of vegetation cover and 79% loss of wetlands (Ramachandra and Kumar, 2008). Wetlands have become vulnerable ecosystems evident from regular mass fish kill (Benjamin et al., 1996) reduction of migratory bird population (Kiran and Ramachandra, 1999) and ground water contamination (Shankar et al., 2008). Sustained inflow of the city's sewage and industrial effluents apart from conversion of wetlands for other activities have threatened the existence of these fragile ecosystems necessitating the interventions to restore and sustainable management with location specific appropriate conservation strategies. Failure to restore these ecosystems will result in extinction of species or ecosystem types and cause permanent ecological damage.

Wetlands function as kidneys of the landscape and help in treating the nutrients. However, the excess inflow of nutrients beyond the treatment capability results in the changes in the water quality impairing the ecological functions. Diatoms, the major primary producers of aquatic ecosystem, respond quickly to environmental perturbations, hence used as a bioindicator across continents. However, usage of diatoms as a part of environmental monitoring program in Southern Hemisphere is very limited due to inadequate knowledge on its taxonomy. Ecological optima of four dominant species were investigated for standardizing diatom indices for Indian conditions. Current study investigates the influence of LULC in the wetland catchment on diatom communities composition and distribution at spatial scale in an eco-region. LULC analysis was done using remote sensing data with Geographical Information System (GIS). Water quality was analyzed to investigate temporal variation in physicochemical parameters and their relationship with diatom community during pre-monsoon (August), monsoon (September and October) and post-monsoon (November) months.

Study area

Bangalore is located at 12^o 39' N and 13^o 18' N and longitude of 77^o 22' E and 77^o, almost equidistant from both eastern and western coast of the South Indian peninsula, and is situated at an altitude of 920 m above mean sea level. Major soil types are red loamy and laterite soil and physiography variations ranges from rocky upland, plateau and flat-topped hills forming slope at south and south east, and pedi-plains along western parts (http://cgwb.gov.in). The mean annual total rainfall is about 880 mm with about 60 rainy days a year over the last 10 years. The summer temperature ranges from 24 to 38 °C, while the winter temperature ranges from 12 to 28 °C. Bangalore is located over ridges delineating four watersheds, viz. Hebbal, Koramangala, Challaghatta and Vrishabhavathi watersheds. The undulating terrain in the region has facilitated creation of a large number of tanks providing for the traditional uses of irrigation, drinking, fishing and washing (Figure 1). Their creation is mainly attributed to the vision of Kempe Gowda and of the Wodeyar dynasty. This led to Bangalore having hundreds of such water bodies through the centuries. Recent studies reveal that there has been 63.2% increase in built-up area with 78% loss of vegetation cover and 79% loss of wetlands (Ramachandra and Kumar, 2008).

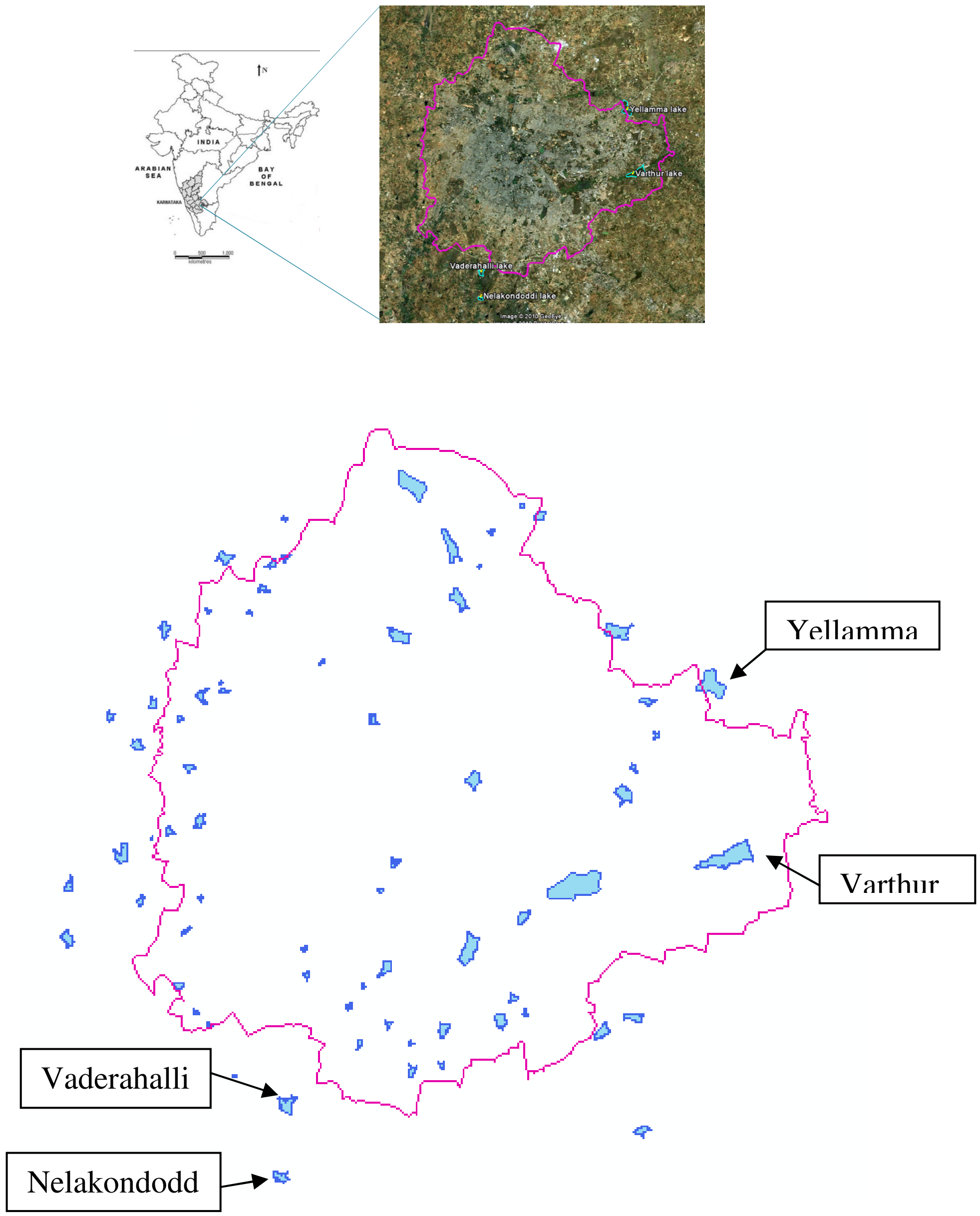

Figure 1: Study area with India Map and Bangalore map with 4 lakes marked on the digitized vector layer of Bangalore

Four wetlands were selected for the current study. Among these Yellamallappa chetty (110 ha) and Varthur (166.87 ha) are located in Bangalore urban district and drained from densely populated area of Bangalore metropolitan (Mahadevapura zone, Population of 5,19,663). Industrial waste and agricultural runoff (Usha et al., 2008) contaminated Yellamappa chetty and Varthur together with macrophyte growth and severe sludge deposition (Ramachandra, 2008). Two other wetlands Vaderahalli (55ha) and Nelakondoddi (36 ha) are located in Bangalore Rural district with less human population and more of plantation and forested land in catchment area.

Table 1: Variation in physical and chemical parameters across months at Varthur and Yellamma Wetland

Sampling site	VARTHUR INLET (Vri VTI)				VARTHUR OUTLET (VroVTO)				YALLAMMA INLET (YMI)				YALLAMMA OUTLET (YMO)			
Sampling months	**Aug**	**Sep**	**Oct**	**Nov**	**Aug**	**Sep**	**Oct**	**Nov**	**Aug**	**Sep**		**Nov**	**Aug**	**Sep**	**Oct**	**Nov**
pH	7.46	7.25	7.10	8.50	7.84	7.58	8.00	8	7.49	8.90		7.5	7.5	8.00	7.20	8
Water temperature (^{0}C)	25	27.00	26.00	24.00	29.5	27.50	26.50	26	25.3	29.00		-	26.2	28.60	-	-
Electric conductivity (µScm^{-1})	823	948.00	-	-	798	890.00	-	-	1083	1120.00		-	1092	863.00	-	-
Total dissolved solids (ppm)	654	730.00	-	-	636	700.00	-	-	865	850.0		-	870	654.00	-	-
Salinity (ppm)	403	550.00	-	-	385	563.00	-	-	538	620.0		-	537	490.00	-	-
Turbidity (NTU)	92.5	110.00	82.20	-	83.5	81.30	62.20	-	42.7	44.00		70.8	42.8	60.50	-	38.5
Dissolved Oxygen (mgL^{-1})	0.813	0.00	1.22	0	4.065	7.15	1.63	4.06	4.227	0.00		-	5.04	1.95	0.00	-
Biological oxygen Demand (mgL^{-1})	49.95	71.54	56	95	46.28	55.28	44.7	-	33.74	117.07		35	24.29	104.07	87.9	30
Chemical oxygen demand (mgL^{-1})	293.33	197.73	133.00	314.67	192.00	298.67	-	234.66	581.33	213.33		85.33	570.66	218.67	186.70	74.67
Nitrates (mgL^{-1})	0.05	0.27	0.157	0.299	0.03	0.28	0.162	0.24	2.57	0.85		-	0.394	0.57	0.179	-
Phosphates (mgL^{-1})	0.21	1.94	3.217	1.637	0.05	1.73	4.175	0.718	0.51	0.61		1.94	2.98	0.44	3.3	1.813
Total Hardness (mgL^{-1})	268	256.00	240.00	336	264	236.00	292.00	420	276	320.00		360	300	284.00	296.00	288
Calcium Hardness (mgL^{-1})	120	120.00	144.00	88.17	132	112.00	200.00	188.17	372	132.00		68.93	280	124.00	196.00	57.71
Magnesium Hardness (mgL^{-1})	189.92	136.00	96.00	28.261	85.392	124.00	92.00	48.757	185.232	188.00		45.838	231.68	160.00	100.00	35.107
Alkalinity (mgL^{-1})	520	55.00	440.00	140	260	56.00	-	120	420	90.00	**	1700	560	65.00	400.00	1580
Chlorides (mgL^{-1})	136.32	153.36	147.68	150.52	119.28	142.00	-	142	107.92	193.12		227.2	167.56	190.28	221.52	213
Sodium (ppm)	33.6	34.30	3.1	20.05	34.6	31.50	-	18.93	40.6	40.30		22.83	49.5	39.70	3.9	23.39
Potassium (ppm)	6.8	7.00	4.4	0	6.7	6.30	0	0	7.7	7.80		0	8.5	8.20	5	0

** No sampling was carried out due to the Ganesha immersion.

Table 2: Variation in physical and chemical parameters across months at Nelakondoddi and Vaderahalli Wetland

Sampling site	NELAKONDODDI INLET (NiNKI)				NELAKONDODDI OUTLET (NoNKO)				VADERAHALLI INLET (VdiVHI)				VADERAHALLI OUTLET (VdoVHO)			
Sampling months	**Aug**	**Sep**	**Oct**	**Nov**	**Aug**	**Sep**	**Oct**	**Nov**	**Aug**	**Sep**	**Oct**	**Nov**	**Aug**	**Sep**	**Oct**	**Nov**
pH	8.05	8.36	8.20	8.60	7.95	7.94	8.10	8.60	9.4	9.11	8.30	8.20	8.5	9.00	8.20	8.20
Water temperature (^{0}C)	28.4	26.30	26	26.00	26	29.50	24.5	25.00	29	27.10	24	26.00	29.5	26.10	24	25.00
Electric conductivity (µScm^{-1})	711	541.00	-	-	661	582.00	-	-	550	687.00	-	-	480	608.00	-	-
Total dissolved solids (ppm)	564	390.00	-	-	496	441.00	-	-	300	433.00	-	-	295	468.00	-	-
Salinity (ppm)	351	218.00	-	-	301	256.00	-	-	255	265.00	-	-	220	278.00	-	-
Turbidity (NTU)	22.9	24.00	17.7	14.60	24.4	22.50	-	8.06	17.5	57.10	7.05	12.40	12.2	24.40	8.77	9.85
Dissolved Oxygen (mgL^{-1})	10.98	6.50	8.29	10.4	7.2	7.80	6.50	11.05	5.854	9.88	1.22	-	6.667	10.73	2.76	-
Biological oxygen demand (mgL^{-1})	5.42	6.50	5.42	18.44	14.92	16.26	3.25	13	20.34	15.00	2.03	13.7	16.00	14.00	3.9	14
Chemical oxygen demand (mgL^{-1})	32.00	20.00	13.33	17	23.00	26.67	17.60	18	32.00	26.00	8.00	16	23.00	19.50	16.00	14.4
Nitrates (mgL^{-1})	0.08	0.18	0.085	0.254	0.06	0.11	0.084	0.153	0.06	0.14	0.634	0.149	0.08	0.06	0.161	0.327
Phosphates (mgL^{-1})	0.017	0.16	0.046	0.052	0.004	0.02	0.225	0.11	0.025	0.13	0.008	0.046	0.1	0.04	0.098	0.028
Total Hardness (mgL^{-1})	300	232.00	160.00	160	364	240.00	204.00	180	284	148.00	148.00	172	144	148.00	160.00	500
Calcium Hardness (mgL^{-1})	16	88.00	80.00	24.04	36	68.00	88.00	32.06	160	36.00	60.00	32.06	76	44.00	44.00	32.06
Magnesium Hardness (mgL^{-1})	296.096	144.00	80.00	24.388	355.216	172.00	116.00	24.384	244.96	112.00	88.00	22.432	125.456	104.00	116.00	4.86
Alkalinity (mgL^{-1})	400	87.50	240.00	666.66	420	70.00	300.00	700	340	77.50	100.00	733.33	360	67.50	260.00	566.66
Chlorides (mgL^{-1})	31.24	187.44	130.64	113.6	39.76	184.60	136.32	122.12	31.24	139.16	127.80	136.32	34.08	130.64	110.76	127.8
Sodium (ppm)	60.9	44.20	3.4	19.49	71.5	44.10	3.4	18.38	32.1	35.20	2.8	18.381	31	34.70	2.6	18.93
Potassium (ppm)	3.1	2.40	1.7	0	3.7	2.60	1.6	0	3	3.20	2.5	0	2.8	3.30	2.1	0

Materials and Methods

Water quality analysis: Water samples from all four wetlands were collected during 4 months viz., August, September, October and November 2010. Samples collected from 10 to 30 cm below the surface of water during the morning hours and stored in disinfected plastic bottles. On-site water analysis included water temperature, pH, turbidity, salinity, electrical conductivity, total dissolved solids and dissolved Oxygen. No preservatives were added as the samples were transported to laboratory and refrigerated for subsequent analysis. Laboratory analysis includes total alkalinity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total hardness, calcium hardness, Magnesium hardness, Potassium, Sodium, nitrates (NO^{3-}), inorganic phosphates (PO_4^{3-}) and chlorides (Cl^-). These water analyses were followed as per standard procedures published by the American Public Health Association (APHA, 1998) and Chemical and Biological methods for water pollution studies, (Trivedy and Goel, 1986).

Diatom analysis: Diatoms have been collected from habitats such as epilithic, (found in stones) epiphytic (found in plants) and episammic (found in sediments) of four wetlands were collected during the month of September 2010. Cleaning and identification of samples is done following Laboratory procedure as per Taylor *et al.,* 2005 and Karthick *et al.,* 2010. Samples are cleaned following Hot HCl and $KMnO_4$ method and slides were prepared using Pluerax as the mounting medium. Relative abundance of each taxon was determined after counting at least 400 valves in each sample using light microscope. Identification of diatoms has been done following key characters mentioned by Krammer and Lang-Bertalot (1986-1991), Round *et al.,* (1990) and Gandhi (1957a-1959d).

LULC analysis: Shuttle Radar Topography Mission (SRTM) data is downloaded from CGIAR Consortium for Spatial Information (CGIAR-CSI). Digital Elevation Model (DEM) was generated using ENVI 4.7 version. The digitized Wetlands were overlayed on the DEM. The drainages were digitized using toposheet of Bangalore, 1972. Catchment of these four Wetlands was delineated using the topographic maps of 1:50000 and referring the digitized drainages. LULC for each catchment was assessed using IRS 1D data (October 2006). IRS data was geo-referenced using image-to-image registration. Training data is collected from field using pre-calibrated handheld Global Positioning System (GPS). IRS data were classified using supervised classification techniques with the Gaussian maximum likelihood classifier into three classes – vegetation, water body and built up. Accuracy assessment was done to validate the classified data.

Statistical analysis: Variation in water quality and diatom species distribution across sites is analysed using PAST software, version 2.11. Canonical correspondence analysis (CCA) included data of 8 abundant diatom taxa (RA >10% at least in 1 sampling site), 17 environmental across 8 sampling sites during 4 month period to evaluate role of environmental variables (water quality and land cover type) in structuring diatom communities.

Results and Discussion

Water Quality Analysis

Varthur Wetland: The overall water quality parameters measured are listed in Table 1. pH was recorded as neutral to slightly alkaline with lowest and highest at VTI (7.1) in October and VTI (8.5) in November respectively. Electric conductivity and total dissolved solids values were consistent with a narrow range of 823 to 948 mgL^{-1} and 636 to 730 mgL^{-1} respectively. Hypoxic and even anoxic condition due to low dissolved oxygen was observed at VTI site (1.22 mgL^{-1}) and at VTO site as well with a range of 1.63 -7.15 mgL^{-1}. This attributed to the presence of water hyacinth covering the water surface with heavy domestic organic load and decomposition of organic matter. This condition is also reflected in elevated concentrations of BOD and COD with exceeding permissible limits at all sampling sites across months (Table 1). Total hardness (236-420 mgL^{-1}), alkalinity (55-440 mgL-1) and chlorides (119.28-153.36 mgL^{-1}) were recorded very high due to sewage inflow.

Yellamma Wetland: pH was recorded as neutral to slightly alkaline with lowest at YMO (7.20) in the month of October and highest at YMI (8.90) in the month of September. Electric conductivity and total dissolved solid values show a significant range. In September, YMO showed a less EC value of 863 μScm^{-1} and Yellamma inlet showed high value of 1120 μScm^{-1} owing to high ionic concentrations inflow from industrial wastes. Dissolved oxygen content varied in both inlet and outlet ranging from 0 to 5.04 mgL^{-1}. DO was less than measurable amount in the month of October in YMO and September in YMI reasoning to high organic load. In the month of August DO of 4.22 mgL^{-1} in YMI and 5.04 mgL^{-1} in YMO was observed. The discharge of sewage containing organic material from the nearby factories contributed to this situation. This condition was also reflected in elevated concentrations of BOD and COD with exceeding permissible limits at all sampling sites across months (Table 1). In the month of October no sampling could be done in Yellamma inlet due to blockage on account of immersion of idols (Ganesha).

Nelakondoddi Wetland: pH ranged from 7.94 at NKO site (Sep) to 8.60 at both the sites (Nov) indicating slightly neutral to alkaline nature of water and within the permissible limits (Table 2). EC, TDS and salinity ranged from 480 to 687 μScm^{-1}, 295 to 468 ppm and 220 to 278 ppm respectively indicating low mineralization in this Wetland. However, slight gradation was observed in September due to monsoon climate. DO at all sampling sites was within the permissible limit and ranged from 6.5 mgL^{-1} at NKI to 11.05 mgL^{-1} at NKO. The higher DO recorded during monsoon and post monsoon seasons (i.e., Oct and Nov) may be due to the impact of rain water resulting in aeration (Ayoade et al., 2006). A huge variation in BOD (5.42 to 16.26 mgL^{-1}) and COD (13.33 to 32 mgL^{-1}) was studied across months, the highest value of BOD being in the November month (18.44 mgL^{-1} at NKI) and COD being highest at both sites in August month (Table 2).

Vaderahalli Wetland: The pH in both sites indicates slightly alkaline ranged from 8.20 to 9.11 (Table 2). Water temperature varied depending on the time of sampling with a range of 24 to 29.5 ^{0}C. EC, TDS and salinity ranged from 541 to 711 μScm^{-1}, 390 to 564 ppm and 218 to 351 ppm respectively indicating low mineralization in this Wetland. However, slight gradation was also observed in September due to monsoon climate. DO at all sampling sites was within the permissible limit and ranged from 5.854 mgL^{-1} at VHI to 10.73 mgL^{-1} at VHO except in October where the DO was observed to be very low. A huge variation in BOD (2.03mgL^{-1} to 20.34 mgL^{-1}) and COD (8 mgL^{-1} to 32 mgL^{-1}) was studied across months being within the permissible limits, the highest value of BOD and COD being in the August month. (Refer Table 2).

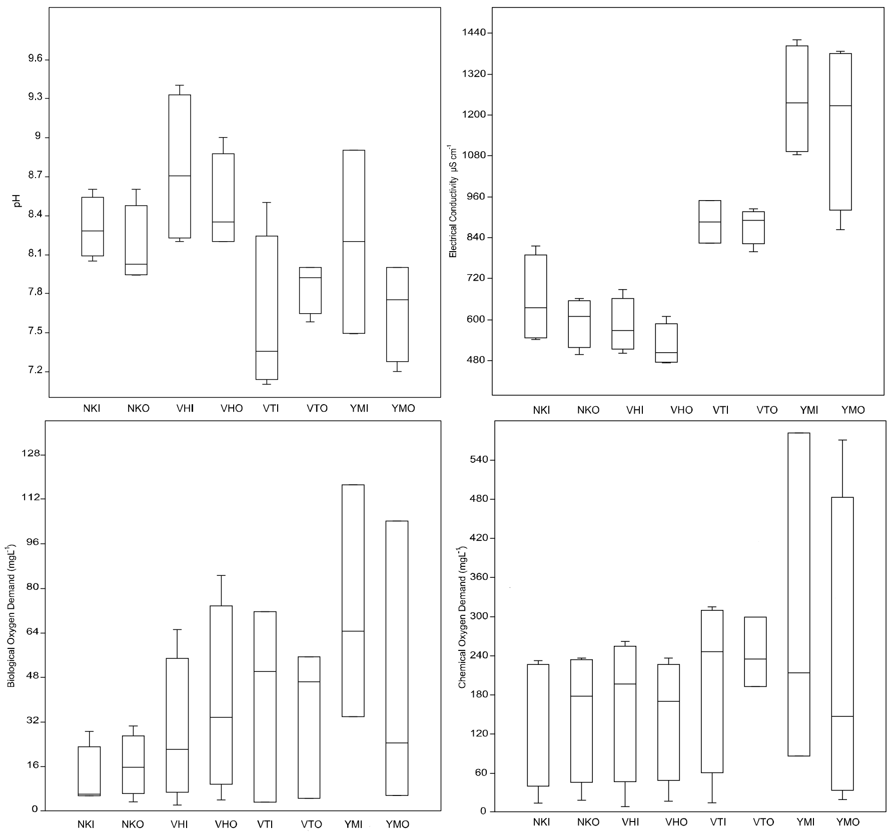

Figure 2: Variation in water quality across sampling sites [For sampling sites and its codes refer annexure I](a) pH (b) Electric conductivity (c) Biological oxygen demand (d) Chemical oxygen demand

Water Quality across Wetlands

The level of pollution status and spatial distribution of Wetlands from urbanized area is well reflected by water quality. Across Wetlands, pH was recorded as slightly alkaline with minimum of 7.6 at Varthur inlet and maximum of 8.75 at Vaderahalli inlet. EC, turbidity and TDS at Varthur and Yellamallappa chetty was in extremely high concentrations due to high cation concentrations. EC was more than the permissible limit at Yellamallappa chetty inlet (1101.50µScm^{-1}) and high turbidity of 94.9mgL^{-1} in Varthur inlet and high TDS of 857.5 was observed in Yellamallappa chetty inlet. These parameters were low in Vaderahalli inlet with 6.18µ$Scm^{-1}$of EC, turbidity of 13.81 NTU and total dissolved solids of 366.50 mgL^{-1}. These parameters show marked seasonal variations (Awasthi and Tiwari, 2004). As in figure 2and 3, BOD and COD values reflected high pollution at Varthur, Yellamallappa chetty and Nelakondoddi sampling sites but contradictory values were observed in Nelakondoddi and Vaderahalli with a range of 8.959 to 12.97 mgL^{-1}. The study by Atobatele et al., 2008 shows pH, conductivity, temperature and dissolved oxygen as important parameters contributing to the annual variability of Wetland water. Dissolved oxygen concentration was found very less in all sampling sites of Varthur Wetland and Yellamallappa chetty Wetlands compared to other two Wetlands, which is quite evident by heavy organic load and macrophyte cover and hence reduces redox potential of the system.

Diatom Distribution

Fifty eight species belonging to 29 genera has been recorded and are listed in annexure 1. The dominant taxa were *Achnanthidium* sp., *Gomphonema*. *parvulum* (Kutzing var. *parvulum* f. *parvulum*) *Gomphonema* sp., *Nitzschia palea* (Kutzing) W.Smith, *Nitzschia umbonata* (Ehrenberg) Lange-Bertalot, *C. meneghiniana* Kutzing, *Cymbella* sp. and *Fragilaria* sp. Most of the species occurred in polluted regions are recorded as cosmopolitan (Taylor *et al.,* 2007). The diatom community structure shows a strong correlation with various environmental variables (Soininen *et al.,* 2004). The species such as *G. parvulum, C. meneghiniana, N. palea* and *N. umbonata* are tolerant to high electrolyte and organic rich condition (Karthick *et al.,* 2009) which inhabited Varthur and Yellamallappa chetty Wetlands. This clearly signifies that both these Wetlands are polluted and eutrophic in condition. Nelakondoddi and Vaderahalli show low electric conductivity, BOD and COD values and were dominated by *Achnanthidium* sp., *Gomphonema* sp. and *Cymbella* sp. These species were recorded as inhabiting in moderate pollution.

Temporal variation and diatom distribution across Wetlands

The monthly variation in water quality was reflected by diatom community composition. *G. parvulum* and *N. palea* were dominated in all months at Varthur outlet while *N. linearis* was recorded as abundant in October at Varthur inlet notifying the pollution level. *C. meneghiniana* and *N. palea* was dominant across months at both sampling sites in Yellamallappa chetty followed by *G. parvulum* in October at Yellamallappa chetty outlet. Diatom species such as *Achnanthidium sp, Gomphonema sp* and *C. kappi* (Cholnoky) Cholnoky being dominant at Vaderahallli Wetland resembled a different community structure than former Wetlands. Ecological significance of *Achnanthidium* sp. needs to be studied as it shows a wide range of occurrence, from oilgotrophic to slightly mesotrophic condition.

Temporal variation is a significant factor responsible for changes in diatom distribution and its abundance (Sivaci *et al.,* 2008). In Nelakondoddi outlet (NKO), *N.palea*, which was dominant in the month of August, was replaced by *C. kappi* and *Mastogloia smithi* Thwaites in September. However, *Achnanthidium* sp. dominated in October followed by *Achnanthidium* sp. together with *Navicula* sp. in November. *C.kappi* was dominant in September which was followed by *N. amphibia* Grunow *f.amphibia* and *Achnanthidium* sp. reflecting moderate trophic status. The eutrophic status and electrolyte rich was significant in November with the dominance of *Fragillaria. biceps* (Kutzing) Lange-Bertalot and *N. linearis* (Agardh) W Smith.

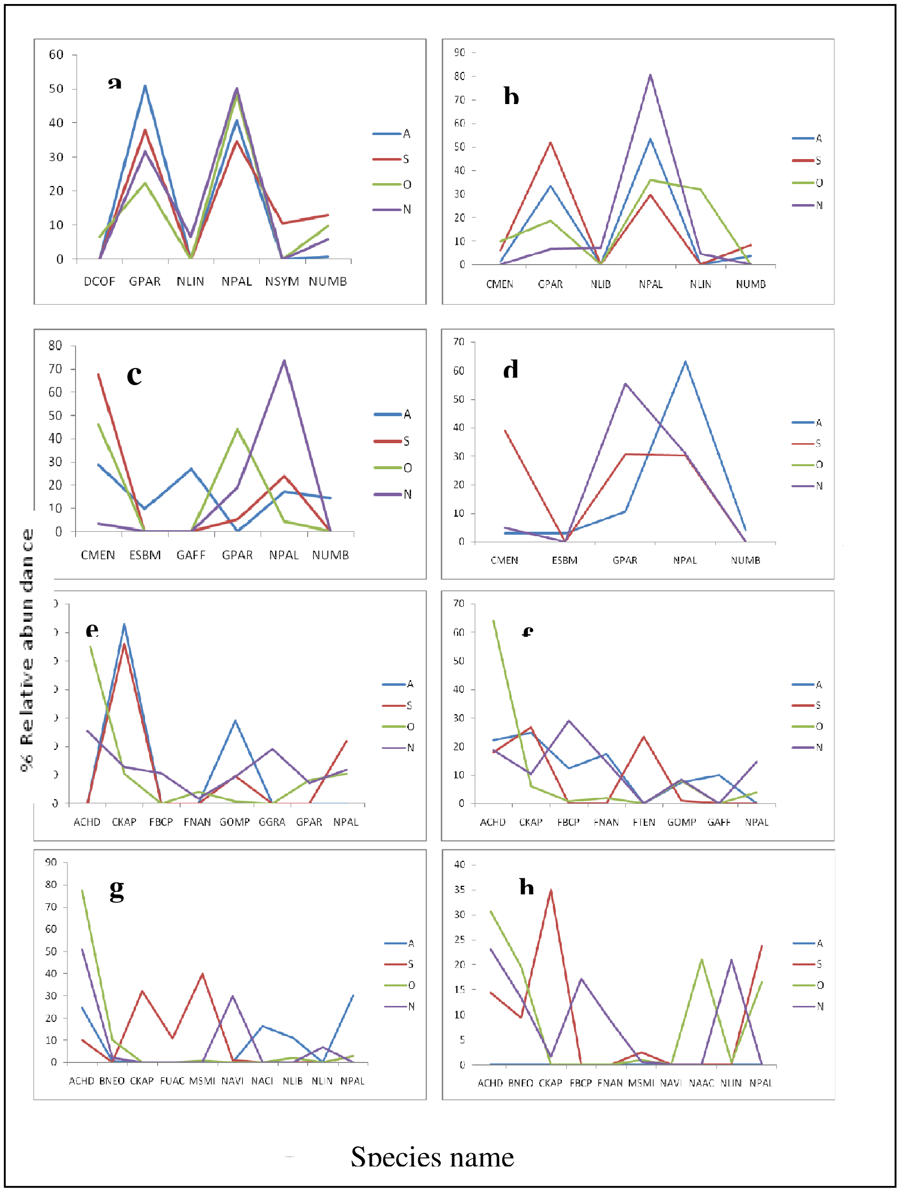

Figure 3: Percentage relative abundance of species across months [A-August, S-September, O-October, N-November] (a) Varthur Siddapura (b) Varthur Fishing (c) Yallamma Outlet (d) Yallamma Inlet (e) Vaderahalli Outlet (f) Vaderahalli Inlet (g) Nelakondoddi Outlet.

Relationship between dominant taxa and Water Quality

CCA triplot explained 65.43% of the variability in the diatom and environmental data with 45.92% in axis 1 and 19.51% in axis 2 (Figure 4; Table 3). Monte Carlo permutation test (n=1000) showed that both axes were statistically significant ($p<0.01$). The ordination of sampling sites was based on the species composition and their relationship with environmental and land-cover variables. The axis 1 represented an urban to rural gradient, where rural sampling sites were ordinated towards the right side and urban sites were on the left side. The sampling sites on the right side were Vaderahalli and Nelakondoddi sites while clustered on the left side were Varthur sampling sites. Axis 2 represented Nelakondoddi and Vaderahalli sites and dominance of ACHD on the right side of the axis. Axis 1 was significantly negatively correlated with variables such as EC, TDS, Turbidity, P, K and % built up and taxa such as NUMB, GPAR and NPAL Likewise, a significant positive correlation of axis 1 was observed with DO, pH and % vegetation along with dominance of CKAP and GGRA. There was no significant correlation of BOD, COD, sodium and chlorides with both axes.

Table 3 Correlation coefficients between selected environmental variables and the first two CCA axes (Significant correlation $p<0.01$).

CCA axes		
Variables	**1**	**2**
Eigen value	**0.725**	**0.308**
pH	0.621	0.25
Conductivity	-0.8588	-0.137
TDS	-0.876	-0.155
Turbidity	-0.77	-0.006
P	-0.6566	-0.095
N	-0.367	0.256
K	-0.909	-0.021
Sodium	-0.211	0.365
BOD	-0.380	0.227
COD	-0.36	0.257
DO	0.663	0.170
Chlorides	-0.414	0.14
% Built up	-0.920	-0.084
% Vegetation	0.928	0.075

Ecological preference of dominant taxa

Figure 5 illustrates the occurrence of dominant taxa at differing water quality. The dominant taxa *G. parvulum* (GPAR), *C. meneghiniana* (CMEN), *Achnanthidium* sp. (ACHD) and *N. palea* (NPAL) at varying pH and EC show the dominance of particular taxa at respective pH and EC optima . *G. parvulum* was persistent across months and abundant at pH ranging from 7.6 to 8 and was less towards alkaline pH. The electric conductivity more than 850 μScm^{-1} attributed to *G.parvulum* optima while sampling sites less than 700 μScm^{-1} comprised a different composition with *G parvulum* as less in abundance. *C. meneghiniana* was recorded to be more dominant at pH of 7.7 to 7.9 and as the EC increases (>900 µScm^{-1}). This range of pH and EC limits the distribution of *G.parvulum* and *C. meneghiniana* to extremely eutrophic water condition. The sensitivity and tolerance of diatoms to such specific environmental factors attributed towards the species- specific ecological characterization (Sabater *et al.,* 2007).

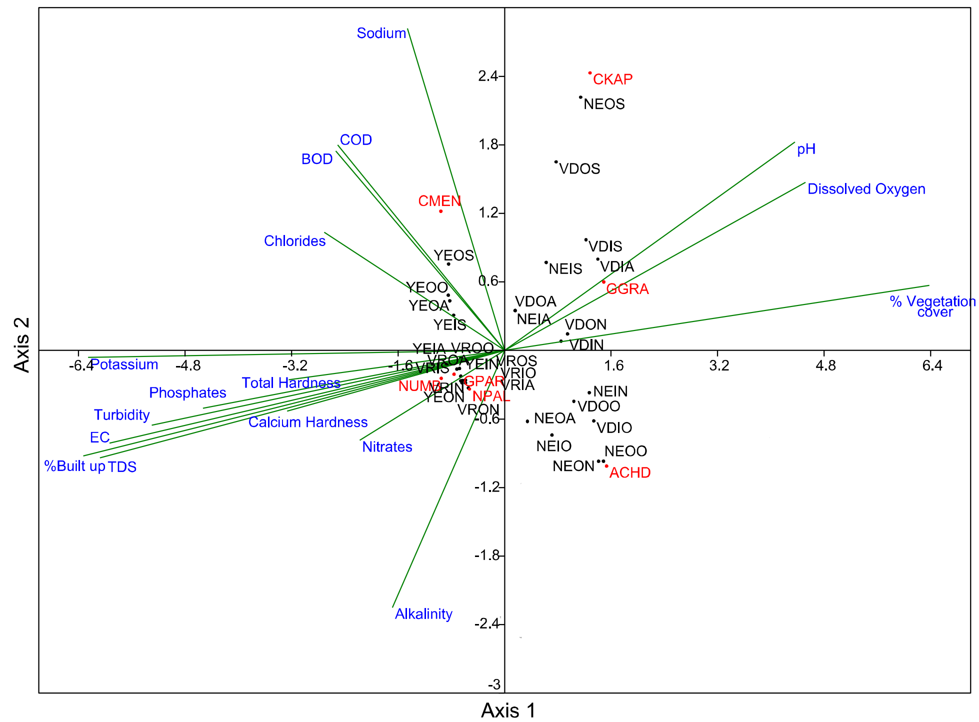

Figure 4 Canonical correspondence analysis (CCA) plot explaining impact of land use/ land cover on species distribution.

Achnanthidium sp. was present at all sampling sites whilst, the abundance was optimum at pH 8.1 to 8.2 and at EC 600 to 650 µScm^{-1} and later decreased at elevated EC concentration. *N. palea* was present at all sampling sites and revealed a wide range of optima though was less abundant at alkaline pH. *N. palea* was also abundant at its optima of EC i.e., more than 850 µScm . Low EC concentration (<800 µScm^{-1}) was limiting the distribution of *N. palea*. Thus, in consideration with observed species autecological values the sampling sites with profuse *Achnanthidium* sp. can be classified as oligo to slightly eutrophic at the same time as, the sampling sites with *N.palea* can be classified as in eutrophic status and extremely polluted. However, many studies have investigated autecological status of indicator species (Taylor *et al.,* 2007; Álvarez-Blanco *et al.,* 2010), very less study contributes to species optima of *Nitzschia* sp., *Gomphonema* sp., and *Achnanthidium* sp. and further none of the study come from Asia region. However, ecological optima of *N. palea* can be classified as eutrophic status. Performing the ecological optima for few more taxa that commonly occur in wetlands of Bangalore can lead to developing specific diatom indices for bioassessment practices.

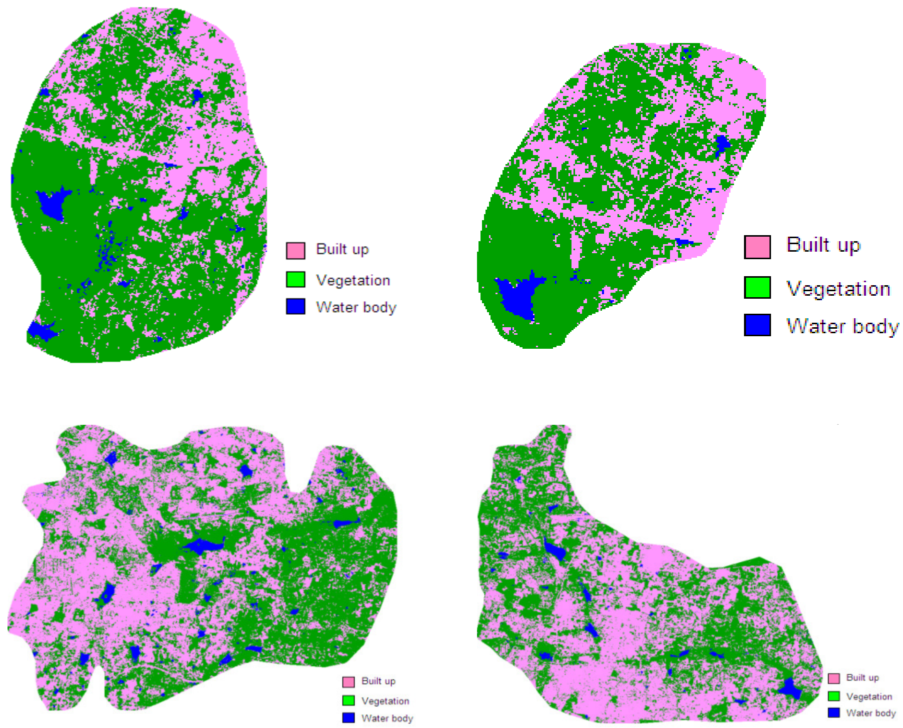

Figure 6: Land use in the catchments of . (a) Nelakondoddi, (b) Vaderahalli, (c) Varthur and (d) Yellamma wetlands.

Chattopadyay et al., (2005) also report of the similar scenario of urban landuse with poor water quality throughout the year. The increased amount of organic concentration and degradation in water quality is mainly due to increasing urbanization (built up) at Yellamma and Varthur regions (Chandrasekhar et al., 2003). In contrast to this situation, vegetation in Vaderahalli catchment (61.21%) and Nelakondoddi catchment (65.98%) is higher compared to the built up land (35.96% and 31.48% respectively). This analysis also shows that the influence of anthropogenic activity was less in these two wetlands. Majority of the area is under vegetation (with less human interventions) and thus less chances of contamination of water compared to the wetlands situated in urban region. LULC changes influence varying diatom community composition (Soininen et al., 2004, Weijter et al., 2009). Yallamallappa chetty and Varthur Wetlands are having high percent of built-up with high sewage and industrial inflow into the Wetland. Diatom community comprised of pollution tolerant species reflecting trophic status. The high percent of vegetation (including forest) cover at Nelakondoddi and Vaderahalli Wetland comprised species, which inhabit oligo to slightly mesotrophic conditions.

Pandey and Verma, (2008) study illustrates that the catchment integrity is significant in determining ecosystem properties of freshwater Wetlands. Li et al., (2010) focused on rapid landscape change and regional environmental dynamics in the Lianyungang bay area from 2000 to 2006 based on remote sensing data indicating that the area has a widespread urban–rural interface with rapid land-use changes, urban expansion and wetland degradation. Rapid increase in urban built-up land has led to large-scale salt wetlands degradation. Allan et al., (1997) highlight that in streams, habitat structure and organic matter inputs are determined primarily by local conditions such as vegetative cover at a site, whereas nutrient supply, sediment delivery, hydrology and channel characteristics are influenced by regional conditions, including landscape features and land use/cover at some distance upstream and lateral to stream sites. Understanding the effects of changes in land use and land cover (LULC) is important for maintaining a desired level of water quality and also for restoring water quality in affected areas (Gove et al., 2001).

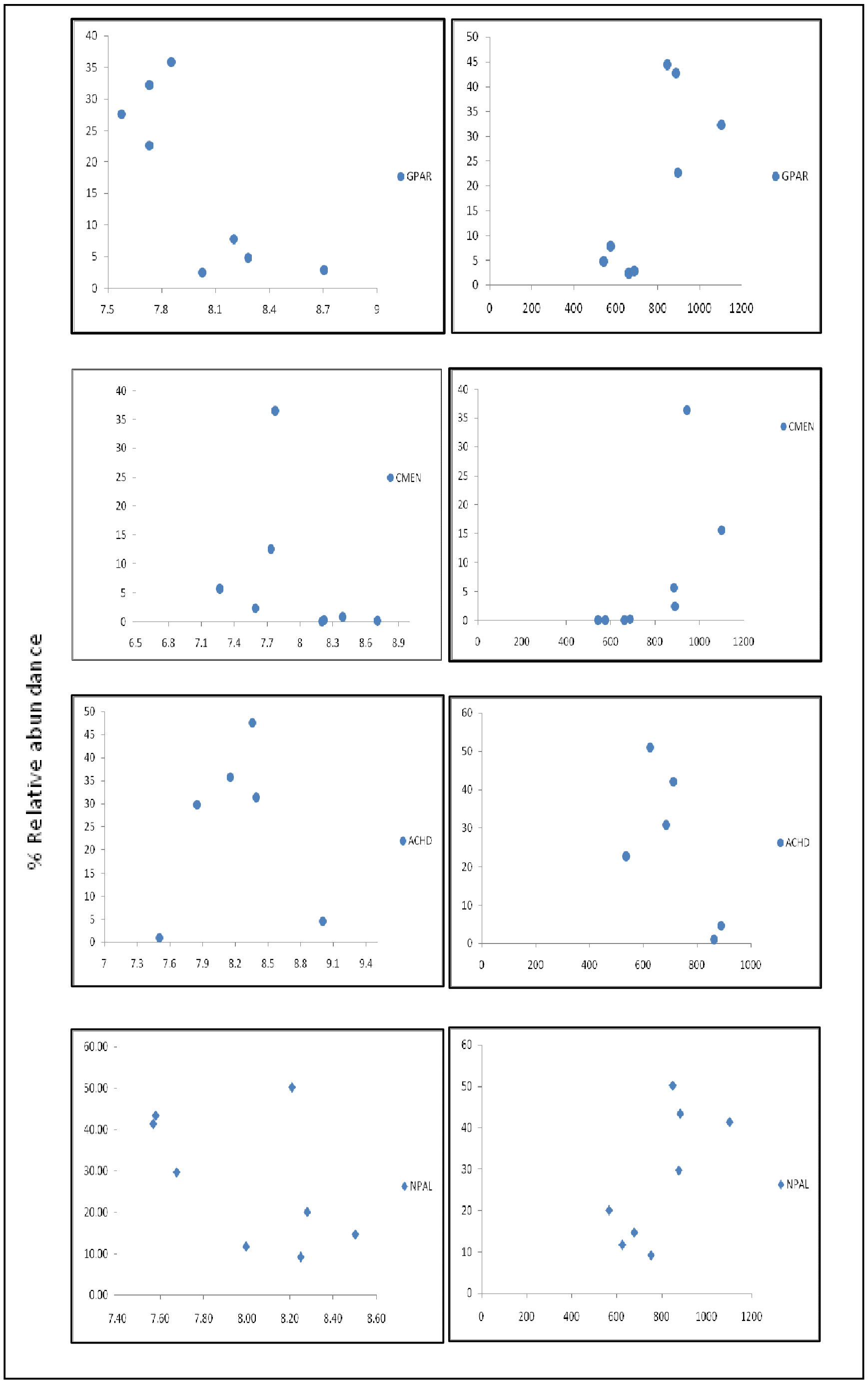

Figure 5 Distribution and autecology of dominant taxa across pH and Electric conductivity

Table 4 Land use/ Land cover classification of selected 4 Wetlands of Bangalore

Class (%)	Nelakondoddi	Vaderahalli	Varthur	Yellamma
Vegetation*	65.98	61.21	45.85	42.90
Built up**	31.48	35.96	55.16	51.68
Water body	2.61	2.82	2.46	1.92

*Vegetation includes cropland, plantation, forest and algal cover.
**Built up include open space also.

Conclusion

LULC changes in the wetland catchment alter the physical and chemical integrity of the system, which influences the diatom community structure. Wetlands with eutrophic water quality conditions were dominated by pollution tolerant diatoms, whereas less polluted wetlands were characterized with diatoms corresponds to oligotrophic – mesotrophic class. Water quality is a decisive parameter in diatom community structure in the respective wetland, even though rainfall seems to have certain influence on diatom succession.

More area of built up in the catchment of Varthur and Yellamallappa chetty increase stress on these wetlands which in turn result in high pollution. Vaderahalli and Nelakondoddi wetlands which is having more vegetation than built up is comparatively facing less disturbance and thus less polluted. Varthur and Yellamallappa chetty wetlands are located in densely populated region with tolerant species whereas wetlands such as Vaderahalli and Nelakondoddi are situated in sparsely populated area and have sensitive species. These results signify that urban wetlands are under severe stress. Thus, catchment characteristics are critical in determining biota of freshwater bodies, thus plans for conservation of wetlands should also be seen at catchment scale, rather than looking wetlands as isolated ecosystem. Ecological preference observed in this study will also lead to development of diatom indices, which can be applicable to monitoring of tropical Asian wetlands.

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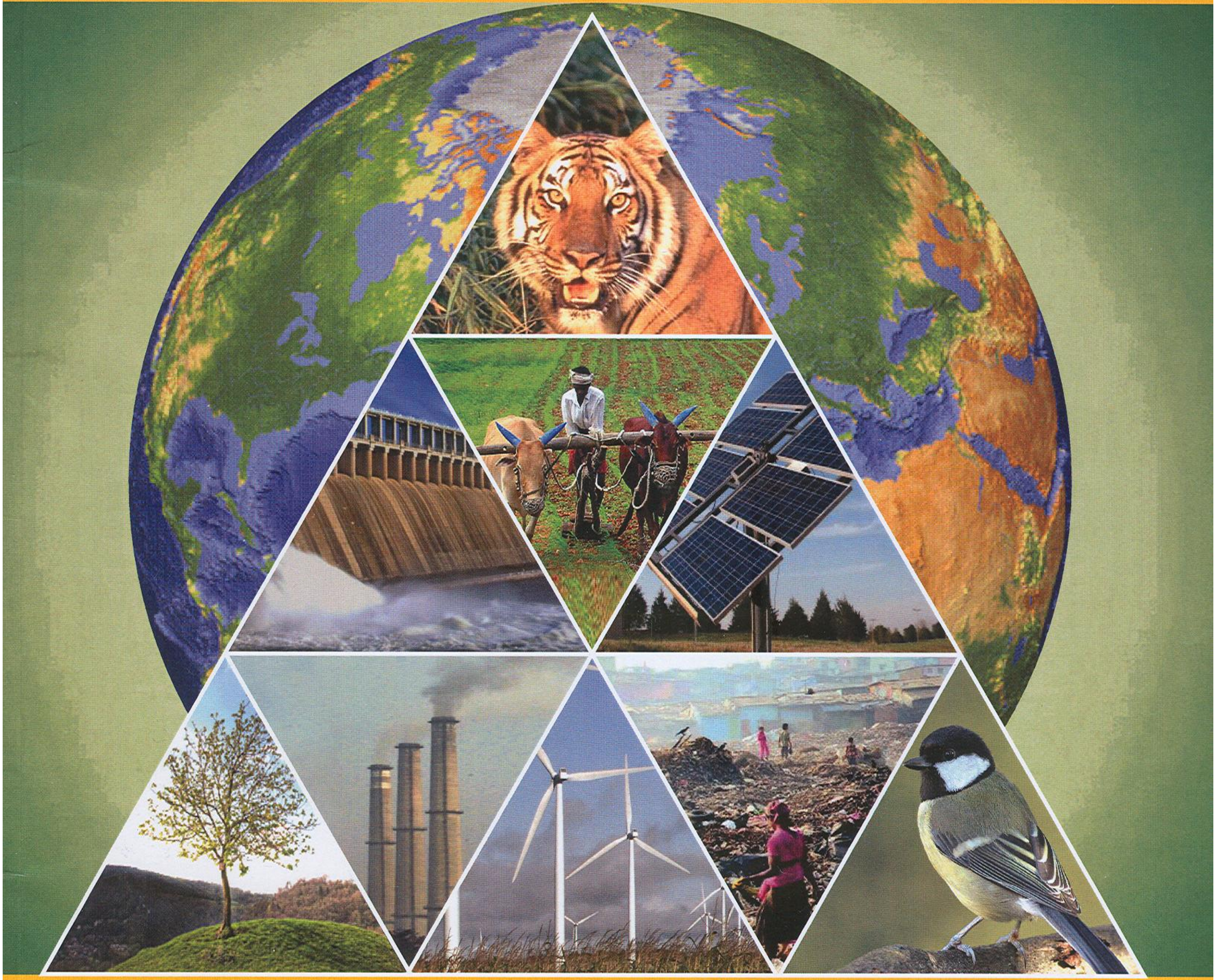

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BIOMONITORING TO ASSESS THE EFFICACY OF RESTORATION AND MANAGEMENT OF URBAN WATER BODIES

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ABSTRACT

Rapid urbanization has induced stress on water bodies, its ecological components resulting in the disappearance of native biodiversity. Water bodies are being restored due to public pressure and implemented by the government agencies focuses only on increasing storage capacity of water bodies than retaining the biological components of the ecosystem. In the current study, wetlands of Bangalore's urban region were selected to assess the effectiveness of restoration using diatoms as bioindicators. Five wetlands viz., prior-restoration, post-restoration, polluted, reference and previously restored wetlands were chosen. The water quality revealed no major changes in conductivity values among prior-restoration and post-restoration period. Influence of chemical factors was evident from the varying diatom assemblages within water bodies. The well-known tolerant taxa like Nitzschia umbonata, Cyclotella meneghiniana, Halamphora veneta *and* Gomphonema parvulum *were predominant in samples prior to restoration reflecting nutrient rich-pollution status. Compared to this,* Achnanthidium *sp. and* Gomphonema *sp were dominant in reference wetlands. One-way ANOVA revealed a significant ($p<0.05$) change in the percentage of eutrophic taxa (%ET) from a reference to polluted wetlands but no significant % ET change was noticed among prior-restoration, post-restoration and previously restored wetland types. Severe fish kill was recorded in ulsoor wetland (restored ~8 years back) because of improper restoration management. Proper restoration and management, requires regular cost effective monitoring and the current study focuses on diatom based biomonitoring in routine water quality assessments. This would reveal the ecological integrity and would also be cost effective supplement to chemical analysis and easily implementable for monitoring urban wetlands.*

Keywords: *Diatom ecology, De-silting, Water quality, Tank ecosystems, Urban pollution, Sewage management.*

INTRODUCTION

The inflow of urban runoff (sewage and effluents) into wetland channels enhances nutrient levels resulting in eutrophication with the bloom of invasive species (Craft and Casey, 2000; Conley et al., 2009). Consequences lead to impairment in hydrological components, sediment type, habitat availability and biological components that differ significantly among eutrophic and oligotrophic water bodies, (Galatowitsch and van der Valk, 1996; Gwin et al., 1999). Conventional water treatment systems fail to remove nutrients, which is also expensive unless one opts for algae based treatment systems (Mahapatra et al., 2011a, b). Any physical treatment, for instance, the drastic disturbance in sediments and water levels impair the nutrient and light availability for benthic macroinvertebrates and algae, leading to the imbalance in the higher group of organ-

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isms in the food chain (Ellings and Hodgson, 2007). This poses challenges for water resource managers and aquatic ecologists, necessitating effective restoration and conservation practices. Restoration is adapted for recovering the aspects of clean wetland functions that are lost due to physical, chemical and hydrological alterations (US EPA 2005; Kaye et al., 2006). Traditional restoration methods respecting ecological goals have improved the physical functioning of wetlands, with least improvements in biodiversity aspects (Zheng and Stevenson, 2006).

Monitoring of wetlands during prior and post restoration period would help in assessing the effectiveness of restoration and understanding on relation between chemical and biological community. Aquatic biota have been monitored prior to wetland restoration in England (Bennion et al., 1996); Finland (Miettinen, 2003); Denmark (Bradshaw et al., 2005) and other European waters, which provided vital clues on the gaps in the restoration techniques worldwide. Species composition and assemblages of macroinvertebrates, aquatic plants, zooplankton and algae have been investigated to assess metal contamination, nutrient transport, sedimentation and functioning of food chain (Nakano et al., 2007; Bennion et al., 2011). Biota like benthic diatoms is useful potential bioindicator as their species composition corresponds to chemical and habitat impairment (Miettinen, 2003; de la Rey et al., 2004).

Diatoms are a prominent group among photosynthetic algae integrate conditions of their respective habitat types , which explains better species-environment relationship. Species tolerance level is associated with specific anthropogenic changes (macrophytes, eutrophication and agricultural waste) across globe (Bere and Tundisi, 2011). On the contrary, sensitive species characterize clean or oligotrophic waters, which facilitates as ideal or clean or reference condition to accomplish restoration goals (Bennion et al., 2011). For better understanding of restoration, wetlands located at urban regions are to be investigated along with undisturbed or reference sites. Dong et al., 2008 recorded species assemblage shift to eutrophic conditions over a time period in Taihu lake which aided in the restoration. Bennion et al., 2011 discusses the use of biological proxy like diatoms to identify environmental drivers and derive reference conditions based on sensitive species assemblages. Investigations of diatom distribution prior to restoration would reveal the impact of chemical conditions like nutrients on organisms. Diatom assemblages in lake sediment cores and surface sediments explained nutrient and human influences on present day water conditions (Flower et al., 1997).

In this study, Bangalore, one of the most urbanized regions of peninsular India, was selected because of the rapid urbanization and consequent severe human pressures on wetlands in recent years. Bangalore's wetlands have been monitored during the last two decades for water's physical and chemical variables and this has helped in developing appropriate monitoring and restoration strategies in order to achieve good water quality and ecological status (Ramachandra, 2005). However, this aspect has not been implemented in the routine regional wetland management programs. The efficacy of wetland restoration depends on the biological components, socio-economic aspects, apart from the reduction of physical stressors. In this backdrop, diatom based water quality monitoring with the assessment of diatom distribution, ecological significance was undertaken for the first time for the regular monitoring of water bodies in Peninsular India. This study aims to investigate changes in and response of species composition to chemical conditions during prior and post restoration within and among selected wetlands Further, to assess the impact of restoration over a period, previously restored (>10 years) wetlands were compared to a reference (oligotrophic) water body and polluted (eutrophic) water bodies. Wetlands similar to reference (clean) conditions was defined based on Bennion et al., 2011.

Study area

The studied wetlands are shown in Figure 1. Polluted, reference and restored wetlands fall within the Bangalore region at a latitude of 12.95º N and longitude of 77.57º E and altitude of 920 meters a.m.s.l. The spatial extent of the region is about 900 sq.km., with an annual precipitation of 924 m and the temperature varying from ~15º C (January) to ~36ºC (April/May) (http://www.imd.gov.in accessed on 21/12/2012). Kempegowda, the founder of Bangalore constructed several lakes during the 16th century to meet the domestic water needs (drinking, irrigation, etc.). These lakes with biological entities function as wetlands and have been recognized as wetlands as per Ramsar Conventions. During the 19th century, industrialization paved way for the conversion of major watersheds into residential and commercial areas, causing a decline in the number of wetlands. Rapid urbanization in recent times has led to 63.2% increase in built-up area (from 1973 to 2010) and the loss of 78% waterbodies and 76% vegetation cover (Ramachandra et al., 2012). Sewage generated in the city is either untreated or partially treated that finally gets into these waterbodies leading to the enrichment of nutrients due to the sustained inflow. An earlier analysis has revealed an increase in air temperature by 2Ë%C annually (Ramachandra and Kumar, 2008). Bangalore being located on a ridge has four watersheds namely Hebbal, Koramangala, Challaghatta and Vrishabhavathi with an interconnected wetland system. In this study, five wetland types were selected for monitoring the changes during prior-restoration (PRR) and post-restoration (POS) periods. In addition to these, three polluted (POL) wetlands , three reference (REF) wetlands and three previously restored wetlands (PVR) were monitored for comparative assessment of water quality (refer Table 1).

Table 1 List of wetlands studied in respective groups (in Bold) and their number of taxa, % Eutrophic taxa, Shannon diversity index and dominance.

Wetland names	Number of taxa	% Eutrophic species	Shannon diversity H'	Dominance D
Reference wetlands				
Hoskere	18.5	20.7	2.1	0.20
Nelakondoddi	17.5	6.2	2.2	0.15
Hesaraghatta	7.5	0.79	1.16	0.37
Previously restored wetlands				
Ulsoor	2.5	100	0.38	0.8
Hebbal	15.5	44.8	2.28	0.13
Madiwala	12	79.9	1.8	0.23
Polluted wetlands				
Yelahanka	7	90.5	0.75	0.65
Varthur	5.5	91.7	1.28	0.37
Yellamallappachetty	6.5	93.8	1.52	0.27
Prior- restoration wetlands				
Kommaghatta	13.5	25.6	1.7	0.31
Kothanur	17	63.4	1.9	0.21
Rachenahalli	15.5	31.4	1.9	0.27
Jakkur	21.5	84.9	1.93	0.29
Somapura	21.5	10.3	1.29	0.51
Post- restoration wetlands				
Kommaghatta	24.5	63.7	2.5	0.12
Kothanur	10.5	68.8	1.72	0.26
Rachenahalli	18	81.8	2.23	0.15
Jakkur	17.5	71	2.3	0.12
Somapura	12	30.9	1.64	0.26

METHODS

Diatom Sample Analysis

Benthic diatoms were collected from 30 sampling sites across selected wetlands during both prior to restoration (October 2009) and post-restoration (November 2011) from all available habitats (Epiphytic, Epilithic and Episammic). Samples were carried to laboratory and observed immediately in order to record live and dead valves. Samples with dead valves were not considered for further analysis. Cleaning and enumeration of samples was carried out following laboratory procedures as per Taylor et al., (2005) and Karthick et al., (2010). Samples were cleaned using Hot HCl and $KMnO_4$ and slides were prepared using Naphrax® as the mounting solution. 400 valves were counted using light microscope model Olympus BX51 equipped with JENOPTIC mircophotographic system from each sample to determine percentage relative abundance of each taxon. Diatoms were identified to species level using Taylor et al., 2007; Krammer and Lange-Bertalot, 1986-1991 and Gandhi, 1998.

Water sampling

Water samples were collected from 10 to 30 cm underneath the water surface and stored in disinfected plastic bottles for laboratory analyses. Samples were immediately transported to the laboratory and refrigerated for subsequent water quality analysis. Parameters such as water temperature, pH, electrical conductivity and dissolved oxygen were assessed onsite using portable electrode probe. Laboratory analyses included total alkalinity, biological oxygen demand (BOD), chemical oxygen demand (COD), total hardness, inorganic phosphates (PO_4^{3-}), nitrates (NO^{3-}) and chlorides (Cl^-) following standard protocol of American Public Health Association (APHA, 2005).

Data Analysis

Principal component analysis (PCA) was carried out to prioritize the environmental factors that reflect variation in species across wetland types. Diatom taxa occurring in at least one sample with a relative abundance >10% were considered for diversity estimations and statistical analyses. Diversity indices like Shannon, species richness, evenness and dominance were estimated. % Eutrophic taxa were calculated following van Dam et al. 1994 classification. Non- metric multidimensional scaling (NMDS) was performed using PAST version 2.19 (Hammer et al., 2001), to describe patterns in diatom composition with respect to five groups of wetlands. The resulting pattern represents similar wetlands cluster in ordination space while no/dissimilar wetlands were spaced apart. The stress value assigned reflects how well the ordination summarizes the observed distances among the samples.

Results

A total of 115 species belonging to 41 genera has been recorded from the investigated wetlands. The species occurring at e"10% relative abundances (RA) in at least one sample has been considered for further analyses and plotted in figure 2 and 3. The dominant taxa at reference (Clean) wetland were *Achnanthidium* Kützing, *Encyonema mesianum* Cholnoky, *Gomphonema gracile* Ehrenberg, *Gomphonema angustatum* (Kützing) Rabenhorst and *Fragilaria* sp., whereas polluted wetland was characterized by abundance of *Cyclotella meneghiniana* Kützing, *Nitzschia umbonata* (Ehrenberg) Lange-Bertalot, *Nitzschia palea* (Kützing) Smith, *Fallacia pygmea* (Kützing) Stickle & Mann and *Staurosirella pinnata* Ehrenberg. Previously restored wetlands have been included in this study for a comparison analyses of species distribution in clean, polluted and recently restored wetlands (Figure 2a-2c). Previously restored wetlands continued to inhabit dominant taxa like *Fragilaria ulna* var. *acus* (Kützing) Lange-Bertalot, *Cyclotella meneghiniana*, *Diadesmis confervaceae* Kützing and *Seminavis strigosa* Hustedt. Species level identification of genus *Achnanthidium* is incomplete due to complexity and its wide range of occurrence. Two *Gomphonema* sp. could not be identified to species level necessitating further taxonomic assistance. *Fragilaria ulna* var. *acus* was found to be abundant (e"90% RA) at previously restored wetland (Ulsoor wetland) while analyses of Hebbal wetland recorded the dominance of *F. ulna* var. *acus*, *G. parvulum* and *Bacillaria paradoxa* Gmelin that showed less similar assemblage pattern from the rest of the wetland types.

Prior- and Post-Restoration Diatom Assemblages

Distribution of dominant species across wetlands during prior to restoration is given in Figure 3a. Forty diatom genera comprising of 101 species were identified

Table 2 Summary of physical and chemical parameter across wetland types (refer method section for water quality parameters)

Wetland Names	pH	EC (°C)	DO (mgL^{-1})	BOD (mgL^{-1})	COD (mgL^{-1})	N (ppm)	P (ppm)	TH (mgL^{-1})	CHL (mgL^{-1})	ALK (mgL^{-1})
Reference wetlands										
Hoskere	7.25	401	7.5	3.32	18.6	0.24	0.004	116	42.6	180
Nelakondoddi	7.41	368	7.85	3.95	18.33	0.54	0.04	106	44.02	180
Hesaraghatta	8.29	574.5	8.35	3.35	14.3	0.64	0.12	168	99.4	250
Previously restored wetlands										
Ulsoor	9.43	657	2.84	16.47	42.94	0.22	1.95	254	376	476
Hebbal	7.99	641.5	6.62	16.56	41.22	0.07	0.17	152.16	319.5	225.5
Madiwala	7.38	1787	4.86	64.5	177.3	0.29	2.74	386	328.02	620
Polluted wetlands										
Yelahanka	9.19	1285	3.69	24.16	58.32	0.22	1.48	275	429	566
Varthur	7.04	1245.5	2.96	34.27	81.3	0.42	1.71	268	187.44	500
Yellamallapa chetty	6.93	1253	0	32.63	78.66	0.44	1.58	260	190.28	520
Prior- restoration wetlands										
Jakkur	8.04	1283	5.79	23.9	64.01	0.01	0.03	336.6	291.1	163
Rachenahalli	9.07	870	7.54	18.63	56.72	0.02	0.02	222	199.75	120
Kommaghatta	8.99	773.25	5.34	19.50	56	0.06	0.02	292	114.45	209
Kothanur	9.12	667	7.23	21.9	46.5	0.07	0.05	75	140.58	193
Somapura	8.74	1022.66	6.49	8.59	26.33	0.08	0.05	111	101.53	276
Post- restoration wetlands										
Jakkur	7.92	877	5.5	9.2	46	0.07	0.03	188.6	188.33	124
Rachenahalli	8.19	867	4.63	7.15	35.75	0.03	0.05	124	139.3	156
Kommaghatta	8.3	651	8.21	6	30.02	0.11	0.04	144	33.66	203
Kothanur	7.17	1039	1.58	13.9	69.5	0.11	0.33	172.75	256.06	105
Somapura	8.265	548	6.99	4.5	22.5	0.1	0.11	62.25	33.2	50

from 15 sampling sites (3 sites in each wetland). The most common and abundant species were *Achnanthidium* Kützing, *Cyclotella meneghiniana*, *Diadesmis confervaceae*, *Gomphonema parvulum*, *Gomphonema* sp.1, *Gyrosigma accuminatum* (Kützing) Rabenhorst, *Nitzschia amphibia* Grunow, *Nitzschia palea* (Kützing) W. Smith, *Halamphora veneta* Kützing, *Gyrosigma rautenbachiae* Cholnoky and *Cymbella kappi* (Cholnoky) Cholnoky. Distribution of dominant species across wetlands during post restoration period is given in Figure 3b. A total of 71 taxa from 32 genera had been recorded (15 sampling sites with 3 in each wetland). Dominance of species like *Rophalodia gibba* (Ehrenberg) O. Muller, *Nitzschia palea*, *Gomphonema parvulum*, *Achnanthidium eutrophilum* Lange-Bertalot, *Caloneis bacillum* (Grunow) Cleve, *Encyonopsis microcephala* (Grunow) Krammer, *Gomphonema affine* Kützing, *Navicula symmetrica* Patrick and *Tryblionella apiculata* Gregory were observed. *Gomphonema* sp.1 which was identified as new taxa was found to be absent in post restoration in Somapura wetland.

Comparison among wetland types

The pattern in the number of taxa, % eutrophic taxa, Shannon diversity (H') and dominance (D) within studied wetlands are listed in Table 1. Highest number of taxa was recorded at reference sites (Hoskere and Nelakondoddi wetlands) and post-restoration sites of Jakkur. Percentage eutrophic taxa explained the trophic status at polluted wetlands (92.055 ±1.68%) followed by previously restored wetlands (74.9±27.9%). Even though taxa were equally high at post-restoration (POR) (no. of taxa =17.8±3.59) and prior restoration (PRR) (no. of taxa =16.5±5.55), eutrophic taxa dominated in the former group. This might be due to the removal of macrophytes and disturbance of sediments during desilting restoration process. Lowest species diversity was observed in polluted wetland type (H'=0.74-1.52) and previously restored sites (H'=0.38-1.8), while highest species diversity were observed at reference sites of Nelakondoddi (H'=2.2) followed by post restoration wetlands at Kommaghatta sites (H'=2.5). *Fragilaria ulna* var. *acus* were dominant in previously restored wetlands (D=0.84) and *Nitzschia palea* were dominant at polluted wetland (D=0.69) types, however the lowest dominance was observed at reference (D=0.24) and post-restoration (D=0.182) sites showing more evenly distributed taxa. Physical and chemical analyses of different wetland groups are given in detail in Table 2. Results provided a comparison between wetland types with similar pattern of pollution status among polluted and previously restored wetlands. Most of Bangalore's wetlands showed neutral to alkaline pH range (7.04-9.43). Electric conductivity (EC) represented higher values at polluted, prior restoration and previously restored sites, which were exceeding Bureau of Indian Standards (BIS) for Inland/Surface waters' limits of surface waters. While wetland like Kothanur (average=1039μScm^{-1}) showed persistent higher values even after restoration.

Variation among wetlands with respect to biological oxygen demand (BOD) and chemical oxygen demand (COD) are listed in table 2. One-way ANOVA (analysis of variance) was performed to determine significant differences ($p<0.05$) among wetland groups with respect to diversity and % eutrophic taxa (Table 3). Percent eutrophic taxa (%ET) differed significantly among reference (REF), previously restored (PVR), post-restored (POR) and polluted (POL) wetland type with significant $p<0.05$, but similar between post-restored (POR), previously restored (PVR) and most of the prior restored wetlands (PRR). This indicated that there is no improvement in water quality in the earlier restored wetlands of Ulsoor and Madiwala due to continued inflow of sewage or misuse of wetlands during post restoration. Thus, identical values of chemical parameters at POR, PRR and PVR resulted in similar diatom community structures. ANOVA analyses also demonstrated that there was significant ($p<0.05$) difference within the wetland groups due to the various human disturbances.

Non-metric multi-dimensional (NMDS) analyses was plotted to demonstrate the clustering of wetlands based on the diatom distribution and is represented in Figure 4. With a stress value of 1.499, NMDS axis 1 and 2 showed 0.48 and 0.368 variance, distributing all sampling sites into three clusters (Figure 4). Prior (shown as circles) and reference (shown as plus signs) sites were clustered into one group along with the Somapura wetland sampled during post-restoration (shown as rectangles). Top left group clustered polluted sites (shown as cross signs) with post restoration sites. The

Table 3 One-way ANOVA analyses to measure variation among wetland type in terms of %eutrophic taxa and Shannon diversity index. (PVR- previously restored wetlands; POR- post restoration wetlands; PRR- prior-restoration wetlands; POL- polluted wetlands; REF reference/clean wetlands)

% Eutrophic taxa	SS	df	MS	F	p-value
PVR v/s POR	289.45	1.5	289.4	0.48	0.51
REF v/s POL	10281.69	1.4	10281.69	187.9	0.00016
REF v/s PVR	6464.78	1.4	6464.78	14.57	0.018
REF v/s POR	4753.03	1.5	4753.03	14.37	0.012
PRR v/s POR	1018.81	1.8	1018.81	1.58	0.24
Shannon diversity	**SS**	**df**	**MS**	**F**	**p-value**
PVR v/s POR	1.3	1.5	1.3	2.6	0.13
REF v/s POL	1.24	1.10	1.24	5.4	0.04
REF v/s PVR	0.35	1.10	0.35	0.62	0.44
REF v/s POR	0.47	1.11	0.47	1.82	0.2
PRR v/s POR	0.58	1.18	0.58	2.9	0.1

top right group characterized previously restored (shown as squares) polluted sites and Jakkur during prior restoration. Thus, Jakkur continued to be with higher levels of pollution in both prior and post restoration samples. NMDS axis 2 and relative abundance of *Achnanthidium* sp. indicated a strong similar species pattern along REF and PRR wetlands. NMDS axis 1 displayed scatter without any prominent cluster between top right and top left groups. However, high relative abundance of *Fragilaria ulna* var. *acus* (>80%) characterized Ulsoor among polluted wetlands.

DISCUSSION

In the current study, an attempt was made for the first time to analyze the degree of pollution in wetlands using diatom assemblage patterns and assessment of water quality class during post-restoration period. A wide range of species distribution was observed reflecting both clean and pollution status in various wetland types. The relationship between species composition and chemical parameters in different water bodies, their influence on the former has been proved to be indicative of anthropogenic disturbances (Stenger-Kovács et al., 2007). Diatom distribution within Bangalore's wetlands showed clear differences in five wetland types, and across prior restoration and post-restoration periods. Samples collected prior to restoration and at polluted sites were characterized by pollution resistant taxa of high saprobic status and low oxygen saturation (van Dam et al., 1994). Diatom taxa composition, which was sampled five months after completion of restoration, showed continued pollution at Jakkur, Rachenahalli and Kothanur, which were identical to polluted wetland type (as in Table 2), implying that the impact of wetland restoration program is minimal or nil.

Cyclotella meneghiniana in 2008-2009 was replaced with *Nitzschia palea* in 2011 at Jakkur owing to the persistent human disturbances and inappropriate restoration technique where physical restoration was implemented rather than biological restoration. Pristine water bodies were characterized with pollution sensitive species of genus *Achnanthidium* and *Gomphonema* sp. (excluding *G. parvulum*). The restored wetlands (except Somapura), previously restored and polluted wetlands were composed of >50% taxa that are indicative of their polluted status (excessive contamination with high BOD and COD). This clearly concludes that either the restoration was ineffective or these wetlands continued to receive untreated sewage even after the restoration process. Thus, the treatment of sewage to avoid contamination of surface water has been a dilemma for environment managers (Ramachandra, 2005). The time required by (a solitary or colonial) species to be stabilized/ restructured into a new environment might also

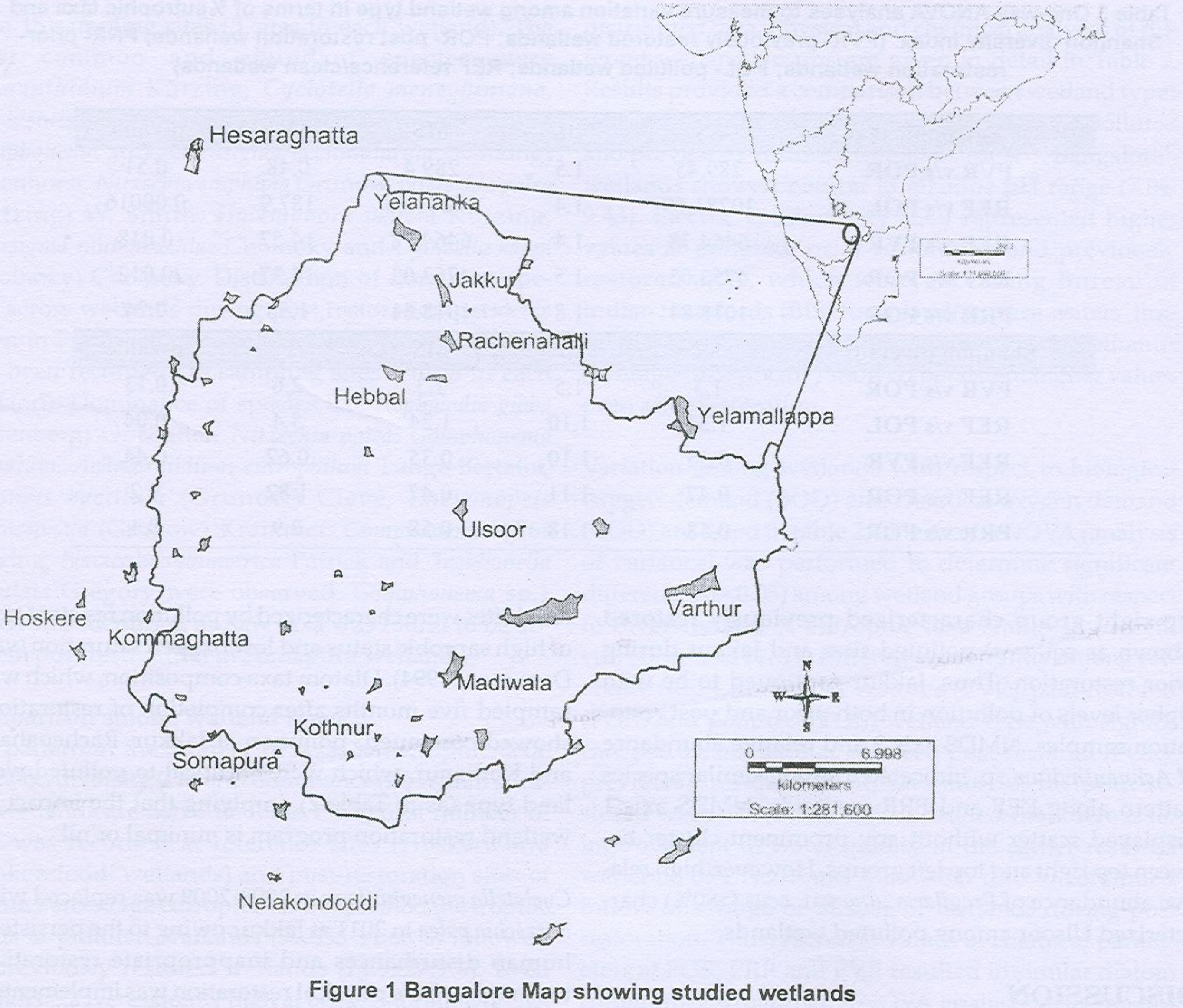

Figure 1 Bangalore Map showing studied wetlands

vary depending on the environmental conditions in each eco-region. Recovery of aquatic organisms in the restored water body would take time spanning from months to years (Craft and Richardson, 1998; Jüttner et al., 2010). Though we consider the concept of the time period of years to be reasonable enough for the re-growth of original/lost species for reflecting good water status, it has not been observed in any of the wetlands that were restored a decade ago in Bangalore region. Previously restored wetlands such as Ulsoor, Hebbal and Madiwala, showed species composition that characterized high levels of pollution. Diatom species composition reflected trophic levels in water quality based on nutrient load and was similar to that of water quality analyses derived from physical and chemical analyses of water. Thus, diatom based biomonitoring could be used as surrogate as well as supplement for chemical variables. Regular monitoring of wetlands using diatoms help in nutrient management and sewage inflow regulations for better management of different components (water, biodiversity, etc.) of wetlands. Further, the process of restoration must ensure that the restored wetland should provide habitat for all forms of life ranging from microscopic to larger benthic organisms. It has been documented that any disturbance or removal of submerged macrophytes in a shoreline region declines species diversity and if sewage inflow persists, it might impact in en-

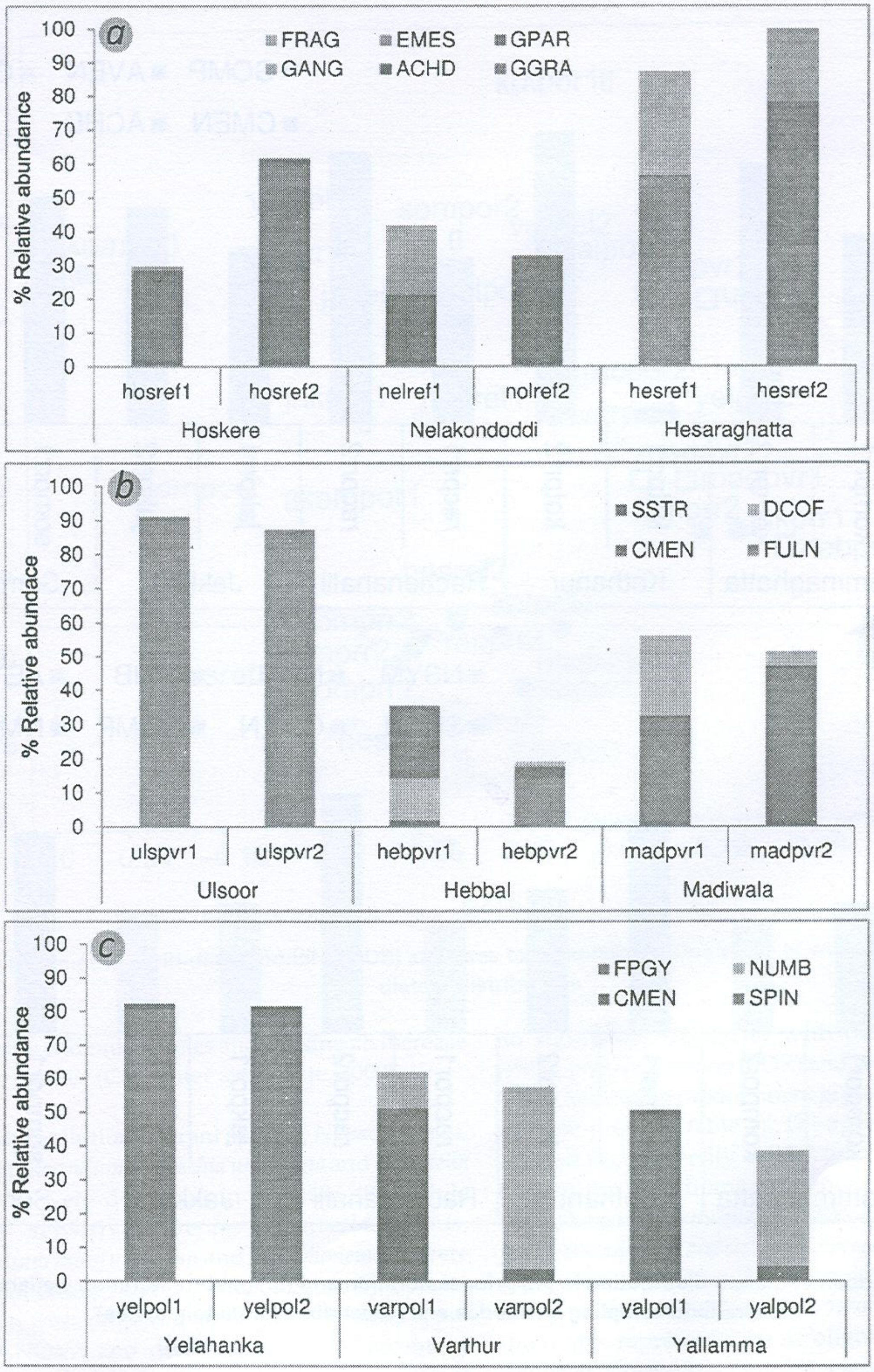

Figure 2 Diatom distribution in different wetlands (a.) reference wetlands, (b.) polluted wetlands and (c.) previously restored wetlands. (See Table 1 for wetland sampling site codes).

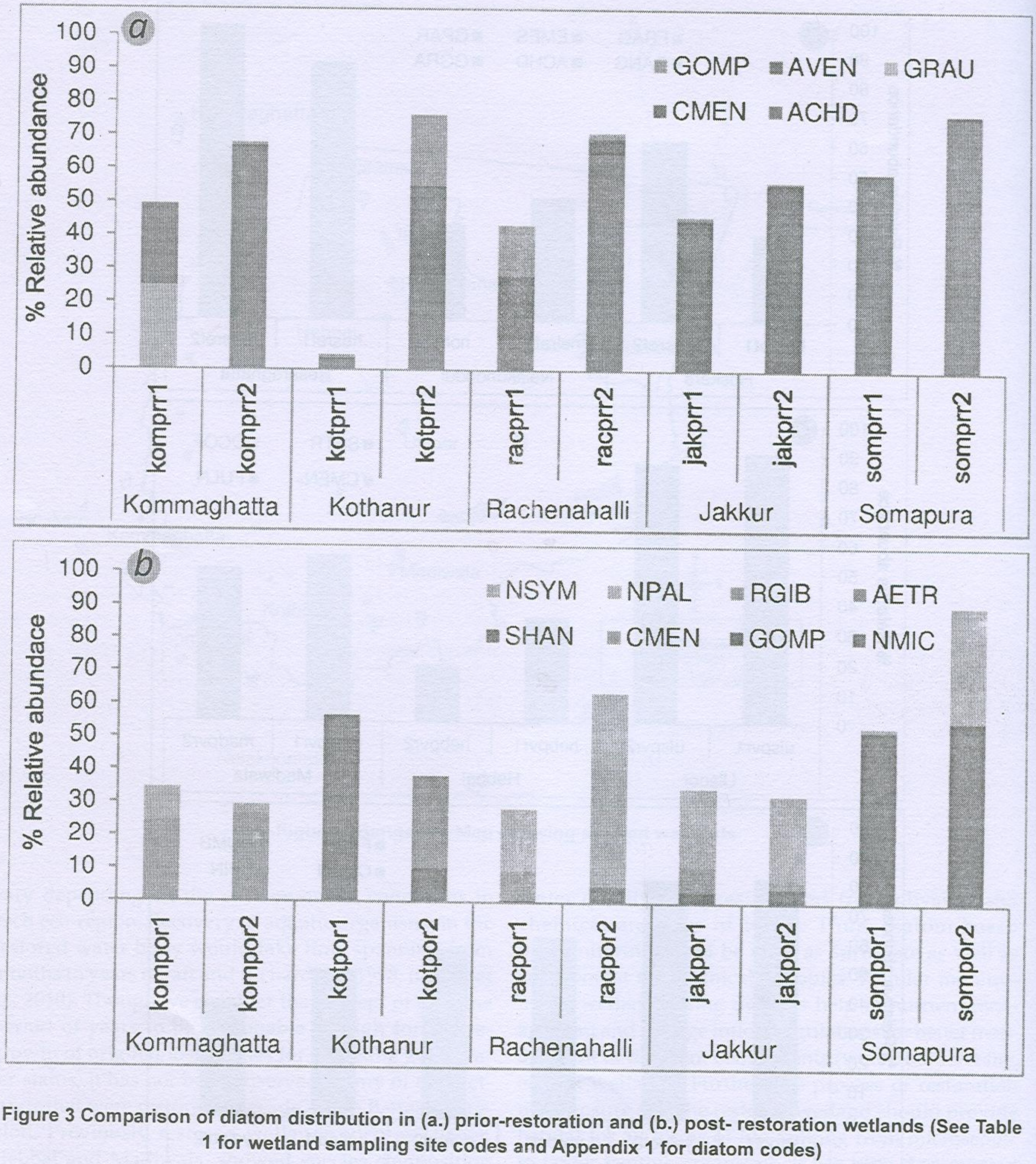

Figure 3 Comparison of diatom distribution in (a.) prior-restoration and (b.) post- restoration wetlands (See Table 1 for wetland sampling site codes and Appendix 1 for diatom codes)

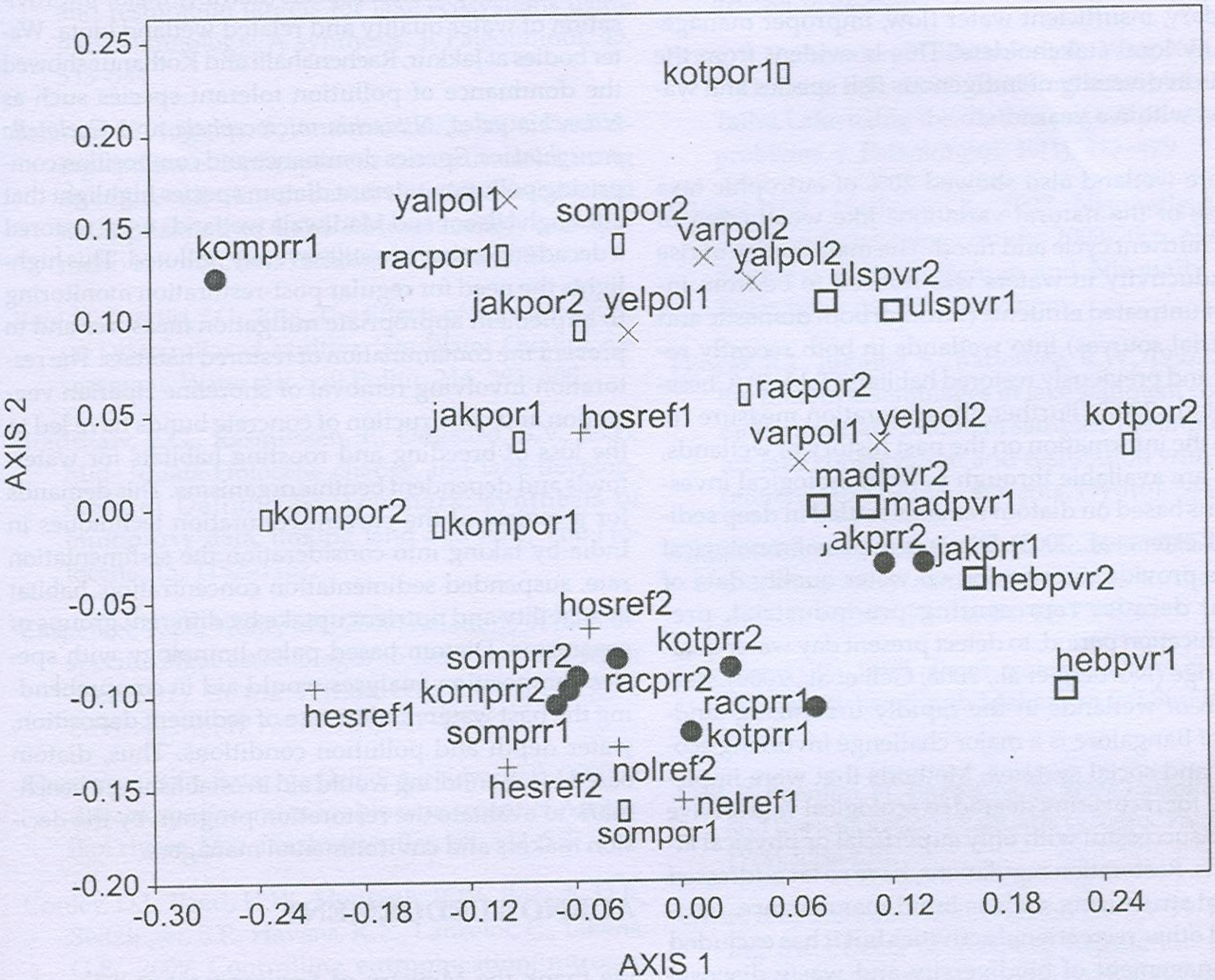

Figure 4 Non-metric multi-dimensional (NMDS) analyses to demonstrate clustering of wetlands based on the diatom distribution.

dangering the endemic species and causing an increase of invasive species (Carpenter and Waite, 2000).

In this study, pollution tolerant species; *Nitzschia palea, Gomphonema parvulum, Nitzschia umbonata* and *Cyclotella meneghiniana* were dominant in polluted sites while pollution sensitive species *Cymbella affinis, Achnanthidium minitussimum* and *Gomphonema* sp were dominant in clean/ reference sites (Figure 2). Species distribution was compared among five wetland types through ANOVA and diversity indices. Percentage eutrophic taxa composition was significant ($p<0.05$) at polluted wetlands (POL), whereas REF sites showed no significant similarity with previously polluted (PVR), post-restoration (POR) and prior restoration sites (PRR), indicating predominant growth of eutrophic taxa in latter groups (Table 1). Though Shannon diversity showed high diversity at POR than REF, it was caused due to the dominance of pollution tolerant taxa (*Gomphonema parvulum, Rophalodia gibba, Cyclotella meneghiniana* and *Nitzschia microcephala*). Hesaraghatta (REF)-devoid of any anthropogenic activity (during the study period of 2008-2011) showed less primary productivity- representative of oligotrophic conditions; however, Currently (2012-13), Hesaraghatta is experiencing severe anthropogenic activities including the problems associated with the undefined wetland boundary, insufficient water flow, improper management by local stakeholders. This is evident from the decline in diversity of indigenous fish species and waterfowl within a year.

Hoskere wetland also showed 20% of eutrophic taxa because of the natural variations like weathering of rocks, nutrient cycle and flood. The main source of rise in conductivity in waters was noticed to be from inflow of untreated effluents (through both domestic and industrial sources) into wetlands in both recently restored and previously restored habitats (Table 2) (Chessman et al., 2007). Further, the restoration measure requires the information on the past history of wetlands, which are available through paleolimnological investigations based on diatom remains settled in deep sediment (Köster et al., 2005). Diatoms in paleolimnological studies provide information on water quality data of several decades representing pre-industrial, pre-eutrophication period, to detect present day water quality change (Norberg et al., 2008; Gell et al., 2009). Restoration of wetlands in the rapidly urbanizing landscape of Bangalore is a major challenge involving ecological and social systems. Methods that were implemented for recovering degraded ecological values have been unsuccessful with only superficial or physical alterations. Restoration regulations, have so far addressed physical structuring such as bund maintenance, fencing and other recreational activities but it has excluded the management of biodiversity and waste disposal (Ramachandra, 2005; Ramachandra and Majumdar, 2009). This study addresses various issues related to degradation of urban wetlands, especially in Bangalore, and the complexities faced in the restoration process (Ramachandra et al., 2002; Ramachandra, 2005). Goals of wetland restoration have to be prioritized based on the scale and nature of threats along with supplementary information on biodiversity prior to the restoration. Further, wetlands management should include biomonitoring using diatoms, sediment analyses, buffer zonation, microhabitat analysis and efficacy of waste management.

CONCLUSION

Restoration of wetlands in Bangalore has only resulted in changes of physical aspects than any major improvisation of water quality and related wetland biota. Water bodies at Jakkur, Rachenahalli and Kothanur showed the dominance of pollution tolerant species such as *Nitzschia palea*, *Nitzschia microcephala* and *Cyclotella meneghiniana*. Species dominance and composition comprising pollution tolerant diatom species highlight that although Ulsoor and Madiwala wetlands were restored a decade ago, they are still severely polluted. This highlights the need for regular post-restoration monitoring to implement appropriate mitigation measures and to prevent the contamination of restored habitats. The restoration involving removal of shoreline riparian vegetation and construction of concrete bunds have led to the loss of breeding and roosting habitats for waterfowls and dependent benthic organisms. This demands for a review of the current restoration techniques in India by taking into consideration the sedimentation rate, suspended sedimentation concentration, habitat availability and nutrient uptake by different groups of organisms. Diatom based paleo-limnology with species composition analyses would aid in comprehending the past water quality, rate of sediment deposition, water depth and pollution conditions. Thus, diatom based bio monitoring would aid in establishing a benchmark to evaluate the restoration program by the decision makers and environmental managers.

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Annexure 3

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RESEARCH ARTICLE OPEN ACCESS

ROLE OF MACROPHYTES IN A SEWAGE FED URBAN LAKE

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ABSTRACT

Macrophytes play a major role in maintaining the nutrient levels in urban aquatic systems. However their prolific growth result in spread of invasive species such as water hyacinth (Eichhornia crassipes) due to the availability of higher nutrient concentrations. This hinders aerobic functioning of the lake by restricting sunlight penetration and also affecting algal photosynthesis. This also results in anoxic environment due to blockage of air-water interface, influencing oxygen diffusivity. Reduction in DO (0 mg/l) impacts the viability of aquatic biota and result in the disappearance of biodiversity. This communication evaluates the influence of the invasive macrophytes in the functioning of lake across the seasons. Significant seasonal changes in water quality were noticed due to changes in the redox conditions (- 235 mV) and dissolved oxygen levels at various locations depending on the extent and location of macrophyte spread based on the nutrient levels coupled with wind regime prevailing during the season. The analysis of seasonal data reveals that dissolved oxygen concentration and redox condition is dependent on the extent of macrophyte spread. N content in Lemna and Alternanthera species (of 4 g/100 g dry weight) is significant compared to other species (p<0.005). During monsoon, lake functions in the absence of macrophytes, predominantly as aerobic lagoon; and functions as aerobic-anaerobic lagoon (pre-monsoon) and as anaerobic–aerobic system (post-monsoon). Anaerobic conditions are mainly due to the interference of macrophytes in lake functioning and inefficient handling of nutrients in the absence of algae. This necessitates the regular removal of macrophytes from the lake. Provision to allow the growth of primary producers will help in nutrient management.

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macrophytes; wastewater; nutrients; eutrophication; lagoon; sewage; urban lakes

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[I] INTRODUCTION

Macrophytes grow in or near water and are emergent, submergent, or floating, forming a vital component of lake ecosystems. However, the introduction of invasive-exotic species such as water hyacinth (*Eichhornia crassipes*), alligator weed (*Alternanthera phyloxiroides*), water lettuce (*Pistia stratiotes*) etc. have changed the lake dynamics significantly. In recent times the urban waterbodies are being used for the disposal of sewage, etc. Sustained inflow beyond the assimilative capacity of waterbodies has lead to eutrophication, resulting in the profuse growth and spread of invasive species. Influx of partially treated and untreated sewage has resulted in overgrowth, ageing, and subsequent decay of macrophytes creating anoxic conditions and devouring the system from life giving oxygen. This has impacted the food chain and hence the ecological integrity of the system.

Water hyacinth (*Eichhornia crassipes*) native to Brazil has been introduced to tropical and subtropical region, [1] is amongst the fastest growing, free floating freshwater invasive weed species which derives required nutrients directly from water. Its distribution and dispersal is aided by water currents and wind. It consists of 5% dry matter with 50% silica, 30% potassium, 15% nitrogen and 5%protein[2]. Its potential negative characteristics pose a threat for the habitat quality of waterbodies. The average growth rate of water hyacinth is 10-12 $g/m^2/d$ and the maximum is 45-50 $g/m^2/d$ [3, 4, 5]. During growth, water hyacinth can store N up to 909 g/m^2 [6]. These invasive aquatic plants form a thick 'mat' that restricts the exchange of oxygen across the air/water interface and also hampers algal photosynthesis resulting in reduced dissolved oxygen. The anoxic conditions under water hyacinth mats also favour the release of nitrogen and phosphorous (N and P) from sediments which may further aid the rapid growth of macrophytes [7, 8, 9]. In addition, it influences the wind-driven water movement, impeding circulation of oxygen-rich surface water [10]. Bank side grasses grow over the water hyacinth mats, anchoring the mats to the bank edges. Varieties of grasses and sedges as *Cyperus* sp. and in some instances, plants like *Colocasia esculenta* (taro) etc. have established themselves on these mats. Once established, very large flows are required to break them up and disperse.

The southwest monsoon winds tend to push the floating macrophytes over spillways of lakes situated on their south-eastern, eastern and southwestern edges, thereby ridding the water surface free of macrophytes each year. This natural flushing of macrophytes during monsoon associated with the

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phenological events was considered to be the most important short-term process for cleaning urban lakes. The macrophytes in their matured stage are infested by the mottled water hyacinth weevil and caterpillar that reduces about 75% of the leaf surface areas in 2-3 weeks, consequently resulting in loss of the major photosynthesizing machinery i.e. the leaves and greatly helps in compacting the water hyacinth mass, as they also disrupt the long, spongy and bulbous stalk tissues, the plants lose their buoyancy and settles faster which is followed by leaching of plant nutrients and subsequently rapid bacterial degradation takes place which reduces the DO levels significantly and creates anaerobic conditions throughout the lake. Thus this process submerges a large quantity of organic matter which ultimately decomposes, increasing the biochemical oxygen demand (BOD) that deteriorates water quality. Dissolved oxygen falls to such low level that leads to massive fish kills [11].

Oxygen is amongst the most important of several dissolved gases vital to aquatic life. It is a principal and direct indicator of water quality in surface waters. Primary source of oxygen in surface water is from photosynthesis of aquatic plants, algae and diffusion of atmospheric oxygen across the air water interface. The dissolved oxygen content of natural water varies with the temperature, photosynthetic activities and respiration or decomposition of plants and animals [12]. On a daily basis they maintain equilibrium as per the consumption and production. The diurnal oxygen cycle varies in a sinusoidal manner with minimum values observed early in the morning and maximum concentrations at midday [13]. A decline in DO has serious implications on the health of the aquatic system, as hypoxic and anoxic conditions reduce or eliminate sensitive native fish and invertebrate species.

During aerobic decomposition, cellulosic materials are converted into carbon dioxide and water by the bacterial action. CO_2 in the dissolved form maintains equilibrium with its carbonate and bicarbonate forms and decides the C supply for the algae and aids in photosynthesis bringing manifold increase in the primary productivity of the system. Oxygen level of the waterbodies are reduced by continuous inflow of sewage, containing large loads of organic carbon, phosphates and nitrates that finally lead to profuse growth and spread of aquatic biota. Under such circumstances, aquatic plants and algae proliferate incredibly and when they die they form food for bacteria, which in turn multiply and use large quantities of dissolved oxygen. In addition to this, when plant biomass increases at the surface of the water (pelagic zone) they block transmittance of sunlight into deeper layers and diffusion of oxygen from the atmosphere into the water, thereby, reducing photosynthetic potential of submerged plants and algal species. In addition to this, their extensive root system in the water provides a large surface area for the growth of microbes which rapidly consume DO [14]. These microbes render the system more anoxic by carrying out the anaerobic digestion on a myriad of substrates. Moreover, under anoxic conditions, ammonia, iron, manganese and hydrogen sulphide concentrations can rise to levels deleterious to biota. In addition, phosphate and ammonium are released into the water from anoxic sediments further enriching the ecosystem [15].

Varthur lake, situated in the south of Bangalore, was built to store water for drinking and irrigation purposes [16]. However, over the last five decades, due to sustained influx of sewage, nutrients in the lake are now well over safe limits. Sewage brings in large quantities of C, N and P which are trapped within the system. This lake receives about 40% of the city sewage (c.500million liters per day, MLD) resulting in eutrophication. There have been substantial algal blooms, dissolved oxygen depletion and malodour generation, apart from extensive growth and spread of water hyacinth that covers about 85% of the lake during the dry season.

Water hyacinth mats greatly reduces DO content in water under the mats [17, 8, 9] affecting aquatic diversity and productivity. Decomposition of macrophytes happens due to ageing, over-crowding, wind driven compaction, pest damage, etc. During oxidation, microflora utilize detritus C as an energy source and reduces electron acceptors such as oxygen, nitrate and sulphate [18]. Water hyacinth litter breaks down as a result of aerobic, anaerobic and facultative anaerobic microbial activity [19]. Bacteria accentuate degradation process and fungal decomposition under such conditions is negligible [20]. O_2 concentrations in water play an important role in the release and transformations of nutrients [21].

This paper focuses on the impact of wind induced drift of macrophytes, its removal during monsoon, and its rapid growth which governs the aerobic-anaerobic status of the lake and thereby brings out its relation with the water quality. The objectives of the study were to:

i. Determine the major contributor of the BOD load that disrupts the lake's functioning,
ii. Map oxic, hypoxic and anoxic zones based on DO levels and to understand the influence of wind induced drift of macrophytes on seasonal water quality changes and
iii. Quantify nutrient loads (C and N) and their uptake by macrophytes.

[II] MATERIALS AND METHODS

The field study was conducted in Varthur lake (12°57'24.98" - 12°56'31.24" N, 77°43'03.02" - 77°44'51.1"E) situated in the south of Bangalore, **[Figure-1]** which is the second largest lake in the city. It covers a water-spread area of 220 ha (maximum depth 2 m) and has a varying extent of floating macrophytes during different seasons. It is a part of a series of interconnected and cascading waterbodies. The Varthur lake catchment has seen large scale land use changes after 2000, following rapid urbanization.

Water samples were collected at 10-15 cm from the surface (to avoid floatables and macrophyte debris), every month over a period of twelve months and analyzed for various physico-chemical parameters-pH, water and air temperature, conductivity, turbidity, redox potential and dissolved oxygen (DO), BOD, COD and inorganic nutrient as per standard protocol of APHA [22]. The biomass/macrophyte coverage over the lake surface was also monitored with the help of GPS and remote sensing data. For macrophyte biomass estimation, 1 m^2 quadrate sampling method was adopted [23]. C and N contents were determined using CHN analyzer. The algal community structures at various sampling sites were also investigated. The nutrient content in water and biomass were analyzed. The pattern of the wind induced drift resulting in the movement of macrophyte population and the accumulation at different extremes of the lake was studied. Changes in the dissolved oxygen concentration and other water quality parameters were investigated with the macrophyte cover and resultant oxidizing or reducing environment.

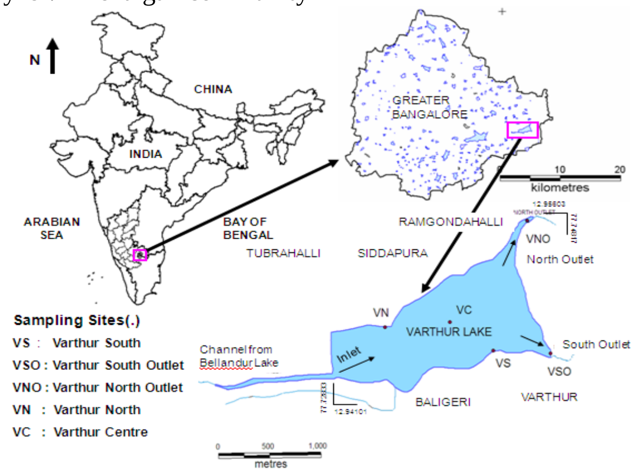

Fig: 1. Varthur lake, Greater Bangalore, India with sampling locations

[III] RESULTS AND DISCUSSION

3.1. Monthly variations of dissolved oxygen (DO) concentrations

Water quality parameters were monitored on monthly basis **[Table-1]**. Significant variations in mean monthly values of DO were observed **[Figure-2]**. DO ranged from 0-5 mg/l depending on the extent and density of macrophytes during the morning. In anthropogenically modified, weed-infested streams from upper reaches, deoxygenated water (DO = 0-0.3 ppm) arrives for most part of the day, due to high flow rates of water through extensive weed mats. The influx of hypoxic, nutrient rich wastewaters during the mid day is more stressful to aquatic biota as fish and invertebrates that undergo higher metabolic rates during the day require a higher DO than in the night.

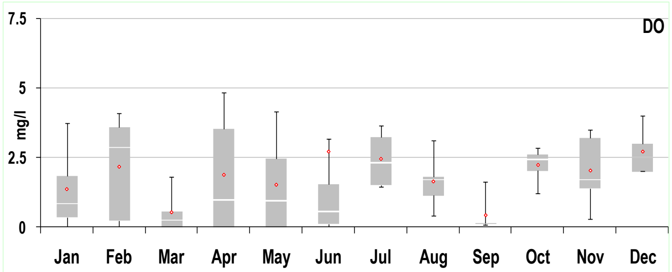

Fig: 2. Month-wise variations in Dissolved Oxygen

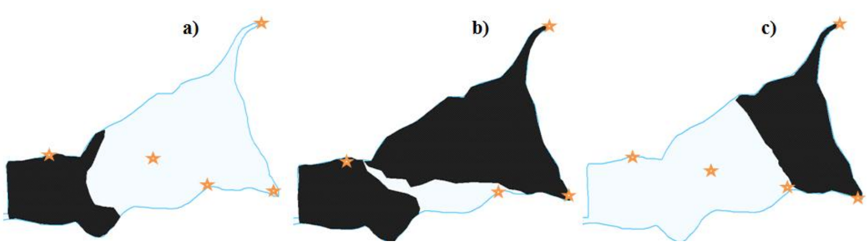

Fig: 3. Extent of macrophyte spread across seasons (extracted from satellite data)
Note: a) Winter b) Summer and c) Monsoon.

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According to BIS (IS 10500-1991) and CPCB standards, the oxygen saturation for surface waters should be around 75% (6 ppm), yet it is the minimum that decides the aptness of habitat for various species (rather than average-based guidelines). Most of the DO data for urban Indian lakes are spot one time measurements during daylight hours, when DO would be substantially above its minimum and in many cases, even approaching its maximum level. Such approaches are inadequate for determining the DO status of these urban waterbodies. Spot readings are used when oxygen levels are typically at their lowest and potentially most stressful for aquatic biota when there is an absence of continuous data [24].

Parameters	Units	µ	σ	Min	Max
Nitrates	ppm	0.304	0.219	0.1	0.96
Ammonium	ppm	15.06	7.6	3.93	30.73
Phosphates	ppm	0.98	0.7	0.14	3.5
Total Phosphates	ppm	7.86	2.44	3.14	9.87
BOD	ppm	89.65	38.54	44	186.1
COD	ppm	98.2	21.24	52	197.3
pH	units	7.61	0.64	6.2	8.22
EC	µS/cm	1054.4	158.64	751	1420
DO	ppm	1.56	0.67	0	13
Transparency	cm	23	3.16	18	28
Turbidity	NTU	78.5	25.6	29	224
ORP	mV	-9.33	129.29	-235	135

Table: 1. Physico-chemical parameters of Varthur lake.
Note: µ: mean; σ: standard deviation; Min: minimum, Max: maximum.

Field investigations reveal that DO is correlated to temperature (r = 0.79). Higher DO levels during the mid-day are due to enhanced algal photosynthetic activities with higher insolation. However during the night due to respiration of aquatic biota, DO levels drop to zero. Furthermore, higher variability in DO was observed during summer. In stagnant systems, which are not light limited, minima is typically around dawn, but in flowing conditions, upstream conditions, flow rates and mass loading make this less predictable.

3.2. Spatial analysis and seasonal effects on wind-induced macrophyte drift and consequent deposition

Varthur is a shallow, wind-influenced hypereutrophic lake characterized by consistent phytoplankton blooms and having higher deposits of unconsolidated organic sediment. The lake receives about 500 MLD sewage (measured) which undergoes anaerobic stage in the upper reaches of the lake. BOD at the inlet is about 120-200 mg/L, Algae driven oxidative BOD reduction facilitate the water to be oxic and brings down the BOD to about 30mg/L at outlets when the lake is not infested with exotic weeds. The algal population plays a pivotal role in maintaining the oxic condition's of the water. Preponderance of ammonia (~40 ppm; **[Table-1]**) at critical levels when the lake is infested with macrophytes poses a threat to the lake's aquatic biological food chain and its activities. The wind regime plays a decisive role in the spread and location of macrophytes mats in the lake. A study conducted to understand the DO levels in various locations of the lakes, reveals significant differences in the dissolved oxygen depending on presence or absence of macrophytes cover. The DO values were monitored in various seasons during the study period to address seasonal variability's. **[Table-2]**.

During the pre-monsoon summer period, the macrophytes grows luxuriously all over the surface of the lake **[Figure-3b]** thus creating anoxic zones (Oxidation reduction potentials ORP -65 to -225 mV), along with enhanced bacterial activities under higher reigning temperatures. Roots of the floating macrophytes provide a good substratum for the attachment of bacteria, drastically reducing the DO levels and resulting in hypoxia and anoxia. DO varies depending on the extent and density of macrophyte mats, evident from the significant difference ($p=0.00006<0.001$) **[Table-3]** in regions with or without macrophytes. This emphasize that lake functioned as anaerobic lagoon. The floating mat of macrophytes gets compacted with an anoxic environment just beneath it. With the increased amount of plant litter decomposition, it significantly contributes to higher autochthonous organic load and hence BOD. The DO values reveal consistent anoxic zones associated with the macrophytes and thus the seasonal changes in the pattern of oxygenation at various extremes of the lake.

During June, gusty westerly winds (4.7 m/s) drifts water hyacinth towards outlets **[Figure-3c]** and subsequent drifts compact water hyacinth which forms thick mat in the region. This compaction is aided by the pest infestation and ageing, which further helps in compacting and also reducing the biomass. This aids in rapid settling while decomposition often creates an anoxic environment near the outlets. The regions near the outlets were highly anaerobic (ORP -180 to -218 mV) with DO values 0 mg/l, compared to the upper reaches which were free from macrophytes (ORP +70 to +85) with DO values from 6.5 to 11.5 mg/l. DO concentrations at outlets were significantly different ($p=1.1 \times 10^{-12} <0.0001$) **[Table-3]** from the regions free of macrophyte cover (inlet and middle regions).

During monsoon, higher catchment run-off into the lake pushes macrophytes including decomposed, semi-decomposed plant litter to the downstream. This exposes water surface to air and sunlight allowing photosynthetic activities in the lake aiding algal growth **[Figure-3a]**. This process rejuvenates the system to aerobic status. Furthurmore higher inflow help in cleansing the system from superficial sludge accumulated at outlets which improves the system's performance. The sludge up-welled by wind turbulence comprises of semi-degraded macrophyte biomass (C: N = 50.05:3.02) showing that most of the C forms are intact. However lower values of N indicates uptake by micro organisms, algae and macrophytes.

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Table: 2. DO concentrations at the mid-day at various sites in all seasons

Sampling Location	DO Concentration at Mid-Day (ppm)		
	Pre-monsoon	Monsoon	Post-monsoon
Inlet	8	2.5	3.73
Centre	9.5	6.5	0.13
Outlet North	0	1.3	0.0
Outlet South	0	12.6	0.48
South	12	8.2	1.2

Table: 3. One way ANOVA for DO concentrations in all four studied seasons

Dependent Parameter	Source	Degree of Freedom	F value	p-value at < 0.00001
Summer DO	A	1	23.56	6×10^{-5}
	B	24		
	C	25		
Winter DO	A	2	24.99	4.16×10^{-5}
	B	24		
	C	25		
Monsoon DO	A	1	29.02	6.04×10^{-5}
	B	16		
	C	17		
Spring DO	A	1	396.93	1.1×10^{-12}
	B	16		
	C	17		

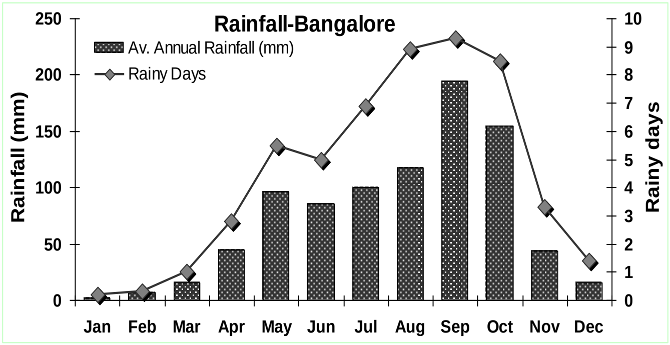

Fig: 4. Monthly rainfall variations near the Study area

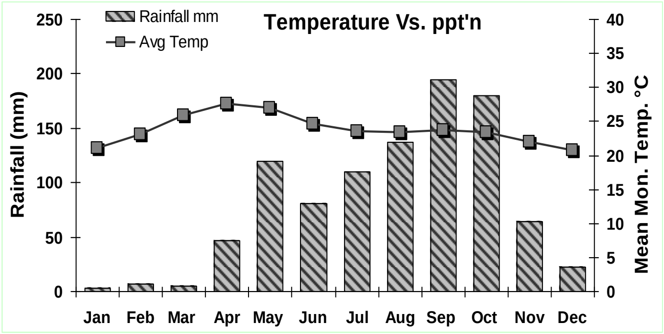

Fig: 5. Comparison between Mean monthly temperatures with the precipitation.

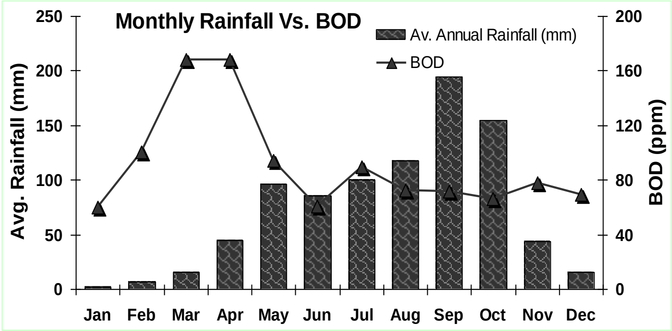

Fig: 6. Relation between the precipitation and mean BOD values

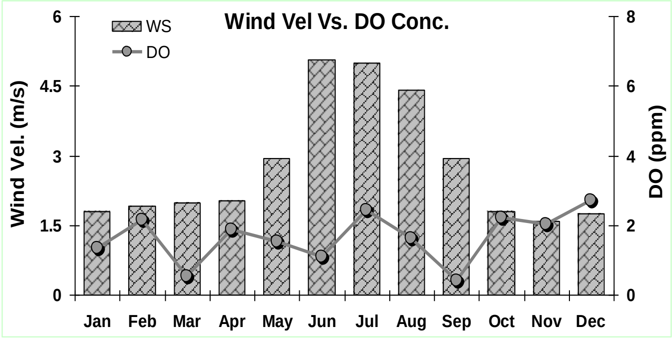

Fig: 7. Relation between the monthly wind velocities with avg. monthly DO level

3.3. Algal seasonal dynamics in the lake and role in supplementing DO level

Algal communities identified upto the genus levels shows algal species from four different families [Table-4]. During summer *Scenedesmus* sp., *Anabaena* sp. and *Anaycstis* sp. were dominant while enormous *Chlorella* sp. was observed during monsoon season (80 %). Micro-algal sampling studies also revealed a greater dominance of diatoms especially *Nitszchia* sp. near the inlet reaches during the summer and

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euglenophycean members like *Euglena* sp. and *Trichellomonas* sp. dominated in the monsoon. Filamentous algae's like *Oedogonium* sp. and *Oscillatoria* sp. were observed near outlets. Comparative analysis of algal populations in biofilms showed a marked difference in the community structures in various zones of the lake. Diatom species such as *Gomphonema* sp. and *Nitszchia* sp. at the inlet and chlorophytes and euglenoides were observed at the outlets. Field investigations reveal that there is a periodic transition from an anaerobic-aerobic (in monsoon) to anaerobic (in summer) and aerobic-anaerobic system (winter/pre monsoon) as algae play a vital role in oxygenating the system that lowers BOD. This depends upon the wind direction and the extent of growth and movement of the macrophytes together with the nutrient influx.

Table: 4. Algae communities identified upto genus level

Chlorophyceae	Cyanophyceae	Bacillariophyceae	Euglenophyceae
Chlamydomonas	*Cylindrospermo*	*Gomphonema*	*Phacus*
Chlorogonium	*-psis*	*Cymbella*	*Euglena*
Scenedesmus	*Arthrospira*	*Navicula*	*Trachelomonas*
Ankistrodermus	*Microcystis*	*Pinnularia*	*Lepocinclis*
Chlorella	*Oscillatoria*	*Nitzschia*	
Oedogonium	*Anabaena*	*Synedra*	
	Merismopedia	*Fragillaria*	
	Lyngbya	*Cocconeis*	
		Melosira	

3.4. Characteristic change in water quality and its improvement after flushing out of macrophytes by wind and water flow

The rainfall pattern shows an increase in the intensity mostly during August, September and October **[Figure-4]**. During pre-monsoon period dense mats of water hyacinth and other weeds covering 85% of surface had contributed to low DO levels that are detrimental for the phytoplankton. Faster decomposition of macrophytes and algal organic biomass due to high temperature (summer) **[Figure-5]** resulted in very high BOD values. The degree of mineralization and bacterial respiration was also very high at this time. BOD values were found to be lower during the other seasons especially in monsoon **[Figure-6]**. Prevalence of hypoxic conditions below critical thresholds over a long period is detrimental to the survival of aquatic biota. Onset of monsoon with higher wind velocities and higher catchment run-off allow the water surface to sunlight and re-aeration, enhancing DO levels **[Figure-7]**. The improvement included greater diurnal cycling **[Figure-8]**, both higher maxima and minima and reduced amount of time spent below the adopted 25% threshold for ensuring survival of all naturally occurring biota.

3.5. Macrophyte spread and DO levels

Dense macrophyte mats limit re-aeration by isolating the air/water interface [24] and block sunlight, limiting photosynthetic oxygen production. The concentration of DO in the lakes diminish as a result of biodegradation of carbonaceous and nitrogenous wastes discharged into the waterbodies, deposited in the sediment and the influx of plant limiting nutrients which leads to eutrophication. [25]. In addition, the large organic load created by water hyacinth mats and other vegetation associated with these mats, increase oxygen consumption [26, 27], and they act as a physical substrate for microbes, the metabolic activity of which further increases oxygen demand [26, 24, 9]. Additionally, the extent of water hyacinth infestation within the lagoons may modify edge roughness, water depth and current velocity allowing flowing water to pass through the middle layers of the water column thus reducing the detention time and greatly inhibiting mixing and re-aeration within the lake [26, 28]. In tropical semi-arid zone lakes, there are also substantial variations in DO between different periods of a day where occasional low DO levels can result in the elimination of key aquatic species. In the case of eutrophic lakes though the DO levels become supersaturated at the mid-day, there are chances of DO reaching 0 ppm due to respiration at night when the concentration of algal biomass is very high and bacteria as well as aquatic biota compete for oxygen resulting in anoxia at night.

During summer around 85% of the exposed water surface area is packed with macrophytes. Total N trapped in the biomass accounts to 1.8 ktons (for a macrophyte cover of 85% in a water spread area of 220 hectares) as water hyacinth can store 1 kg/m^2. Significant diurnal (January and April 2009) variations of DO levels in water were observed to be influenced by the macrophytes in the lake **[Figure-8, 9]**. Figure 8 shows DO measured at the south outlet when it is free of water hyacinth, while the **Figure-9** shows lower DO values measured near the macrophyte infested area which represents restriction of algal growth and algae driven photosynthesis. There was no improvement in the DO levels of the north outlet because of persistent stagnation and the presence of floating macrophytes. As the water flow passes the macrophytes, it undergoes an anaerobic phase, thereby bringing down the DO levels to zero. **Figure-9** gives a comparison between the inlet and outlet DO concentrations, during the dense macrophyte cover.

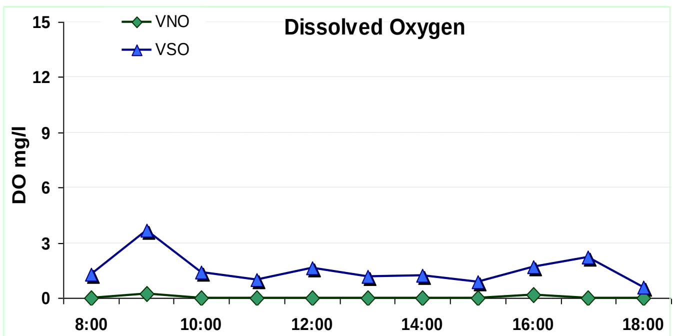

Fig: 8. Diurnal changes of DO levels during April 2009 (summer) at north outlets.

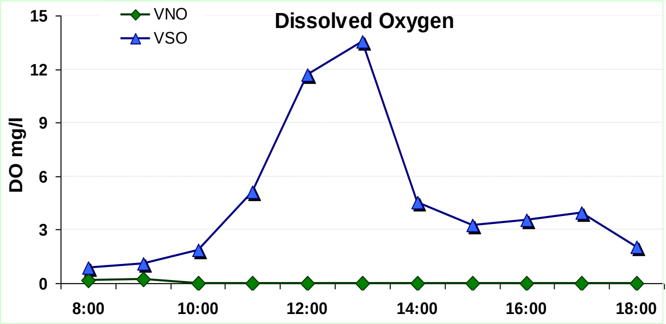

Fig: 9. Diurnal variations in DO concentrations at inlet and outlets

Upstream conditions greatly influences the downstream DO. Improvement in the oxygen content in the Varthur lake outlets shows increasing DO levels with flow. When water is released into storm water drains, its oxygen level is high. However, the oxygen content rapidly diminishes as water move downstream due to mixing of fresh sewage and prevailing anoxic conditions with high organic load and infestation of weeds. This necessitates the clearance of the macrophytes/weeds. Macrophyte removal in the upstream and increasing DO levels at earlier stages would improve the quality of water discharged and that accumulating in the downstream lakes.

3.6. Modified flows, nutrients, proliferation of water hyacinth and rapid nutrient uptake

There is a dynamic interaction between flow, habitat condition and DO saturation in these lakes. Almost all lakes in Bangalore region receive a continuous supplemental dry season flow from sewage or the adjacent agricultural fields. Although the nutrient concentration in the water of Varthur lake was more or less similar with respect to nitrates but an increase in phosphate concentration was observed in summer which correlates positively with the growth of macrophytes and conducive environments for the release of nutrients trapped in the sediments.

The bulk of nutrient uptake during the summer season is performed by the widespread free floating macrophytes. These macrophytes which mainly comprises of water hyacinth and *Alternanthera sp*. covering a substantial portion of the lake surface (85%) captures about 4.5 tons of N/day as depicted in the earlier figure. They propagate very fast with a very high growth rate and engulf the entire water surface in about three months.

The nutrient (C and N) content of the dominant macrophyte population in the lake (from left to right) was investigated. In the lake 10 macrophyte species were observed out of which five dominant macrophyte species arranged as per their abundance from left to right are plotted against their % N content **[Figure-10]**. Higher N content were observed in case of *Lemna gibba* and *Alternanathera phyloxiroides* ~4 g/100 g of dry wt., followed by water hyacinth (2.3 g/100 d of dry wt), *Typha augustifolia* (1.5 g/100 d of dry wt) and *Cyperus* sp. (1.2 g/100 d of dry wt). In other studies, the highest N content was found in *Potamogeton trichoides* Cham. (2.33 g/100 g dry wt.) and *Baldellia ranunculoides* (L.) Parl (2.26 g/100 g dry wt.)[29]. The study conducted in an agricultural drainage lake showed an N content of 2.65 g N /100 g dry wt. in *Potamogeton nodosus* Poir [30]. The N content in *Lemna gibba* in treating the domestic primary effluent in Israel was recorded to be 4.3 % dry wt. which is comparable with the present studies [31]. The study on growth and nutrient storage of water hyacinth showed that 1.6 g N/100 g of dry wt was stored under condition of higher productivity [32].

The study shows that *Alternanthera* sp. together with water hyacinth would have been a dominant accumulator of nutrient in NH_4-N forms. However there was no significant variation in the C content **[Figure-11]** among the major macrophyte species.

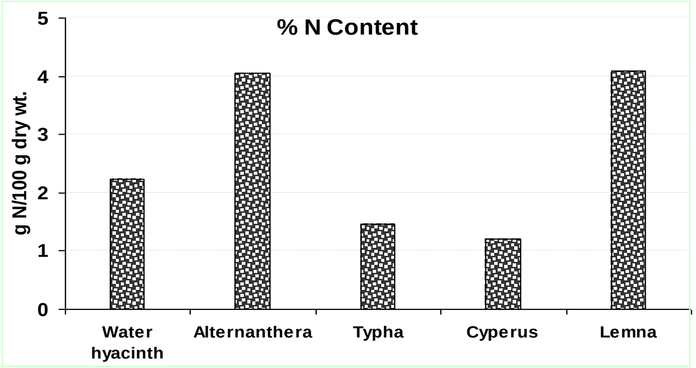

Fig: 10. Variations in percent N content among the dominant macrophytes from left to right.

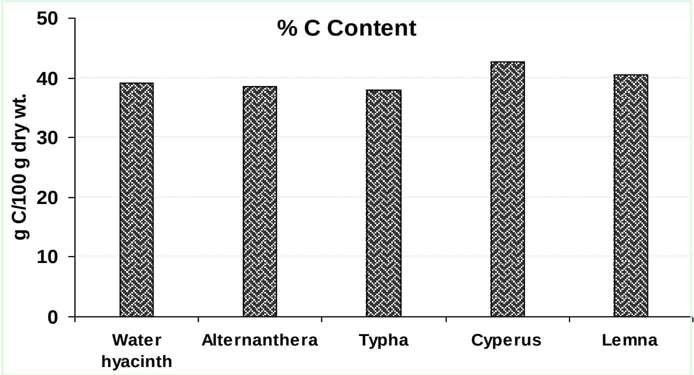

Fig: 11. Variations in percent C Content among the dominant macrophyte species.

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3.7. Plans for the management of macrophytes and associated lower levels of DO

Management arrangements need to recognize that when macrophyte infestations cover the surface of the lagoons, the quality of the aquatic habitat provided is very poor, and opportunities to provide healthy aquatic habitat in a region where most of the existing urban wetlands have been lost or seriously degraded, should be utilized. It is suggested that harvesting and removal of aquatic weeds from the lake rather than letting them sink to the bottom is a necessary prophylactic need. However, due to the large water hyacinth biomass and associated weeds, it was felt that their decomposition process (involving bacteria) would have resulted in significant consumption of the limited DO. Unmanaged exotic aquatic weeds consistently results in poor water quality and reduces the economic value of these otherwise productive habitats. Although the lake examined in this study is impacted by many factors such as altered hydrological regime, increased turbidity and nutrient loads, loss of their riparian zone and run-off from surrounding agricultural areas, the wind induced compaction and removal of macrophytes showed an immediate and substantial improvement in DO levels which were previously excluded because of the low DO content created by weed infestations.

Given the importance of these urban lakes in terms of their role in the livelihood of poor farmers, hydrological cycling, maintenance of micro-climate, as a sink to enormous pollutants and of their high recreational and commercial values there is an immediate need for a rapid improvement of the health of the system which would benefit to maintain the aquatic ecological integrity with optimal balance in urban aquatic systems. The lakes would be very essential further down the years looking at the serious crisis of water, and needs to be well managed for its sustainable functioning and reuse.

Findings of the study show waterbodies further being degraded by the spread and cover of the aquatic weeds/macrophytes and presses on the issues related to complete breakdown of the urban aquatic systems. The results of this study paves a way for initiation and implementation of aquatic weed control programs under existing Urban infrastructure planning and management.

[IV] CONCLUSION

Macrophyte population in the lake maintains the nutrient levels in urban aquatic systems. The increase in nutrient content (32 t N/d) has resulted in a prolific growth of invasive species. During summer, maximum quantity of nutrients in dissolved form is taken up by the macrophytes that cover almost 85% of the lake surface thereby reducing the nutrient content significantly. The lack of air-water interface hampers the aerobic functioning of the lake. Highly anaerobic conditions (-235 mV) are formed which consequently reduces the DO level further creating anoxia. This invasive macrophyte growth in summer raises the quantity of BOD load to about 180 mg/l on the lake significantly. Severe reduced conditions during summer aids in rapid fall of DO levels as low as 0 mg/l. During monsoon in the absence of macrophytes, lake functions as aerobic lagoon driven by micro-algae with satisfactory nutrient uptake and treatability. However in the pre monsoon the system behaves as an aerobic-anaerobic lagoon and finally in the post monsoon period it behaves as an anaerobic–aerobic system.

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ENV SCIENCE

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Ecological and Socio-Economic Assessment of Varthur Wetland, Bengaluru (India)

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Wetlands are the most productive ecosystems, recognized globally for their vital role in sustaining a wide array of biodiversity and provide goods and services. But presently increased anthropogenic activities such as intense agriculture practices, indiscriminate disposal of industrial effluents and sewage wastes have altered the physical, chemical as well as biological processes of wetlands, which is evident from the present study carried out to assessVarthur wetland in India. Coastal wetland ecosystem in the world has 14,785/ha US$ annual economic value. An earlier study of relatively pristine wetland in Bengaluru revealed the value of ₹ 10,435/ha/day while the polluted wetland showed the value of ₹ 20/ha/day. On the contrary Varthur, a sewage fed wetland has a value of ₹ 118.9/ha/day. The pollutants and subsequent contamination of the wetland-Varthur has telling effects such as disappearance of native species, dominance of invasive exotic species (such as African catfish), in addition to profuse breeding of disease vectors and pathogens. Water quality analysis revealed high phosphate (4 22-5.76 ppm) level in addition to the enhanced BOD (119-140 ppm) and decreased DO (0-1 06 ppm). The amplified decline of ecosystem goods and services with degradation of water quality necessitates the implementation of sustainable management strategies to recover the lost wetland benefits of Varthur.

Key words : *Urban wetlands, ecosystem services, water quality, urbanization, conservation strategies*

Introduction

Wetlands represent a combination of aquatic and terrestrial environment, in which the soil is seasonally or permanently covered by shallow water and the water table is close to or near the surface[1, 2]. Wetland covers thousands of square kilometers; at spatial scale ranging from a crack in the rock to rain forest or ocean. Being highly productive, in terms of biodiversity and as well ecosystem's benefits; human community derive, directly or indirectly from ecosystem functions. Ecosystem functions refer varyingly to the habitat, physical and biological benefits/processes of the ecosystem[3]. On a larger scale, anthropogenic activities impact physical, chemical and biological processes, which impair the ecosystem functioning[4] causing decline and degradation of ecosystem services and also economic value of the wetland[5]. Wetlands predominantly endure change in wetland hydrology and habitat, loss of catchment area adjacent to urban growth, increasing runoff of nutrients and pollution, introduced species replacing indigenous species, land clearance and over-use of resources by losing its subsistence economies of that region mainly due to urbanization. The benefits which may be lost are not effectively quantified in viable markets and also in terms comparable with economic services, are often specified with too little weight in policy decisions. Hence, quantifying economic values of ecosystem are essential to respite human activities apart from accounting their services in the regional planning.

Valuation entails assigning an economic value in direct market for all the benefits (such as food, fodder, remediation, clean water, biodiversity, groundwater recharge, etc) of wetlands. Nevertheless, the possible way of addressing the economic value is to estimate the value which is exactly the price payable to replicate the natural ecosystem[3] or the price estimated/ paid for the same in direct market by means of economic valuation.

Economic valuation

Economic valuation is an attempt to assign values in terms of market price for the goods and services offered by the ecosystem. In Economic terms, the goods and services are broadly grouped as use and non-use values[6] as indicated in **Table 1**. Valuation technique includes "willingness to pay" reflecting individual's choice for the ecological commodities (aesthetic value, recreational opportunities), wood products and intrinsic values[7,8] and also captures its values in an economic value framework[9]. The commonly used technique for the valuation is the contingent valuation technique based on personal interactions with the local people using questionnaires; information on willing to pay for something they value or willing to receive in compensation for tolerating a cost.

The zero ecosystem benefits imply zero human welfare[3], thus economic value of a wetland varies from a pristine

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Table 1: Classification of total economic value for wetland

Use Values			Non - Use Values
Direct use values	**Indirect use values**	**Option value & Benefits**	**Existence value**
Fish, Agriculture, Fuel wood, Fodder, Recreation,(Boating, Fauna, Walking) Transport, Wildlife, harvesting, Peat/ Energy Education	Nutrient retention, Flood control,Storm protection,Ground water recharge,External ecosystem support, Filtration,Micro-climate, Shoreline stabilization	Potential future use (as per direct and indirect use). Future value of information, e g., pharmaceuticals, education.	Biodiversity,Culture, Heritage,Bequest

Source [14]

(natural benefits) to polluted (degraded ecosystem's benefits) wetland; influenced by a defined set of environmental conditions Wetland value increases with quality of goods and services derived and vice versa.

Numerous studies on economic valuation of wetlands have been carried out around the world; however, most of these studies have focused on wetlands in developed countries[11]. Economic studies for Indian wetland are meager addressing serious threats due to agricultural conversion, hydrological alteration followed by urbanization in recent years owing to 60 % loss

Several studies across countries in the past few decades support the estimation of economic value of a wide variety of goods and services. The annual value of wetland was estimated to be second highest, US$ 14 785/ha based on the assessment of 17 ecosystem services in 16 biomes which emphasize that ecosystem functions provide an important portion to the total contribution to human welfare[3] Other studies include wetlands of Africa[11], China[12], Bangladesh[13] and the European water framework directive of European Union (EU) (2000/60/EC). Assessment of the health of wetlands in China highlights that among all factors, water quality, ecosystem function and structure of waterfront area as the main factors that limit the wetlands value. Study of Mississippi Alluvial Valley focuses on the restoration of wetland ecosystem services in the floodplain area which has profound consequences due to habitat loss, fragmentation, flood storage loss and water quality degradation due to non point source runoff[14]

Many wetlands in India including those in Bengaluru are being degraded due to the apathy of the decision makers and planners. These wetlands, urban as well as rural, paved way to residential layouts, industrial complexes and indiscriminate disposal of urban wastes which has led to the deteriorating water quality and significant changes in local climate. Number of wetlands has dwindled from 250 to 81 (1985) and 33 in 2006[15]. Population of Bengaluru reached 7 million in 2007[16] due to the spurt in unplanned urbanization and consequent land use activities Effect of sustained inflow mainly of sewage, industrial effluents and agricultural runoff is evident from the results of regular monitoring of water quality at Hebbal, Varthur, Madiwala, Rachenahalli and Amruthalli wetlands[17]. A comparative evaluation of Amruthhalli lake with the relatively unpolluted Rachenahalli lake[2] brings out the impact of degrading ecological integrity of wetlands evident from the drastic decline of values from ₹ 10, 435/ha/day (Rachenahalli lake) to ₹ 20/ha/day (Amruthalli lake). Lower value is mainly due to eutrophication and water being unavailable for any use with an excessive nutrient inflow (sewage and industrial effluents) and storm water. Discharge and dumping of waste into catchment area lead to high levels of phosphates, Total Suspended Solids (TSS), Alkalinity, Hardness, Odour, weed infestation and low dissolved oxygen (DO) Study of Hebbal lake also reflects decreased water quality due to excessive sewage and industrial effluents inflow from surrounding area The Contingency valuation technique employed for preliminary socio-economic survey reveal high level of dependency on wetlands for groundwater, food, fodder, fuel and so on. The lake supports irrigation, provides food (fish, etc.) and fodder to the livestock in the surrounding areas The investigation of causes of mass fish mortality in Sankey Lake[18] revealed that the death was due to a sudden and considerable fall in dissolved oxygen (DO) levels in some locations caused by sewage let into the lake resulting in asphyxiation. An incidence of mass-scale fish mortality in Bengaluru reported from Ulsoor Lake[19] supported the above study These studies highlight the significance of maintaining wetland's quality to ensure sustained ecological functions contributing to economic values.

Bengaluru was known for its lush greenery with numerous wetlands, Varthur wetland being one of the largest amongst all. Rapid unplanned urbanization coupled with the increase in population has affected both Bengaluru and its surrounding towns and villages, including Varthur[15]. Varthur lake constructed 1000 years ago by Ganga rulers, today receives almost 40% of Bengaluru sewage to the extent of 450-500 minimum lethal dose per day (MLD/day). Part of city's untreated sewage passes through the network of interconnected lakes such as Bellandur and Ulsoor apart from many households directly in the immediate vicinity in a span of 220 hectares. The quantum of sewage exceeds the wetlands ability to assimilate contaminants and hence water quality has declined and has become unfit for human consumption. The contaminated water from Varthur ultimately flow downstream connecting Dakshina Pinakini River. Considering the dependence and impaired livelihood due to decline in ecological functional ability and capability consequent to sustained inflow of sewage and effluents, necessitates the ecological restoration of the lake. This entails understanding of the physico-chemical aspects with the wetland dynamics and the valuation of ecosystem services and goods. The study was carried out with a hypothesis that accumulation of contaminants has been responsible for degradation of water quality and consequent erosion of ecosystem services and goods. In this backdrop, Varthur wetland was investigated for water quality and valuation of the benefits to understand the drivers responsible for wetland degradation and impairment of economic benefits.

The study objectives were to: 1. assess physicochemical water quality variables and 2. economic valuation of wetlands through contingent valuation technique, focusing on the causes for wetland degradation and appropriate allocation of wetland use.

The study region

The study was carried out in Varthur wetland, one of the largest wetland located to the south of Bengaluru with 12.940699°N and 77.746596°E geographic position and a surface area of 220 sq. km. The wetland water accounts to irrigate 625 hectares of agricultural fields in the command area, for growing crops like rice, ragee, coconut, flowers and a variety of fruits and vegetables. It provides habitat for a wide variety of flora and fauna, including resident and migratory waterfowl. The inlet receives sewage and industrial wastes, contaminating not only wetland water quality but also Pinakini river at the downstream. Decreased water quality in recent years has influenced the economical significance of wetlands. **Fig.1** represents the study area and sampling points.

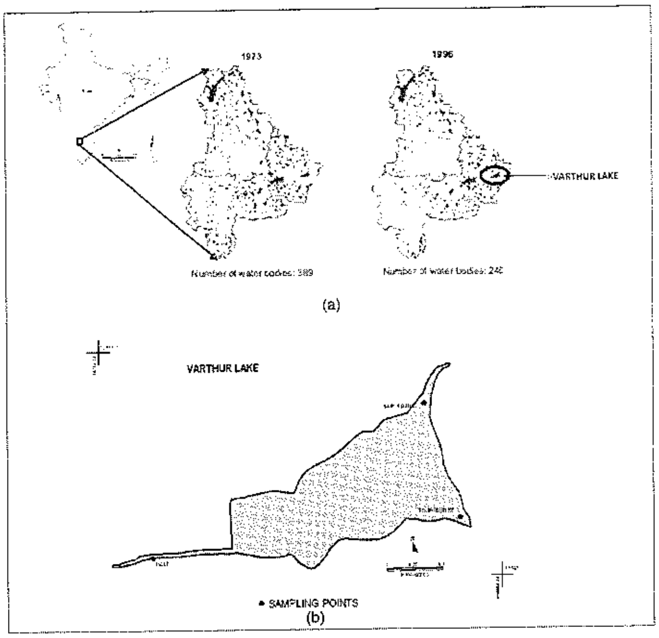

Fig. 1: (a) No. of water bodies in Bengaluru in 1973 and 1996 and (b) Varthur Lake with samplig points (inlet, north outlet and south outlet)

Methods

Water quality analysis

Water samples (triplicates) were collected from three sites viz. inlet (12°56'35.99"N lat. and 77°44'5.32"E long.), south-outlet (12°56'43.91"N lat. and 77°44'48.21"E long.) and north outlet (12°57'22.86"N lat. and 77°44'40.56"E long.) in Varthur wetland during February 2009. Samples were stored in polythene bottles and were carried to laboratory for further analysis. Dissolved Oxygen was analyzed on-site using 125mL BOD bottles. Physical variables like pH, temperature (°C); total dissolved solids (mgL^{-1}); salinity (mgL^{-1}) and electric conductivity (μScm^{-1}) were measured using EXTECH EC500 Probe immediately after collection. Other water chemistry variables like chloride, hardness, magnesium, calcium, sodium, potassium, nitrates and phosphates were analyzed in laboratory and analyses were carried out as per the standard methods for the examination of water quality as mentioned[20].

Socio-economic survey

A contingency valuation technique was applied for the economic survey of wetland through a participatory approach involving local school students. 235 people from 43 randomly selected households from Varthur and nearby villages were interrogated using a standard questionnaire by KK High School students (VIII to X grade), Bengaluru. The questionnaire was made to quantify use-values of the lake including demographic information, domestic water usage, irrigation, fishing and aquaculture, water usage for livestock, livestock fodder, groundwater recharge, health effects and family history. Valuation of resources through the survey was aimed to evaluate the economic status and dependency of residents. Demographic information included total number of persons/houses, occupation and income per annum which relate to the dependency of residents on lake domestic water usage, irrigation, fishing and aquaculture, water usage for livestock and livestock fodder in turn the dependency of residents on lake water, aquatic plants and organisms. The use of groundwater resources highlights the indirect association with the Varthur lake, responsible for recharging local aquifers.

Results

Water quality analysis

Characteristics of water collected from various sampling sites are mentioned in **Table 2**. pH ranged from 7.5-7.7 across sampling sites. Conductivity was found to be high in inlet (1420 µS) compared to outlet sampling sites (South outlet, 1075 and North outlet, 1224 µS). Higher conductivity value at inlet was mainly due to the sustained sewage inflow and dissociation of minerals from soil. Total Dissolved Solids which account for the amount of sedimentation did not show much variation (749-994 ppm) in lake. Dissolved Oxygen (DO) was 0 ppm and 1.06 ppm as observed in inlet and north outlet respectively while at south outlet 8.16 ppm was recorded. Biological Oxygen Demand (BOD) was higher (119-140 ppm) at the inlet which confirms the inflow of higher amount of nutrients into the lake. Chemical Oxygen Demand (COD) range (124-188 ppm) indicated the presence of increased oxidizable load. This highlights the anoxic conditions prevailing at inlets. Total hardness and alkalinity were found in the range of 236-288 ppm and 400-420 ppm respectively. The sodium and potassium values were174-180 ppm and 19-21 ppm respectively. Nitrates and phosphates varied from 0.31-0.55 ppm and 4.22-5.76 ppm respectively. Phosphate concentrations were found above the permissible limits.

Socio-economic survey

235 people from 43 houses were surveyed for evaluating the level of dependence for goods and services of Varthur Lake, which are listed in **Table 3**.

Domestic use: Few residents in the catchment area depend on lake for domestic usage due to its poor quality. Among all, 15 houses rely on bore wells. Groundwater or bore well water usages are categorized as indirect use value as wetlands play significant role in recharging the groundwater sources in and around catchment area. On an average 5 individuals in a house utilize 200 liters of water per day. The dependency value is ₹ 25, 000 per house per year. For drinking water the amount spend on bottled water accounts to ₹ 30,000 per house per year.

Agriculture: Among 43 households surveyed, 35 houses depend on agriculture for livelihood. Wetland water is utilized for irrigating a total land area of 24.28 ha for growing mainly paddy, radish, carrot, tomato, chilly, coconut, beetle leaf and floriculture and the area under each crop is listed in **Table 3**. Apart from this, many paddy, coconut and beetle fields are cultivated nearby which are not included in this survey. The dependency for water for agriculture amounts to ₹ 12, 24,000 every year.

Table 2: Water quality analysis

Variables	Inlet	South outlet	North outlet	Surface Water Standards (permissible limit)
pH	7.70	7.50	7.50	6.5-8.5
Water Temperature (^{0}C)	29.00	30.00	26.00	—
Air Temperature (^{0}C)	28.00	31.00	29.00	
Salinity (ppm)	710.00	532.00	605.00	<400
IDS (ppm)	994.00	749.00	849.00	<500 ppm
Electric Conductivity (µS)	1420.00	1075.00	1224.00	<1200 µS
Total Alkalinity (ppm)	420.00	400.00	420.00	<600 mgL^{-1}
Dissolved Oxygen (mgL^{-1})	1.06	8.16	0.00	> 5 mgL^{-1}
Chlorides (ppm)	167.56	173.24	191.70	< 200 mgL^{-1}
Total Hardness (ppm)	252.00	236.00	288.00	< 300 mgL^{-1}
Calcium Hardness (ppm)	108.00	128.00	135.00	<80 mgL^{-1}
Biological Oxygen Demand (mgL^{-1})	122.40	119.50	140.80	< 3 mgL^{-1}
Chemical Oxygen Demand (mgL^{-1})	128.00	124.00	188.00	< 250 mgL^{-1}
Nitrates (ppm)	0.31	0.47	0.55	20 mgL^{-1}
Phosphates (ppm)	5.76	4.22	5.00	—
Sodium (ppm)	177.00	174.00	180.00	—
Potassium (ppm)	21.00	19.00	19.00	—

Table 3: List of resources and their economic values

Use values	Quantity of Resource	Wetland Value in Rupees (₹)
Domestic use (bathing, cooking)	25-50 litres/person/day	25,00,000/year
Agriculture (income)	4,080/house/month	12,24,000/year
Household	2,500/month	30,000/house/year
Fisheries	5 kg fish/person/yr	25,00,000 /year
Domestic animals	6 animals/house	10,000/year
Fodder for Domestic animals	720 kg/year	57,60,000/year
Fire wood	10,000/month	12,24,000/year
Total		Rs. 95,54,000/220 ha/year

Livestock : On an average 5 animals viz cows, buffaloes, sheep and goats were reared in each house. Water hyacinth and other aquatic weeds (*Eichornia crassipes.*, *Typha* sp , *Alternanthera* sp etc) are utilized as feed for cattles. Farms rely on the sale of dairy products for part of their income. The dependency for livestock (fodder) and for washing purposes amounts to ₹ 57, 60,000 and ₹ 10,000 per 6 cows every year respectively.

Fisheries : 5 residents depend on aquaculture for occupation. Fishing is the major source for people nearby. As per the survey consumption of fish is 5 kg/person/year and the value from fisheries amounts to ₹ 25,00,000/year.

Fire wood (Energy): The dependency of people for the fire wood on the wetland amounts to ₹ 10,000 per year.

Discussion

Residents are residing in the catchment of Varthur lake for nearly 30 years to more than 200 years and at least 60% of the families persist for over 100 years[2]. It plays a significant role in providing daily requirements for the local inhabitants such as for domestic use of water, irrigation, fuel and fodder for livestock; while undergoing the stress sequentially due to anthropogenic activities. Higher values of BOD, COD, Nitrates and Phosphates reveal that lake water is severely contaminated. DO of lake was quite low (1.06 ppm) in inlet mainly due to increased inflow of organic material through untreated sewage. DO decreases due to presence of inorganic reducing agents such as Hydrogen Sulphide (H_2S), ammonia, nitrites and certain oxidizable substances[21]. Profuse growth of macrophytes mainly water hyacinth, limits air water interface, light penetration and consequently there is a drop in the penetration of atmospheric oxygen as well as algal photosynthetic activities. This maximizes the probability of hypoxic and anoxic conditions in the lake making difficult for survival of aquatic organisms in the water. Higher values of alkalinity show the presence of more carbonates, bicarbonates and hydroxyl ions. Water quality analysis of Varthur during 2002 also reported similar conditions of low dissolved oxygen, alkaline pH and high nutrient inputs (Nitrates, Phosphates and Ammonia). Varthur contains significant amounts of the macronutrients in large quantities in order to grow and survive aquatic plants under higher concentrations of nitrates and phosphate. Elevated amount of nutrients mainly fortify the contamination of water with sewage and non-point sources - fertilizers[2]. Amplified water quality degradation observed when current status was compared with that of past study (**Table 5**), explaining due to the sustained and enhanced inflow of contaminants over time.

Table 4: Livelihood details

Livelihood	Hectares
Floriculture	11.74
Vegetables	10.32
Paddy	2.02

Calculation : ₹ 9554000/220 ha /year

= ₹ 43427.28/ha/year

= ₹ 118.978/ha/day

Water pollution

Varthur Wetland receives 450-500 MLD of sewage from households and industrial wastewater directly into wetland from Bellandur and surrounding localities. These contribute enriched nutrients and increased amount of toxic substances (heavy metals). Enhanced land cover changes have contributed to siltation and consequent sedimentation decreasing lake's depth. The degree of soil saturation of the wetland depends on the consistency of its freshwater flow. Effluents loading has gone beyond the ability to assimilate contaminants, further degrading the water quality. Along with effluents from households and industrial waste, household garbage, plastics and solid waste from commercial places are being dumped in lake bed.

Valuation of ecosystem highlights that due to the severe contamination of water the wetland's goods and services have declined impinging livelihood of dependent population and also local economy. Even though residing

Table 5: Comparison of major water quality parameters of Varthur (2003 and 2009)

General parameters	2003 (Outlet)			2009	
	October	November	January	Inlet	Outlet
pH	7.61	7.55	7.68	7.7	7.50
Temperature (°C)	27	27	23	29	26
Electric conductivity (µS)	460	474	1420	1420	1224
Dissolved oxygen (mgL^{-1})	2	3	2.9	1.06	0
Chlorides (ppm)	-	100	170	167.56	191.7
Total hardness(ppm)	213.6	209.3	232.5	252.0	288
Calcium hardness(ppm)	132	124	158.1	108	135
Biological oxygen demand(ppm)	-	-	74.2	122.4	140.8
Chemical oxygen demand(ppm)	-	-	82.2	128.00	188
Phosphates(ppm)	-	>1	15.54	5.76	5.00

(Source: Ramachandra *et al.* 2003 and current survey)

community is dependent on lake for manifold use as mentioned in **Table 3** many problems are faced by the wetland for being beneficial. The total economic value of Varthur resources accounts to ₹ 95, 54,000/220 ha/year (ie ₹ 118.98/ha/day), which is much lower compared to a relatively unpolluted lake (₹10,450/ha/day)[3]. The dependency value on wetland water for domestic and agricultural use is maximum compared to other use-values.

Causes of depreciation in lake values

Dumping of garbage and other non-degradable waste materials, inflow of untreated sewage from the residential areas and open defecation are the problems accountable for water quality. Such substances liberate toxic in to the water body; remains suspended; gets dissolved in water or set down on the water bed contributing to groundwater pollution. This majorly deteriorates water quality impinging on aquatic ecosystems. Few effects of these environments are :

- Utilization of contaminated lake water for irrigation purposes has a negative effect on the quality as well as the quantity of crops and this has influenced the major source of income for farmers reliant on agriculture.
- Possibility of contaminants especially heavy metals getting to food chain through fish (which accumulates higher concentrations of heavy metals- bioaccumulation[22]).
- Dumping of municipal solid waste in the lake catchment and letting untreated sewage and effluents into lake has affected the health of the local population due to increase of disease vectors and pathogens (mosquito -*Plasmodium* sp. causing Malaria) and flies population around Varthur region. Current survey also reports health problems like fever, dysentery and skin diseases (dermatitis) in most of the houses. Due to mosquito problem and health hazards, residents spend more than ₹ 30,000 per year in purchase of mosquito repellants (according to survey). Presence of *Eschericia coli* in water sample indicates the fecal matter contamination[3]. Fecal contamination is often associated with other types of pathogenic bacteria and viruses found in untreated sewage and survives for a prolonged period in turbid, warm temperature, mildly alkaline pH, and low oxygen levels in lake water.
- Profuse growth of exotic plant species such as water hyacinth (*Eichornia crassipes*) and exotic fish culture have also contributed to extinction of native species of fauna. Prolific macrophytes growth has roofed water surface completely lessening dissolved oxygen level and hindering photosynthesis process. Algal communities depending on photosynthetic activity have declined together with mortality of sensitive life stages inside water. Disturbance in food chain may also lead to changes in algal community and its metabolism.
- Poaching of waterfowl such as Purple Moorhen (*Gallinula chloropus*), Spot Billed Pelican (*Pelecanus philippensis*), Common Coot (*Fulica atra*) and White Breasted Waterhen (*Amaurornis phoenicurus*) by poachers were observed, resulting in its decline.

Dominant fish species reported in 1962, 1998 and 2009 are listed in **Table 6**. *Clarias batrachus, Heteropneustes fosslis, Mystus dittatus* and so on which once contributed substantially to fish community in earlier years has dwindled in their representation in the catches now. The invasive species currently harboring water body are *Catla catla* (Catla), *Labeo rohita* (Rohu), *Cirrhinus mrigala* (Mrigal), *Clarias gariepinus* (African catfish), *Oreochromis mossambica* (Tilapia) and medium sized carps. Enhanced sewage and effluents inflow coupled with the overexploitation of wetland goods are prime reasons for the decline in indigenous fish species and consequent prevalence of invasive species during the last two decades.

Table 6: List of major fish species in Varthur wetland during 1962, 1998 and 2009

Species name	1962	1998	2009
Catla catla (Catla)	-	+	-
Labeo rohita (Rohu)	-	+	-
Cirrhinus mrigala (Mrigal)	-	+	-
Clarias gariepinus (African catfish)	-	+	+
Oreochromis mossambica (Tilapia)	-	+	-
Clarias batrachus	+	-	-
Heteropneustes fosslis	+	-	-
Mystus dittatus	+	-	-
Minor carps	-	+	-

(Source: current survey + indicates presence and - indicates absence of fish species.)

Comparative analysis of polluted and unpolluted wetlands reveals difference in fish composition and associated economic value. Varthur lake harbors only *Clarias gariepinus* (African catfish), whereas *Catla catla* (Catla), *Labeo rohita* (Rohu), *Cirrhinus mrigala* (Mrigal) and *Oreochromis mossambica* (Tilapia) were found in Rachenahalli while another eutrophic lake at Amruthahalli did not have any species. Varthur and Amruthahalli being eutrophicated with heavy sewage contamination and Rachenahalli is relatively unpolluted. Invasive exotic species, African catfish in Varthur water body has predated native fish and survives under eutrophic condition with the macrophytes covering the entire lake. Subsequently, huge amount of waste along with metals and ions (toxic substances) are accumulated inside fish gut due to bioaccumulation[23]. Consumption of fish rich in heavy metals has carcinogenic influence on humans. According to fishermen, Varthur provides 200-300 kg/day of catfish costing ₹ 50-60 /kg/day due to absence of fish variety while Rachenahalli accounts for ₹ 75 /kg/day specified by varieties of fishes mentioned above[9]. Economic value of fish in Varthur is less than in Rachenahhali mainly because of exotic species and decline of native species, water accomplished with sewage and prolific macrophytes growth in Varthur.

The socio-economic studies on Rachenahalli and Amruthalli lakes showed that the economic dependency in the case of Rachenahalli lake (₹ 10,435/ha/day) is more than that of polluted Amruthalli lake (₹ 20/ha/day). This is mainly because of better water quality in former lake while water quality with severe pollution by phosphates, weed infestations and oxygen deficiency in later case. Although in Varthur, Sorahumase and Valepura village, the land irrigated by utilizing the wetland water amounts to 4211.6/day with water quality indicating eutrophic lake containing high concentrations of organic wastes and phosphorus[2].

Management of wetlands to sustain goods and services

This study highlights the need to manage the wetlands to enhance the use-value of an ecosystem. The strategies include : 1. Restoration of wetlands – removal of contaminants; 2. Letting only treated sewage to the wetlands; 3. Letting the treated water through series of wetlands further improves the water quality; 4. Maintaining food chain in the ecosystem – involves removal of excess growth of macrophytes (if any) and exotic fish species, African cat fish, etc ; and 5. Regular water quality monitoring involving local schools. This would also help in functioning as watchdog to prevent any contamination (solid waste dump, direct inflow of sewage, etc.)

Conclusion

The socio-economic survey and water quality analysis show a decline of ecosystem goods and services with the decline of water quality. This has influenced the livelihood of the local population who are dependent on the goods and services provided by the wetland. The persistent hyper eutrophic condition is due to the sewage from Bellandur lake and also from the surrounding residential apartments. Water treatment plant for Varthur wetland benefits the local environment with better water and impassive sludge that can be utilized for agricultural fields as fertilizer instead of commercial inorganic fertilizers. With the improved water quality, introduction of indigenous and herbivorous fish species into water body along with the removal of African catfish will enhance the food availability. To retain existing reserve and bring back the lost resource, efforts such as restoration process should include wastewater treatment system, removal of over growth of invasive macrophytes and awareness among community and enhanced co-operation among government agencies to manage wetland. Management priorities should mainly include evolving sustainable managing strategies for maintaining water quality, control of invasive species, encroachment, drastic land cover changes in the catchment and identification of buffer zone, providing aquatic resources with adequate water quality and limiting the spread of exotic biota in a sustainable manner evolving managing strategies.

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C:N ratio of Sediments in a sewage fed Urban Lake

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***Abstract*—** C:N ratio of lake sediments provide valuable information about the source and proportions of terrestrial, phytogenic and phycogenic carbon and nitrogen. This study has been carried out in Varthur lake which is receiving sewage since many decades apart from large scale land cover changes. C:N profile of the surficial sediment layer collected in the rainy and the dry seasons revealed higher C:N values[43] due to the accumulation of autochthonous organic material mostly at the deeper portions of the lake. This also highlights N limitation in the sludge either due to uptake by micro and macro-biota or rapid volatilization, denitrification and possible leaching in water. Organic Carbon was lower towards the inlets and higher near the deeper zones. This pattern of Organic C deposition was aided by gusty winds and high flow conditions together with impacts by the land use land cover changes in the watershed. Spatial variability of C:N in surficial sediments is significant compared to its seasonal variability. This communication provides an insight to the pattern in which nutrients are distributed in the sludge/sediment and its variation across seasons and space impacted by the biotic process accompanied by the hydrodynamic changes in the lake.

***Keywords*—** Sediments, C:N, sewage, urban lake, nutrients, macrophytes, algae

I. Introduction

Carbon and Nitrogen as nutrients plays a vital role in maintaining trophic levels in lake ecosystems. The dry weight ratio of total organic carbon to total nitrogen (C/N ratio) has been used as an indicator of the source of organic matter (OM) in sediments. Variations of C:N ratio's within sediments have aided to determine temporal and spatial of organic matter, steroid compounds and lignin phenols changes in sources of organic matter to lakes. Nevertheless the organic matter in the form of $^{13}C/^{12}C$ ratio is an essential indicator. However due to the variability in isotopic ratio of planktonic OM adds to ambiguity in measurements [1-4] due to a wide range inorganic $^{\delta13}C$ values [2]. Also as indicators analysis involves chemical complexities. In this context, the C/N ratio proves to be an efficient and straightforward indicator of organic source, particularly in depositional environments of lakes.

II. C/N Ratio

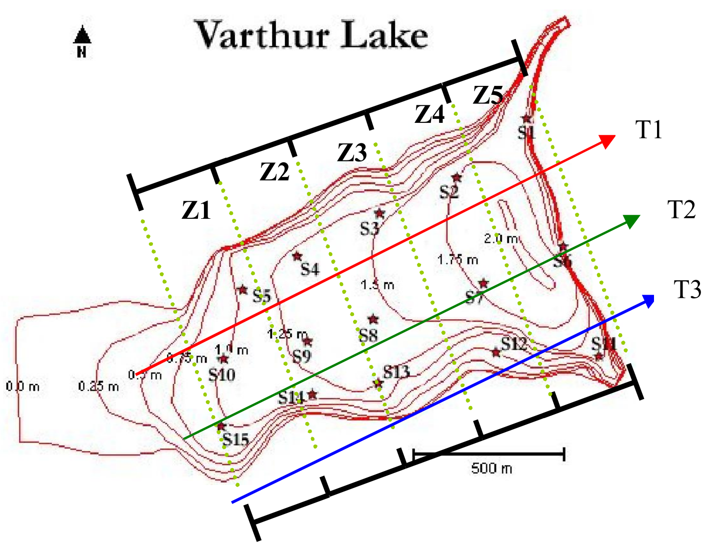
The C/N ratio has been used as a representative proxy to reconstruct the depositional environment of freshwater lake sediments [5-10]. Carbon and Nitrogen in aquatic ecosystems are governed by the mixing of terrestrial and autochthonous organic matter [11-12,5,13-14,4]. C/N ratios of 5 to 6 are reported in phytoplankton and zooplankton, which have proteins, which are primarily nitrogen compounds [15,16]. Freshly-deposited OM, derived mainly from planktonic organisms, has a C/N ratio of 6 to 9 [15, 17-18]; Phycogenic C/N ratio was found to be between 4 and 10 [3]. This is contrary to C/N ratios 15 or higher with [16,19-23] in terrestrial vascular plants and their derivates in sediments, and greater than 20 [3] in terrestrial organic matter and about 39.4 [22] for macrophyte materials.

In this communication we analyze the distribution of OM and the variability in the C/N ratio under the prevailing seasonal oxic and anoxic conditions, and evaluate the sensitivity of the C/N ratio to changes in the proportions of planktonic and terrestrial OM. Variations in C:N ratio within sediment have been used to understand lake's temporal depth profile apart from analyzing the period of high proportion of terrestrial OM input [24]. Conversely, lower C:N ratios help to identify periods when lake sediments have received a high proportion of algal OM [25]. C:N ratio to discern changes in organic matter sources has been the subject of discussion [26,27] as the C:N of terrestrial organic matter decreases during diagenesis, while that of algae increases [28]. In this backdrop, a study has been carried out to identify spatial and a short time temporal variability in nature and sources of organic matter to Lake Varthur, Bangalore (India) through the analysis of C:N of surficial sediments.

III. Spatio-temporal variability in C: N ratio

A significant spatial and temporal variability of water quality in terms of organic compounds and nutrients, with a considerable decrease in the organic matter as water flows from inlet to the outlets during the seasons devoid of macrophytes cover in the lake was observed. Varthur Lake serves as a source for irrigation to the cultivable lands and vegetable cultivation together with horticulture and floricultural activities and has a surface area of 220 ha (Figure 1). The lake was built by the Ganga Kings (Gazetteer of Karnataka) to store water. The lake initially was a deep with water which was used for drinking and other domestic purposes, intense urbanization have dwindled the catchments for the last few decades. During the last two decades there are large scale changes in land use paving way for rapid decline in the number of lakes and eutrophication.

Figure 1. Bathymetric map of Lake Varthur, Bangalore (India). The large dot with the star's indicate the sites where surficial sediments were taken (S1-S15) and contours represent the various depths of the Lake.



IV. Surficial sediment analysis

Surficial sediments were sampled along three transects [shown as arrows] near north shoreline, middle and south shoreline, from different depths in Varthur Lake (Figure 1) during nonmonsoon (NMON-08,09) period (Aug-Oct) and monsoon (MON 09) period (Dec-Jan), 2010 to quantify, assess the nutrient quality, accumulation in sediments and its variability with respect to space (spatial) and with time (temporally). The lake was divided into imaginary zones from Z1 – Z5 taking the inlets as a refrence and considering the flow as a function of residence time (4.8 days). Representative samples were obtained from each site with the help of a sediment sampler; they were then placed into plastic bags, refrigerated at 4°C prior to analysis. The samples were dried; processed and homogenized for the CHN analysis. Organic Carbon content and Total Nitrogen and atomic C:N of bulk sediment samples were determined by combustion of the dried and processed surface sediments in a CHN analyzer (TRUE SPEC CHN Vers. 1.9X, LECO). Settling experiments were carried out to time required for 90% settling for non-monsoon, 08 sediment samples. Dry wt. was calculated for the samples and quantitaion of C and N was carried out for respective zones.

Figure 2a). % C content during Monsoon

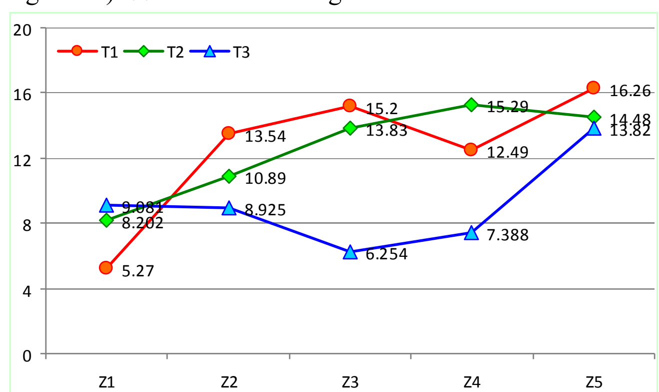


Figure 2b). % C content during Non-Monsoon

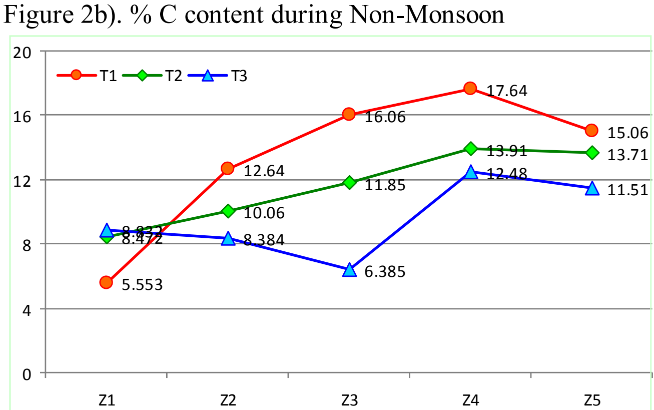


Figure 3 a). % N content during Monsoon

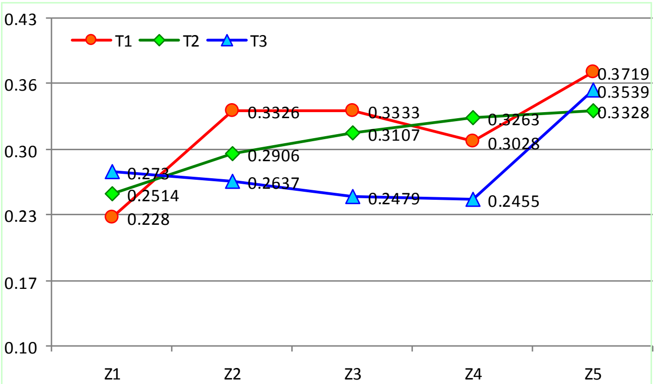


Figure 3 b). % N content during Non-Monsoon

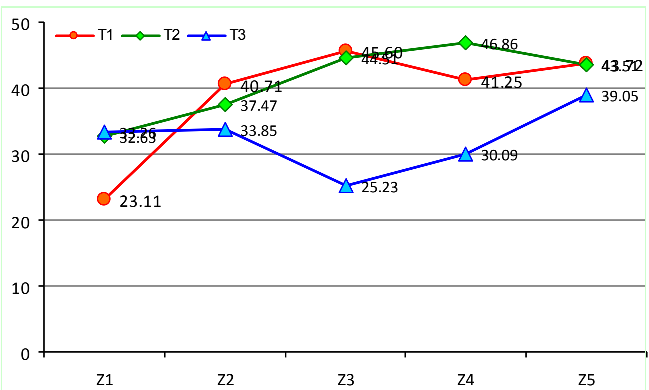


Figure 4 a). C/N ratio during Monsoon

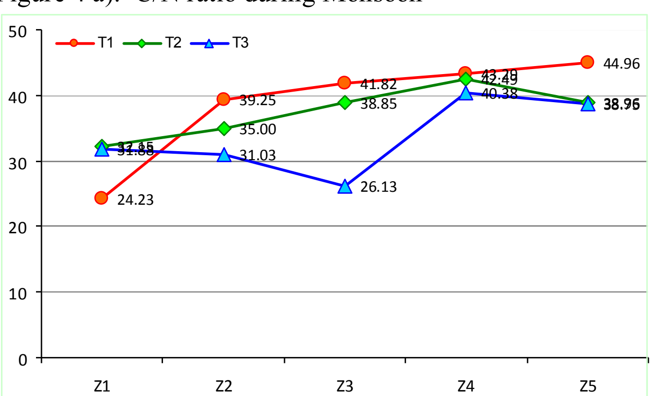


Figure 4 b). C/N ratio during Non-Monsoon

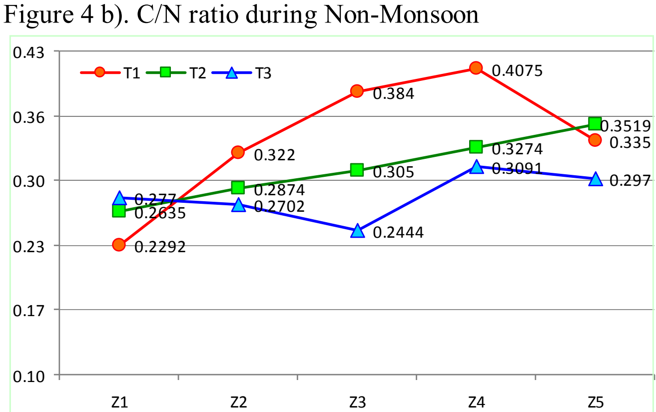
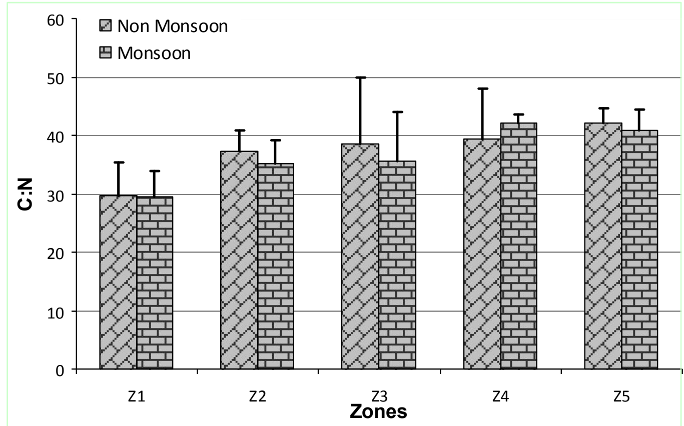


Figure 5.Variability in the C:N ratio at various zones in the lake

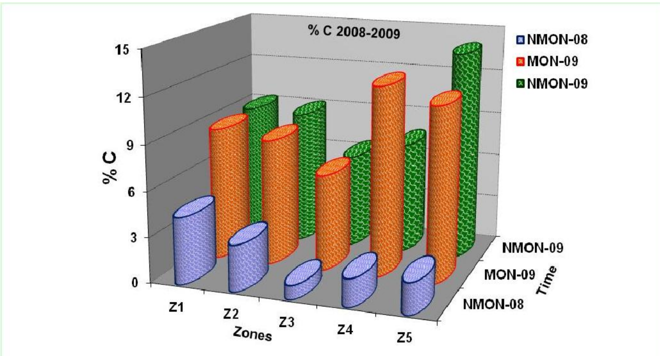


During 2009 analysis the surficial sediments C content for the non-monsoon at depths greater than 1.5 m-1.75 m (Z3 and Z4) showed higher values 17.64 g/100 g dry wt. compared to monsoon values (Figure 2.a & b) which could be due to persistence of organic decomposable and sludge at normal flow conditions. With high wind speeds and high flow rate during monsoon a phenomenal turbulence is created by churning followed by upwelling which releases the sludge from the bottom. The sludge escaping from the system was found to have a similar C and N content as was found in samples from greater depths (Z4 and Z5) where C/N = 50.05$\pm$3.02; C=33.66$\pm$5.12; N =0.68$\pm$0.07. The samples collected along north transect showed higher C values compared to the other regions of the lake. (Figure 2.). This is attributed to higher anthropogenic effects and terrestrial C sources like sewage from the urbanized pocket. A lower C value in the southern side is attributable to suburb type habitations with more agricultural fields in the immediate vicinity.

The N content analysis showed a similar trend in the way in which organic C is distributed across the lakes (Figure 3.a & b). However the entire system was found to be having a relatively lower N content compared to other studies [26]. The seasonal analysis showed a higher N content in the non-monsoon period. The N content was highest at the deeper regions (Figure 3.b). This is attributed to the rapid death and decay of the macrophytes during the late monsoon. The plants parts disaggregate; decompose and settle at a very high rate during the lean season. The N content in case of macrophytes were found to be ~2.25 g/100 g dry wt.[water hyacinth]. This difference in the surficial sediments and the macrophytes indicates substantial N loses from the sediments which can either due to rapid N mineralization followed by volatilization or denitrification which should be looked at systematically.

The seasonal observations showed higher C/N values in the deeper reaches during the monsoon however the ratio becomes more or less constant at those placed during the lean period (Figure 4. a&b). From the figure 4, it was observed that the middle regions of the lake had gained a higher C/N

Figure 6. Temporal variability in C content



* NMON: Non-monsoon; MON: Monsoon

Figure 7. Temporal variability in N content

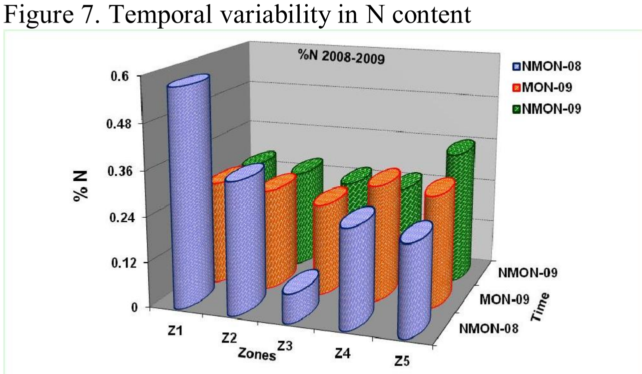
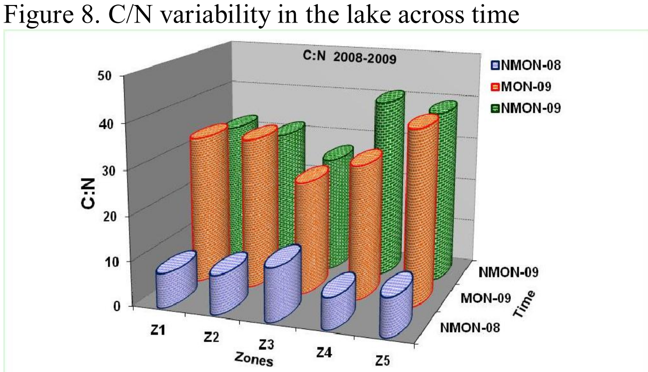


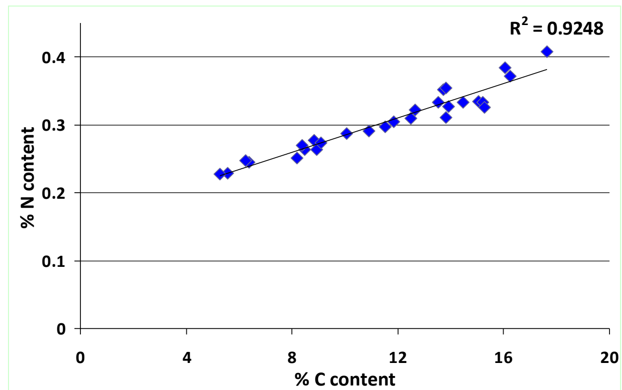
Figure 8. C/N variability in the lake across time



value than the other regions which indicated the flows in both the sides of the lake and the middle regions being undisturbed. The analysis carried out during wet and dry periods reveals that as a function of residence time the C/N ratio increases as we move from inlets towards the outlets as illustrated in Figure 5.

This indicated that the inflowing stream primarily transporting sewage was an important source of terrestrial organic matter. However there was a marked increase in the C (Figure 6) as well as N (Figure 7) content towards the outlets as a function of residence time which could be because of more organic matter settling at these regions. The preponderance of higher C:N ratio again as illustrated in Figure 8, reveals that, there may not be adequate C assimilation at the same time the Organic N in the forms of Ammonia and nitrates are either readily assimilated by bacteria's or are denitrified and are released to the atmosphere in the form of N_2O and N_2. This could result in an altered C:N values as the C:N of terrestrial organic matter decreases during chemical, physical, or biological change undergone by a sediment after its initial deposition, while that of algae and aquatic plants increases [28].

Figure 9. Correlation between % C and % N content in the sediments



The present investigation confirm that C:N ratio's in lake sediments can be used reliably to identify sources of sedimentary organic matter, and reveal the changes in the lake catchment such as land cover changes, aquatic weed infestations, discharge of untreated wastewater, etc. Large physico-chemical and biological changes in C:N, which would have led to an overlie of terrestrial, phytogenic and phycogenic C:N, were not evident in the surficial sediments.

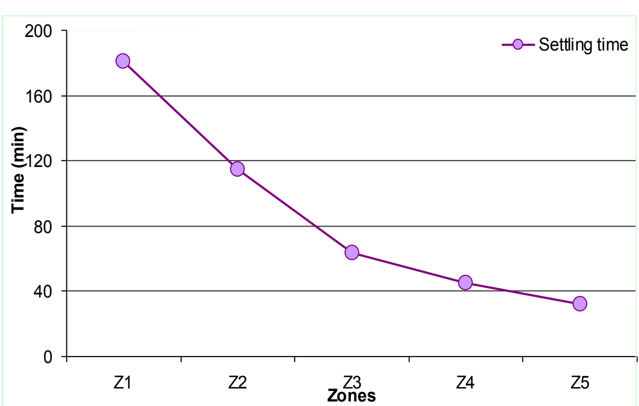
It was also observed that the natural variability of C:N of surficial sediments (Figure 8) at the center of Varthur Lake is small compared to the changes in C:N ratio near by shoreline regions of north and south sides of Varthur lake. Temporally there was a significant increase in C:N during the last two years [to values similar to surficial sediments near the inflow] due to changes in the dynamics with an increase in the proportion of terrestrial organic matter in the lake's central sediments. However, this has varied settling patterns in different seasons. The proportion of terrestrial organic matter could have risen because of increased particulate matter loads [29] and wastewater discharges [Hornbeck et al., 1986] from the upstream lakes through the channels and also direct inflow of sewage from the households near the lake boundary. As the water flow passes the beds of aquatic macrophytes as *Typha* sp. which checks its velocity, most of the particulate organic matter is trapped at the inlet regions. The Lake has a higher OM at the centre and near the outlets, due to rapid decay and settling of the autochthonous organic matter. Morphometry plays a very vital role in deciding the flow patterns. The maximum depth of the lake was observed to be

2m which is near the outlet region. During early monsoon period the north outlet was blocked and persistent stagnation was observed. During the summer the sludge churns and floats on the surface near the stagnant regions. With the removal of blockage at the outlet there was more deposition of OM at the deeper portions of the lake. Relatively higher values of C:N at the deeper points in the middle of zones Z4 and Z5 shows the proportion of terrestrial organic matter incorporated into central sediments probably declined due to stream discharges and sediment loads [30,29]. Consequently, the C:N of the lake sediments in our study are increasing after weed infestations and unrestricted discharges of sewage.

V. Sedimentation Rates

In the sludge settling experiments, it was observed that the sediments near the inlet regions in zones Z1 and Z2 were consisted of 3 different types of sludge. However the sediments near the outlet regions were similar. In the non-monsoon seasons (08) the sludge near the high flow regions were having a higher C content (which is attributed to particulate organic matter and rapid sludge formation). The sludge near the inlet zones was highly organic as seen in the earlier (Dec, 08 samples) but as we approach towards the outlets an improved and a matured sludge (Fig. 9) was observed. This is primarily due to unprecedented discharge of untreated sewage and due to external input from the catchment and surface run off which is in agreement with earlier studies [31]. Figure 10 shows the time taken for the sludge for 90% settling. It is well observed that the sludge settles fast near the outlets unlike the inlet where it takes a much longer time. However the Organic content of the sludge was found to be significantly higher in Dec, 09 which showed a higher organic C content throughout and was more prominent towards the bund region and the outlets. This links to the morphometry of the lake which has the deepest portions near the bund. The sedimentation rate is lowest in the deepest part of the lake, but increases progressively towards the inlets and the shorelines on either side of the lake.

Figure 10. Time required for 90% of the sludge for settling



VI. Elemental Concentrations

A significant variation of organic carbon flux in terms of BOD was observed with space and time in Varthur lake and is ~ 14.8 kg/ m^2 year, which is comparable to eutrophic lakes [32-35]. The variation in TOC can be due to differences in particulate grains; a constraint of C uptake and breakdown due to N limitation or could be due to early stage diagenetic alteration. Limited OM degradation in the anoxic sediments was reported earlier [36-39].

The atomic C/N ratio in Varthur sediments near the inlet regions (Z1) was recorded to be 23–33. The macrophyte derived material as the primary source of sediment OM near the south shoreline has C: N of 23.11 compared to slightly higher value of 33 in the middle and the north side. There was higher accumulation of C near the north side of the lake due higher terrestrial anthropogenic impact. These results are comparable to C/N ratios about 20 attributing to input of vascular plants, and lower C/N ratios [5–8] to algal-derived OM [3, 39].

The N values were consistently very low below 5% of the dry wt., which shows an N deficient system. It indicates that either the N is already leached into the system, or N forms are rapidly up-taken by the microbes. The volatilization and denitrification could be significant processes responsible for the lower sediment N values. The Organic N in the sediments can however be transformed to various inorganic forms as nitrites, ammonia, nitrous oxide or molecular nitrogen. The presence of inorganic N in sediments can alter C/N ratios and thereby confound the interpretation of OM sources [40]. This confirms that the OM source in Lake Varthur sediments is essentially autochthonous macrophyte-derived near the outlets and terrestrial N near the inlet zones. However the middle part OM in phycogenic in origin. Moreover, the C/N ratios indicate that run-off waters from the catchment can increase the terrestrial OM component, as the lake is surrounded by agricultural and horticultural lands nearly 67%.

VII. Conclusions

The analysis of the sediment the C:N ratios indicated a strong correlation between the elemental composition of C and N. This also showed that the sludge/sediments were acting as a major sink for C and N. The C and N values were found to be significantly higher in the deeper areas than the shallow inlet regions. This showed that 60 % of the nutrients are terrestrial in origin. These parts mostly are silt laden which is the reason for low organic Carbon compared to the other parts of the lake. The quantity of C and N stored on the sediments in a daily basis was large which accounts to 9 t C and 2.9 t N. The north side of the lake was anthrpogenically more impacted than the other parts which is evident from the higher C/N ratio.

Therefore, proper wastewater management strategies should consider approaches to minimize indiscriminate sewage ingress and losses of nutrients from agricultural fields into the lake systems. The results indicated that, once nutrients are delivered into the lakes, a substantial part in taken up by biota which ultimately die, decompose and settles as sludge sediment in the lake bottom and with high turbulence created by high wind velocities and overflow of water during monsoon they are likely to be transported downstream without much attenuation in the lake bottoms. Future investigations that would account for nature of various pollutants entering the lake system, the lake bottom soil types, and nutrient loadings from all sources must be conducted to examine impact of the wastewater ingress on sediments at different levels. (Vegetated, non-vegetated, dredged, and non-dredged).

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Assessment of treatment capabilities of Varthur Lake, Bangalore, India

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Abstract: Manmade waterbodies have traditionally been used for domestic and irrigation purposes. Unplanned urbanisation and ad-hoc approaches have led to these waterbodies receiving untreated sewage. This enriches and eutrophies the waterbody. A physico-chemical and biological analysis of sewage-fed Varthur Lake in Bangalore was carried out and its treatment capabilities in terms of BOD removal, nutrient assimilation and self-remediation were assessed. Anaerobic conditions (0 mg/L) prevail at the inlet which improves towards the outlets due to algal aeration. This removed >50% BOD in the monsoon season but was inhibited by floating macrophytes in all other seasons. Alkalinity, TDS, conductivity and hardness values were higher when compared to earlier studies. This study shows the lake behaves as an anaerobic~aerobic lagoon with a residence time of 4.8 d treating the wastewater to a considerable extent. Further research is required to optimise the system performance.

Keywords: nutrients; eutrophication; lagoon; sewage; urban lakes.

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Three different types of biomass-based biogas plants are being disseminated – the plug-flow like biogas plants, solid-state stratified bed (SSB) biogas fermenter and biomass immobilised bioreactors for coffee and agro-processing waste waters.

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1 Introduction

Rapid urbanisation coupled with industrialisation in urban areas has greatly stressed the available water resources qualitatively and quantitatively in India. This has also resulted in the generation of enormous sewage and wastewater after independence. Unplanned urbanisation and ad hoc approaches in planning are evident everywhere, be they settlements or sanitary systems and networks. Urban areas in India lack the infrastructure for sanitation, leading to inappropriate management of the wastewater generated. Most of the sewage and wastewater generated is discharged directly into storm water drains that ultimately link to waterbodies. Since Bangalore is located on a ridge with natural water courses along the three directions of the Vrishabhavaty, Koramangala–Challaghatta (KC) and Hebbal–Nagavara valley systems, these water courses are today being used for the transport and disposal of the city's sewage. The shortfall or lack of sewage treatment facilities has contaminated the majority of surface and ground waters. These aquatic resources are now unfit for current as well as future use and consequently pose critical health problems. Central Pollution Control Board (CPCB, 2006; CPCB, 2009) estimate indicates that about 26,254 million litres per day (MLD) of wastewater are generated in 921 Class I cities (Population > 1,00,000) and Class II (Population 50,000–1,00,000) towns in India (housing more than 70% of the urban population). However, only 27% (7044 MLD) of wastewater is treated.

Bangalore is the principal administrative, cultural, commercial, industrial and knowledge capital of the state of Karnataka. Greater Bangalore, an area of 741 km^2 including the city, neighbouring municipal councils and outgrowths, was 'notified' (established) in December 2006 (Figure 1). Bangalore is one of the fastest growing cities in India, and is also known as the 'Silicon Valley of India' for heralding and spearheading the growth of Information Technology (IT) based industries in the country. With the advent and growth of the IT industry, as well as numerous industries in other sectors and the onset of economic liberalisation since the early 1990s, Bangalore has taken the lead in service-based industries, which have fuelled the growth of the city both economically and spatially. Bangalore has become a cosmopolitan city attracting people and business alike, within and across nations (Sudhira et al., 2007; Ramachandra and Kumar, 2008).

The undulating terrain in the region facilitated the creation of a large number of tanks in the past, providing for the traditional uses of irrigation, drinking, fishing and washing. This led to Bangalore having hundreds of such waterbodies through the centuries. In 1961, the number of lakes and tanks in the city stood at 262. A large number of waterbodies (locally called lakes or tanks) in the city had ameliorated the local climate, and maintained a good water balance in the neighbourhood. A current temporal analysis of wetlands, however, indicates a decline of 58% in Greater Bangalore which can be attributed to intense urbanisation processes. This is evident from a 466% increase in built-up area from 1973 to 2007 (Ramachandra and Kumar, 2008). The undulating topography, featured by a series of valleys radiating from a ridge, forms three major watersheds, namely the Hebbal Valley, Vrishabhavathi Valley and the Koramangala and Challaghatta Valleys. These form important drainage courses for the interconnected lake system which carries storm water beyond the city limits. Bangalore, being a part of peninsular India, had the tradition of storing this water in these man-made waterbodies which were used in dry periods. Today, untreated sewage is also let into these storm water streams which progressively converge into these waterbodies. Varthur Lake is one such lake at the end of a chain of lakes.

Varthur Lake, situated in the south of Bangalore, was built to store water for drinking and irrigation purposes (Government of Karnataka, 1990). Today, large-scale developmental activities in recent times due to unplanned urbanisation in the lake catchment has resulted in reduced catchment yield and higher evaporation losses. Inefficient primary feeder channels feeding the lake have also contributed to water shortage. However, this shortage has been supplemented by an increased quantum of sewage inflow. Due to the sustained influx of fresh sewage over a decade, nutrients in the lake are now well over safe limits. Varthur Lake has been receiving about 40% of the city sewage for over 50 years resulting in eutrophication. There are substantial algal blooms, Dissolved Oxygen (DO) depletion and malodour generation, and an extensive growth of water hyacinth that covers about 70–80% of the lake in the dry season. Sewage brings in large quantities of C, N and P which are trapped within the system. A similar situation prevails in many other cities such as Bhopal (Shahpur Lake), Jabalpur (Sardar Lake), the Sihora, Gosalpur, Kundam and Seoni towns of Madhya Pradesh (Ghosh et al., 2008), Udaipur, Rajasthan (Chaudhury and Meena, 2007), Hussain Sagar (Hyderabad), Nainital Lake (Region Special Area Development Authority, 2002) and Kandy Lake in Sri Lanka (Silva, 2003). Such instances have been recurring despite the fact that a certain part of the sewage undergoes at least primary treatment in most cities of India. Thus, any solution to this problem can go a long way in restoring thousands of such waterbodies in India.

The extent of N (nitrogen) flowing through the Belandur–Varthur lake system is large (16.4 t/d; Chanakya and Sharatchandra, 2008) and is about 20–40 mg/l. The various forms of nitrogen influent in sewage are organic N (protein N), urea, ammonia, nitrites and nitrates through processes like nitrification, denitrification and ammonification. Autotrophic nitrification consists of two consecutive aerobic reactions, the conversion of ammonia to nitrite by *nitrosomonas* and then from nitrite to nitrate by *nitrobacter* (Hooper et al., 1997; Koops and Pommerening-Röser, 2001). Nitrite-Oxidising Bacteria

(NOB) use CO_2 and bicarbonate for cell synthesis and ammonium or nitrite as the energy source (Hooper et al., 1997). Ammonia-Oxidising Bacteria (AOB) belongs to β-Proteobacteria which includes two genera, *nitrosospira* and *nitrosomonas* (Stephen et al., 1996; Purkhold et al., 2000; Purkhold et al., 2003). Complete nitrification stoichiometry requires 4.6 kg oxygen per kg NH_4^+ (ammonia N). Dissolved oxygen concentrations of 1 mg l^{-1} are sufficient for the oxidation of ammonium (Hammer and Hammer, 2001). However, at DO concentrations lower than approximately 2.5 mg l^{-1}, nitrite oxidation is inhibited, leading to its accumulation (Paredes et al., 2007). In such conditions, the oxygen transfer rate may be as important as the actual O_2 concentration. Plants provide an oxygenated zone around the roots which enhances nitrification (Zhu and Sikora, 1994; Johnson et al., 1999; Munch et al., 2005). In less-aerated systems, however, the transfer rate varies according to the plant species and other environmental and operational factors (Faulwetter et al., 2009).

Higher concentrations of nitrates and phosphates primarily contribute to the eutrophication of urban waterbodies. Higher values of NO_3 N were observed during the post-monsoon season (Srivastava et al., 2007; Bharali et al., 2008; Dhanalakshmi et al., 2008; Edokpayi and Aneke, 2008). There is, however, scant mention about the various forms of nitrogen being observed and analysed in all these studies. In most of these studies, the N forms have not been partitioned into protein, urea, ammonia, nitrate, nitrite and nitrate denitrified into di-nitrogen. The conversion rates from one form to another as well as their uptake/release by various biological agents and their quantification are often not carried out. Higher P values were recorded in July (Heron, 1961) and pre-monsoon (Bharali et al., 2008; Kapil and Bhattacharya, 2009). Moderate to high values of Biochemical Oxygen Demand (BOD) were reported in the pre-monsoon (Solanki et al., 2007; Dhanalakshmi et al., 2008; Raveen et al., 2008).

In all the cases above, it is not clear what extent of the input water (influent into the lake) is sewage and therefore the contribution of sewage to the C, N and P loads have seldom been estimated. Earlier estimates indicate that Varthur Lake receives about 500 MLD of sewage (Chanakya et al., 2006). This also serves as a water source for crop irrigation to downstream farmers. There were indications that the sewage passing through such a lake system was being partially treated. In this study, we examined the nature and extent of changes in water quality (treatment levels) during various seasons. It is of interest to determine whether such a lake could be converted to a sustainable and passive sewage treatment system adaptable to other locations, considering that water and energy are fast becoming scarce in the developing world.

2 Materials and methods

2.1 Study area and its characteristics

Varthur Lake (12°57′24.98″ to 12°56′31.24″ N, 77°43′03.02″ to 77°44′51.1″ E) is the second largest fresh waterbody in Bangalore built by the Ganga kings over a thousand years ago (Figure 1) for domestic and agricultural uses. It covers a water-spread area of 220 ha (mean depth 1.1 m, Figure 2). It is part of a series of connected and cascading waterbodies. The Varthur Lake catchment has seen large-scale land use changes after 2000, consequent to the rapid urbanisation process in the region. Now the lake receives inadequately treated sewage of about 500 MLD. The average annual rainfall of Bangalore is 859 mm and temperatures vary from 14°C (December to January) to 33°C (maximum during March to May). There are two rainy periods, i.e. 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. Water samples were collected regularly on a monthly basis from five predetermined sampling points to represent inlets, outlets and midpoints (Figure 1).

These locations were confirmed by using a hand-held GPS (Garmin 48), which was mapped on to the earlier spatial map (of 2002). From a hand-held GPS survey carried out as part of the study, it was confirmed that the shape and water-spread area have not changed drastically (Figure 2). The lake had a varying extent of floating macrophytes during different seasons. The presence of water hyacinth impeded the use of boats for sampling water quality all over the lake in all seasons. Only a sample closer to shore could be reliably sampled at specific times of day during the year-long study as the wind-induced drift of floating macrophytes on the lake made time-specific sampling of all the points unfeasible. Figure 3 illustrates the spatial extent of macrophytes in March as compared to December. A False Colour Composite (FCC) was generated using geo-referenced LANDSAT data (of 30 m spatial resolution) for December, and IRS LISS III data (of 23 m) for March. The lake had less of a macrophyte cover during November–December due to the north-east monsoon runoff with human interventions (pushing macrophytes downstream). Macrophytes cover about 70–80% of the water-spread area during summer, as is evident from the March FCC.

Figure 1 Varthur Lake, Greater Bangalore, India with sampling locations (see online version for colours)

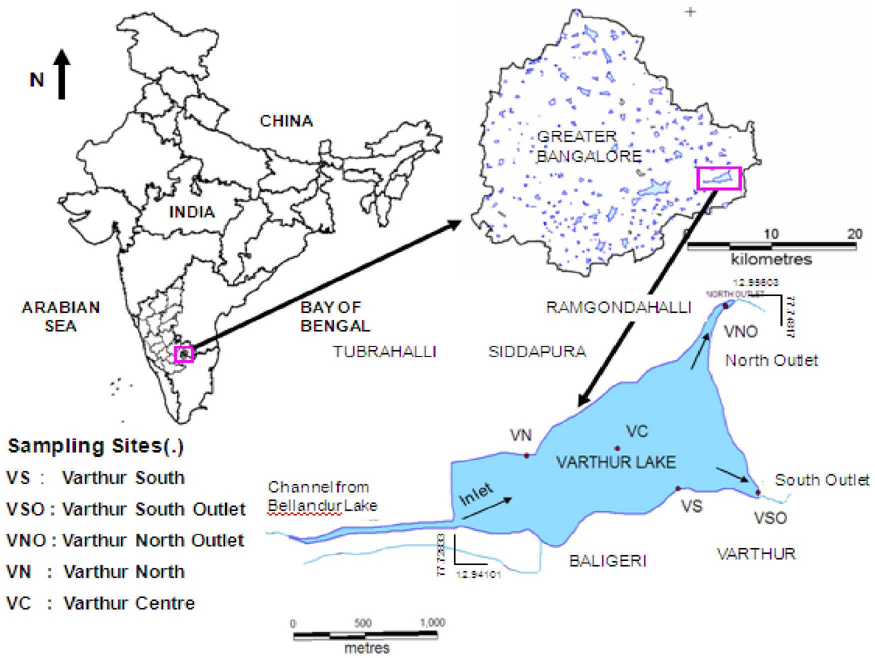


Figure 2 Depth profile of Varthur Lake (see online version for colours)

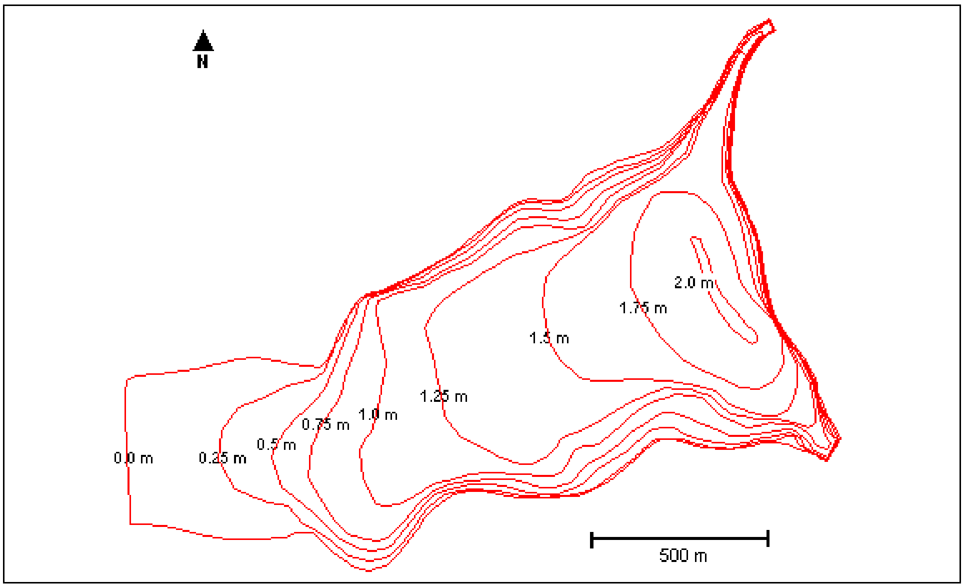
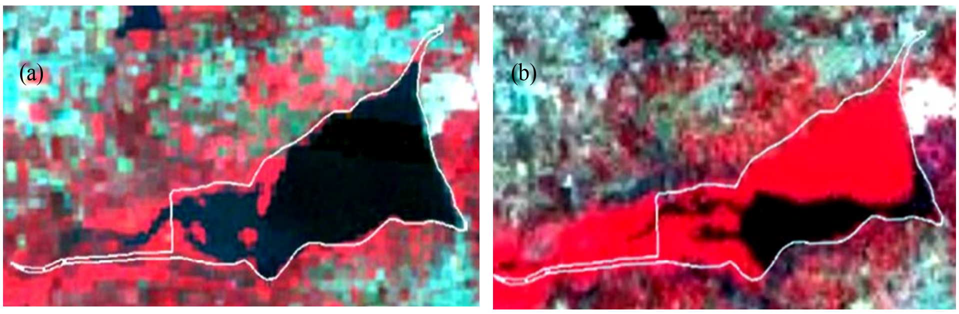


Figure 3 (a) FCC of LANDSAT (30 m) and (b) IRS LISS III (23 m) (see online version for colours)



2.2 Water sampling and analysis

Water samples were collected in the last week of every month during July 2008–June 2009 from five sampling sites (Figure 1) to examine the influent and the effluent water quality. Care was exercised to ensure that the sampling bottles were free of any contaminants. These bottles were treated with 10% HNO_3 and subsequently washed with distilled water. Grab sampling was followed at all points. On-site measurements include estimation of pH (pH probe), water and ambient temperature (lab thermometer), Total Dissolved Solids (TDS) (TDS probe), conductivity (conductivity probe), dissolved oxygen (iodometry) and transparency (Secchi disc). The samples were then carried to the lab and were analysed for various parameters according to Standard Methods (APHA AWWA WEF, 1998). Water samples were analysed for total alkalinity (titrimetry), total hardness, Ca, Mg (complexometric titration), Na, K (flame photometer), chlorides (argentometric method), nitrates (phenol disulphonic acid method), phosphates (stannous chloride method), chemical oxygen demand (dichromate oxidation with open reflux) and BOD (5-d BOD).

3 Results and discussion

The volume of water held is computed to be 2.42×10^9 l at an average water depth of 1.1 m with a water-spread area of 220 ha. The sewage received by this lake is about 5.00×10^8 l/d (500 MLD). Based on these data, the retention time would be 4.84 d. However, as the flow is not uniform and the presence of macrophytes impedes uniform flow, the actual residence time would be lower than the estimated 4.84 d. From an open pan evaporation value of 10 mm in summer and 5 mm in the rainy season, the daily evaporation loss for open surface water is estimated to be 2.2×10^7 l/d in summer and half of that for the rainy months. This, in turn, works out to 4.4% of influent for the summer. It is, therefore, envisaged that any changes in the composition of the wastewater between the inlet and the outlet are not likely to be affected by evaporation losses to any significant extent.

The inlet area is quite narrow and shallow (0.5–0.75 m deep, Figure 2) and has a surface flow rate ranging between 0.16 (Siddapur, VN) and 0.38 m/sec (inlet). This zone is generally covered with floating as well as rooted macrophytes round the year (Figure 3 – a and b). As a result, water flow occurs in a narrow and open channel. Algal species found in water are listed in Table 1 (genus level), while Table 2 lists macrophytes. Algae are dominated by *Microcystis* sp. which is indicative of a stressed lake followed by *Chlorella* sp. and *Nitzschia* sp. It has been observed that the primary coloniser of this zone is the water hyacinth. When the plant density becomes high, these detach themselves from the main body of floating water hyacinth and form small floating islands which later become infected by disease and pests. Significant water hyacinth mortality leads to succession by other species such as *Alternanthera* sp., local grasses, etc. growing on the floating debris of the decaying water hyacinth. Some water hyacinth, however, still grows between these otherwise luxuriant growths of floating terrestrial weeds, especially during the summer months. A large part of this *Alternanthera* sp. and grass biomass is also harvested manually and used as green fodder. However, the biomass growth rates far outstrip the harvest rates. As a result, during the months of April and May, nearly 70–80% of the water-spread area is covered by these macrophytes. This completely changes the way the lake functions in purifying the wastewater of the lake, which is discussed in detail later.

The diurnal (January and April 2009) changes of DO levels in water given in Figure 4 seems to be influenced by the macrophytes covering the lake. Figure 4(a) shows DO measured at the south outlet when it is free of macrophytes cover, while Figure 4(b) shows lower DO values when the lake is infested with macrophytes. Higher levels of nutrients during the summer (due to lack of dilution in the absence of rain and higher evaporation) have resulted in the profuse growth and dense spread of macrophytes hindering the light penetration and hence algal photosynthesis. Reduction of algal population coupled with poor photosynthesis has lowered DO in April month. Also, persistent stagnation of water due to blockage of north outlet has resulted in the consistent lower DO values at north outlet throughout the year.

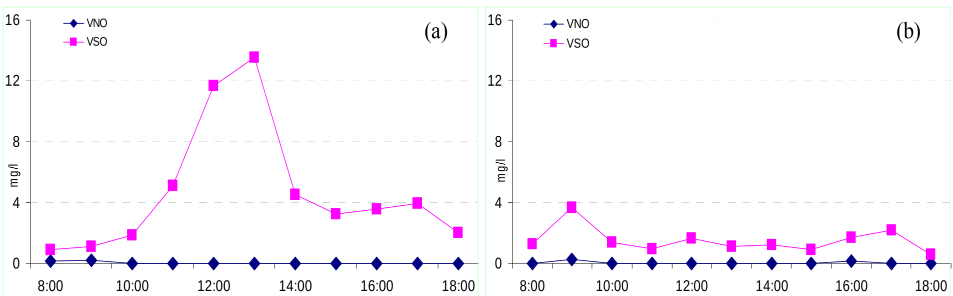
Table 1 Algae communities (identified up to genus level) in Varthur Lake

Algal family			
Chlorophyceae	*Cyanophyceae*	*Bacillariophyceae*	*Euglenophyceae*
Chlamydomonas sp.	*Cylindrospermopsis sp.*	*Gomphonema sp.*	*Phacus sp.*
Chlorogonium sp.	*Arthrospira sp.*	*Cymbella sp.*	*Euglena sp.*
Scenedesmus sp.	*Microcystis sp.*	*Navicula sp.*	*Trachelomonas sp.*
Ankistrodermus sp.	*Oscillatoria sp.*	*Pinnularia sp.*	*Lepocinclis sp.*
Chlorella sp.	*Anabaena sp.*	*Nitzschia sp.*	
	Merismopedia sp.	*Synedra sp.*	
	Lyngbya sp.	*Fragillaria sp.*	
		Cocconeis sp.	
		Melosira sp.	

Table 2 Macrophytes in Varthur Lake (includes riparian vegetation)

Plant species	*Common Name*
Typha augustifolia	Cat tail
Colocasia essculanta	Taro
Cyperus haspans	Dwarf papyrus sedge
Alternanthera phyloxiriodes	Alligator weed
Eichhornia crassipes	Water hyacinth
Lemna gibba	Duckweed
Lemna minor	Lesser duckweed
Pistia stratiotes	Water lettuce

Figure 4 Diurnal changes of DO levels during January and April 2009 at (a) south outlets and (b) north outlets (VNO represents Varthur North Outlet and VSO represents Varthur South Outlet) (see online version for colours)



The inlet region is predominantly anaerobic throughout the year as the channel connecting Varthur Lake from the Belandur lake receives raw sewage from the immediate vicinity (~100 MLD) apart from partially treated sewage (~400 MLD) from Belandur Lake. The samples at these locations are characterised by organic sludge under anaerobic conditions which is evident from dark grey colour, higher turbidity, lower DO (zero mg/l) and negative Oxidation Reduction Potential (ORP), i.e. from −220 to −180 mV. These conditions have aided the spread of macrophyte mats, which has reduced the flow of water. However, there are few distinguishable zones of rapid flow of incoming wastewater in the inlet channel. Spatial analysis of macrophytes spread in the lake using remote sensing data (Figure 3 – a and b) highlights that the anaerobic zone occupies a third of the distance from the inlet (water hyacinth cover is about 74 ha) during the rainy and winter months (July to January) and extend two-thirds of the water-spread area (148 ha) during February to June. During rainy season, the runoff and high-velocity wind (17 kmph, westerly wind) play a major role in the spread and dispersal of floating macrophytes across the water-spread area apart from transporting to downstream regions. In the absence of floating macrophytes, the water rapidly turns green to indicate the presence of microalgae and their role in treating water evident from higher DO and lower BOD during these months. However, at northern outlet, compaction of macrophytes happens due to wind and blockage.

Water quality monitoring was carried out covering all seasons to understand the variations in water quality across space due to seasons. The analysis was carried out as discussed in the methods section. Figure 5 depicts monthly variations at inlet and outlets, while Figure 6 portrays water quality across all sampling locations. Parameters such as DO, BOD, PO_4 and hardness exhibit seasonal variations across the lake. Figure 7 further highlights the extent of variations across space and time through whisker plots. Parameter-wise variations are discussed next.

The ambient air temperature was found to be in the range of 15°C (winter) to 35°C (summer) at the time of sampling (Figure 7a). Water temperature influences the rate of various biochemical reactions, and enhances BOD removal rates. The water temperature showed the variation of 18°C (winter) to 32°C (summer) (Figure 7b).

TDS comprise mobile charged ions, including minerals, salts or metals dissolved in water. TDS value (Figure 7c) ranged from 528 (December) to 994 mg/l (April) and are in agreement with earlier studies (Ramachandra et al., 2006). Higher values of TDS are due to the reduced flow rates, an influx of concentrated sewage and an enhanced water retention period. Electrical conductivity is an indirect measurement of the salt concentration. It varies (Figure 7c) from 751 (December) to 1420 µS/cm (April). EC is positively correlated with TDS ($r = 0.93$, $p < 0.05$) as reported earlier (Kataria et al., 1995; Bharali et al., 2008).

Transparency indicates the extent of turbidity and also measures the light penetration through the water. It ranged from 24 (summer) to 28 cm (monsoon). Reduced transparency during summer is due to increase of suspended particles on account of organic debris's decomposition with higher water temperature and reduced flow.

pH is largely governed by carbon dioxide, carbonates and bicarbonate equilibrium (Chapman, 1996). pH ranged from 6.82 (August–October) to 8.2 (July), which coincides with increased cations found in the water ($r = 0.8791$, Mg; $r = 0.8823$, Na; $r = 8817$, K; at $p < 0.05$) (Figure 7d). A sudden decrease in pH (during June–September) comparable to other studies (Bindiya et al., 2008; Raveen et al., 2008) may be attributed to the dilution on account of the inflow of the runoff. Slightly alkaline conditions are favourable for the growth of primary producers (Bellum, 1956) and a low pH is a consequence of macrophytes cover (Parinet et al., 2004).

Total alkalinity ranged from 240 (October) to 460 mg/l (May), as shown in Figure 6. Higher values during summer are due to reduced microalgal photosynthetic activities resulting in higher respiration (and higher total CO_2) and anaerobic decomposition by bacteria on account of profuse spread of macrophytes (Figure 3b). Total alkalinity is higher at inlet (Figure 5f) due to high concentration of carbon-based mineral molecules suspended in the solution at the inlet region and prevailing anoxic conditions. This is comparable to earlier similar studies (Sinada and Abdel Karim, 1984; Hujare, 2008) but higher (Ramachandra et al., 2006).

Figure 5 Comparison of inlet and outlet characteristics (VN – Inlet and VSO – Outlet) (see online version for colours)

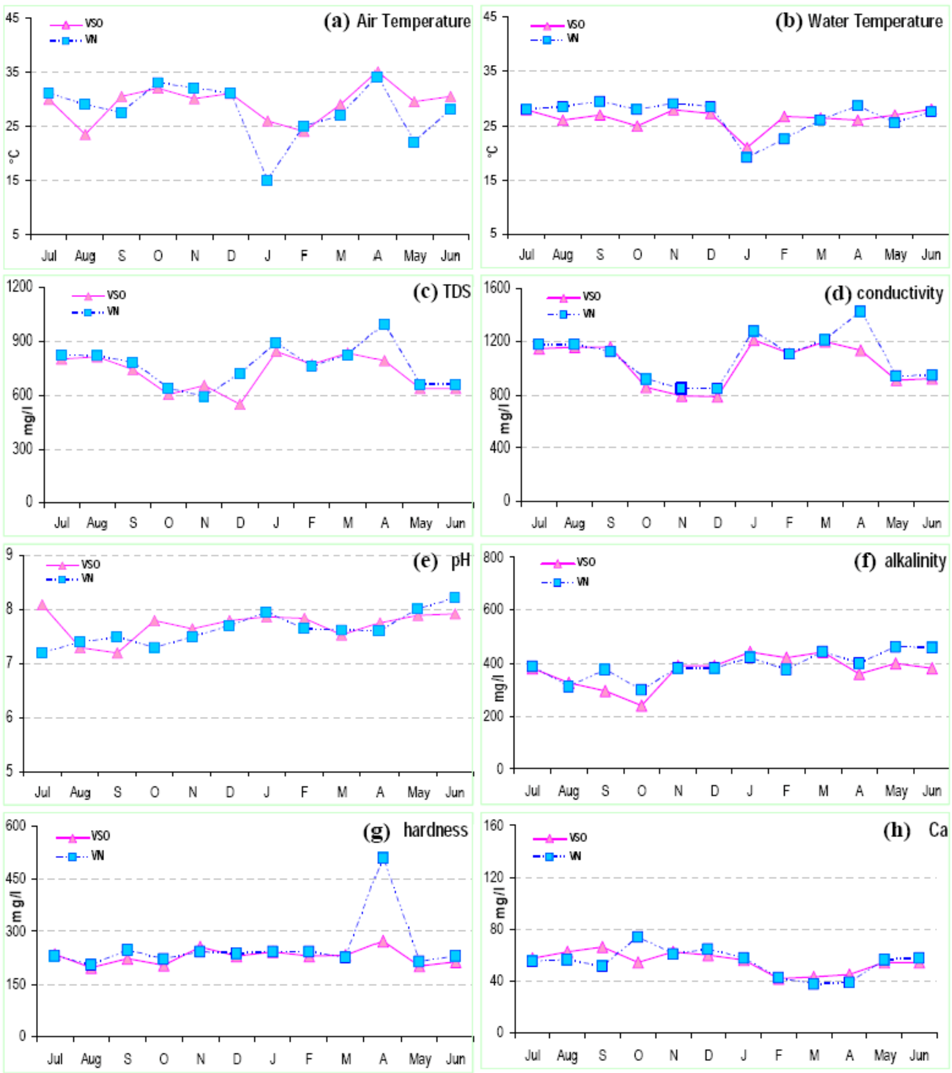
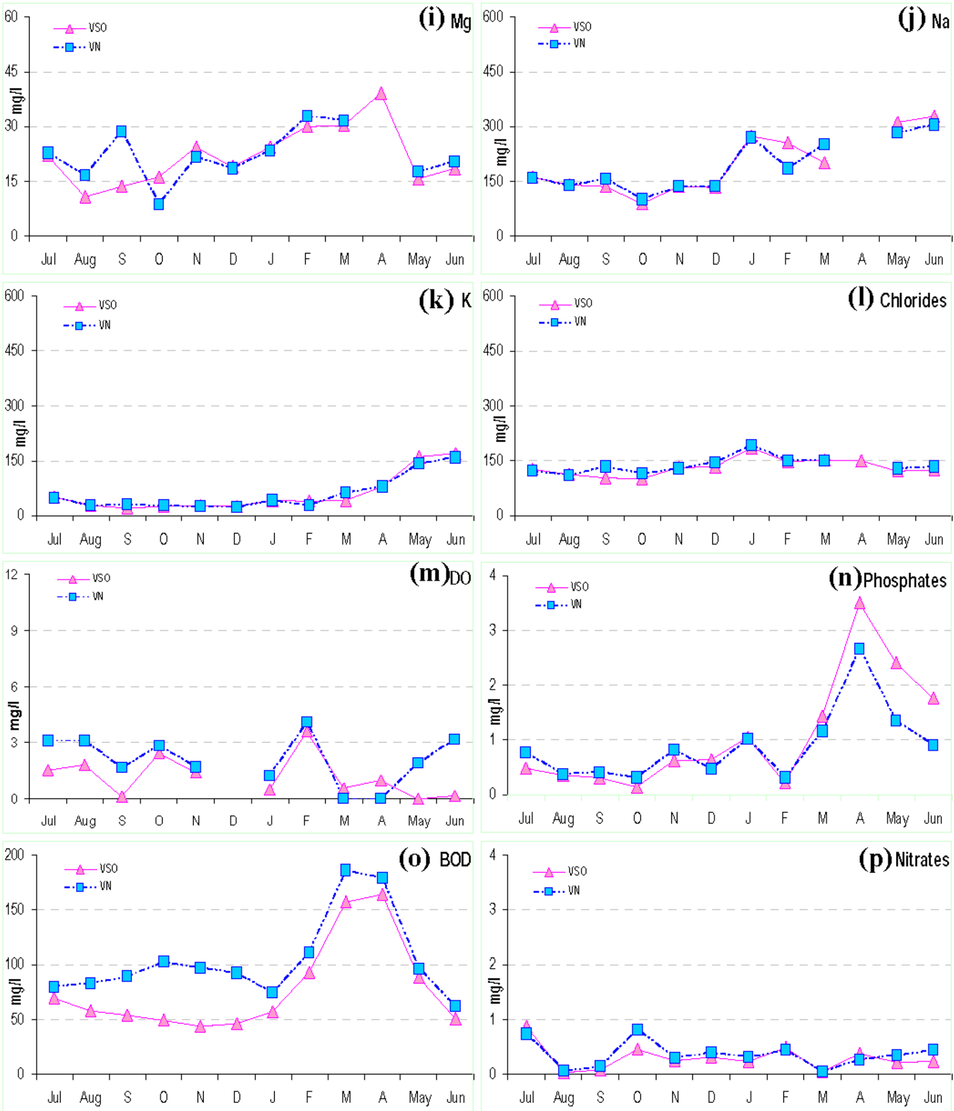
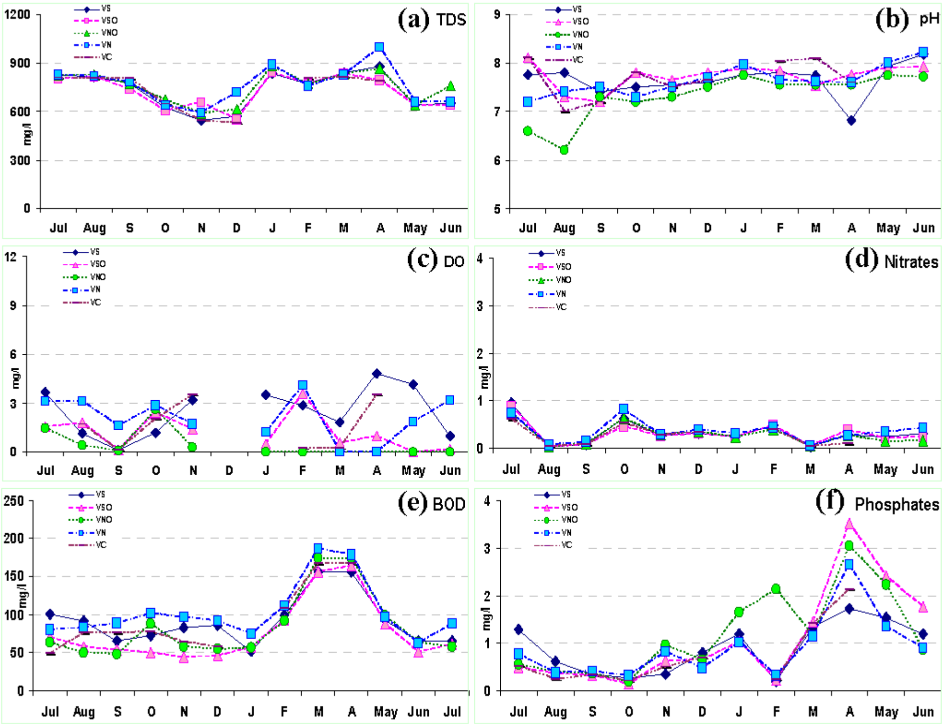


Figure 5 Comparison of inlet and outlet characteristics (VN – Inlet and VSO – Outlet) (see online version for colours) (continued)



The total hardness (Figure 7f) ranged from 192 (October) to 288 mg/l (April). Relatively lower value during monsoon is due to dilution (similar with other parameters), while higher value in summer can be attributed to a decreased flow rate and stagnation due to the blockage of one of the outlets, apart from the profuse macrophyte cover. There is no significant difference (p = 0.307 > 0.05) between the inlet and the outlet values (Figure 5g).

Figure 6 Overall variation of water quality at different sites in different seasons (see online version for colours)



Calcium varies (Figure 7g) between 37.6 (March) and 73.75 mg/l (October) without marked differences between inlet and outlets (Figure 5h). Magnesium ranged (Figure 7h) from 8.7 (October) to 40.5 mg/l (February). Higher value of 40.5 mg/l (February; Figure 7g) can be attributed to higher dependency of groundwater during non-monsoon seasons in the catchment. Sodium (Figure 7i) ranged from 90 (October) to 810 mg/l (April). Higher values during summer are due to higher evaporation and consequent concentrations in summer apart from higher dependency on groundwater. This higher value (of Mg, Na, K, etc.) has also contributed to higher TS. However, this is much higher in comparison to earlier studies (Ramachandra et al., 2006). Potassium is one of the essential nutrients for plant growth and it ranged (Figure 7j) from 11 (September) to 210 mg/l (April). There is no considerable difference between inlet and outlet K concentrations ($p = 0.9 > 0.05$) (Figure 5k) due to anoxic conditions (at inlet) and dense macrophyte cover (at outlet).

Chlorides vary from 100 (October) to 195 mg/l (January) (Figure 7k). These values are in conformity with earlier studies in the range of 120 mg/l for sewage-fed aquatic systems (Toshiniwal et al., 2006; Garg, 2007).

Dissolved oxygen decides the prevailing conditions of the water. Higher DO in the middle and south outlet regions (Figure 6c) is indicative of better algal photosynthetic activities and oxidative decomposition of dissolved organic matter. Low DO at inlet and at north outlet has been discussed earlier (macrophytes bloom hindering algal photosynthesis). Dissolved oxygen ranged from 0 (post-monsoon) to 4.83 mg/l (pre-monsoon) (Figure 7m). Hypoxic conditions prevailed at inlet, due to raw sewage inflow and stagnant conditions at north outlet (due to the blockage). Hypoxic and anoxic conditions can be correlated with a higher demand for oxygen for bacterial decomposition, which results in higher decomposition rates of organic matter and, consequently, creates an anaerobic environment.

Figure 7 Whisker plots showing the extent of variations across space and time (see online version for colours)

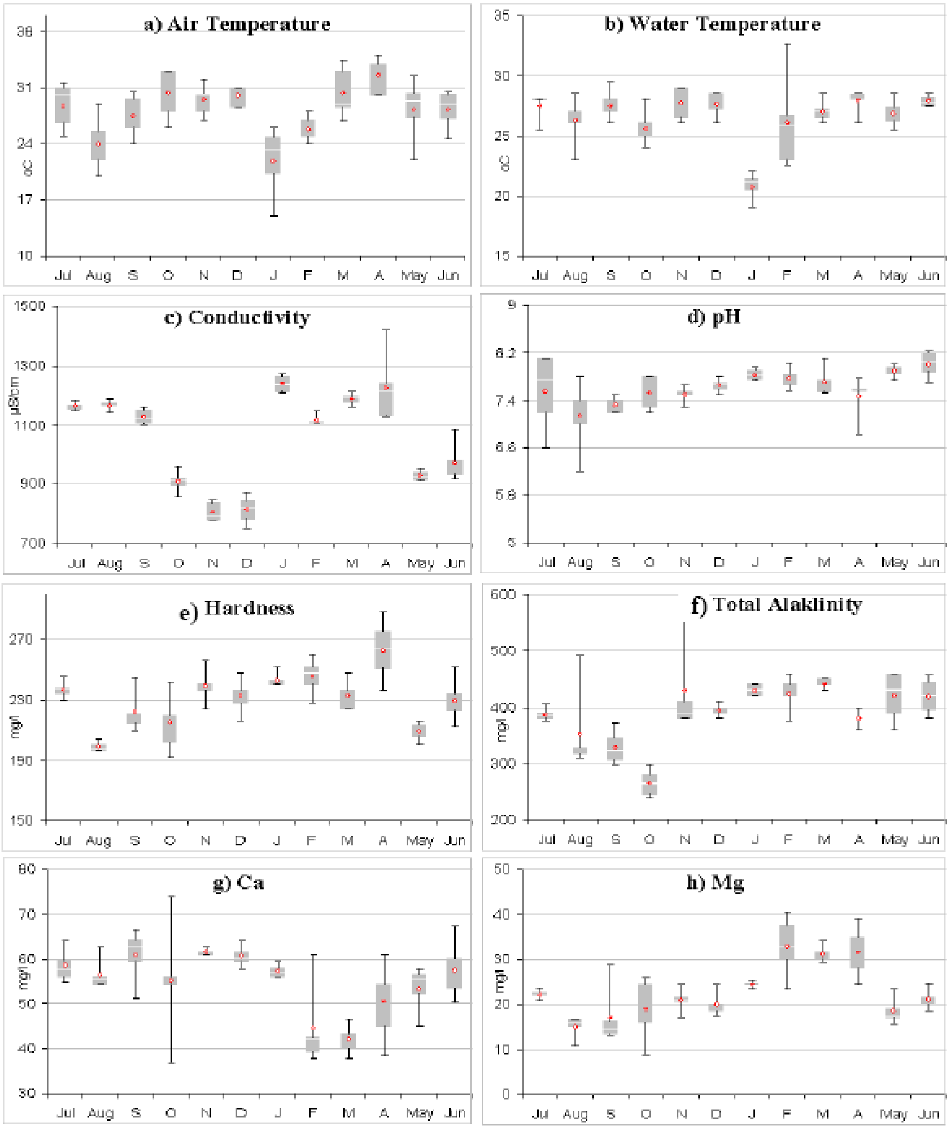
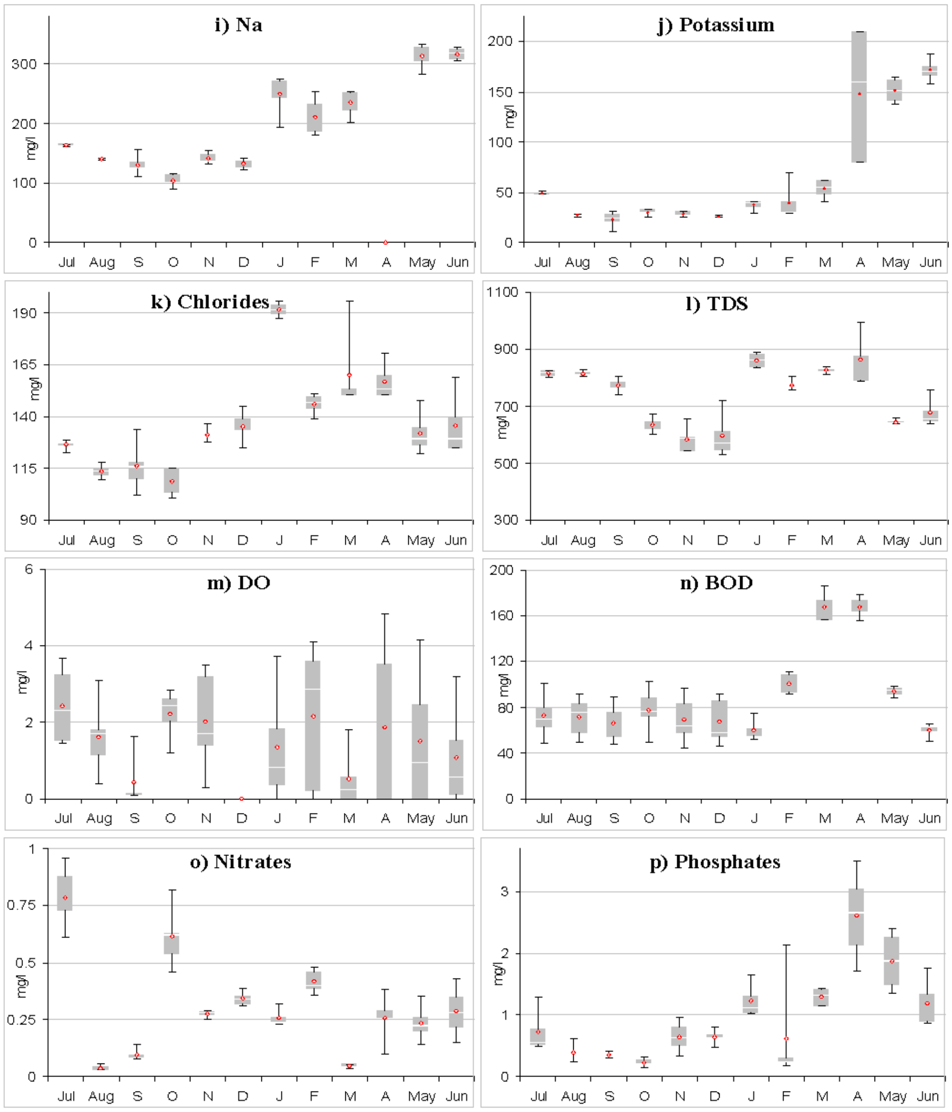


Figure 7 Whisker plots showing the extent of variations across space and time (see online version for colours) (continued)



BOD is indicative of the quantum of biodegradable organic matter in a lake. BOD values ranged from 44 (November) to 186 mg/l (March) (Figure 7m). A considerable reduction in BOD up to 50% (from 100 to 50 mg/l) was observed between the inlet and the outlets (Figure 5o) during August–January. However, the extensive coverage of macrophytes during February–May lowered the organic decomposition, and hence the BOD removal. BOD at the inlet was found to be higher in comparison to the outlet BOD throughout the study period (figure 5o), which shows a gradual reduction of BOD with space and residence time of 5 d. Similar results were reported – 96 mg/l (July–September) in three fresh waterbodies at Chennai (Raveen et al., 2008), 49.0 mg/l in Coimbatore, Tamil Nadu (Dhanalakshmi et al., 2008), 13.8–96.8 mg/l in two freshwater lakes of Bodan, Andhra Pradesh (Solanki et al., 2007).

Quantum and distribution of the nutrients (such as N and P) are decisive factors for biota in an aquatic ecosystem. Nitrogen, generally found as nitrate, is essential to all algal and aerobic microflora and goes predominantly into the proteins, etc. The extent of N (generally as NO^-_3) is also used as an indicator of the trophic state of the waterbodies. Higher concentrations of nitrate primarily contribute to the eutrophication of waterbodies. Nitrate values (Figure 7p) ranged from 0.03 (March) to 0.96 mg/l (July). There were no considerable differences between the inlet and the outlet nitrate concentrations (Figure 5p). The overall nitrate levels were below 1 mg/l (mostly due to uptake by macrophytes or by algae/bacteria) and did not vary temporally or spatially in any significant manner comparable to Kapil and Bhattacharya (2009), Ramachandra et al. (2006) and Kumara and Belagali (2008). However, higher values of NO_3 N were reported due to agriculture runoff (Bharali et al., 2008), from 7.9 mg/l (Srivastava et al., 2007; Edokpayi and Aneke, 2008) to 62.85 mg/l, due to enrichment through domestic sewage (Dhanalakshmi et al., 2008). Lower concentration of nitrates during monsoon is due to dilution apart from algal and bacterial uptake (Sharma et al., 1981).

Ammoniacal N (4–21 mg/l during April) substantiates hypoxic and anoxic conditions prevailing in the lake which is very toxic to biotic components. This is in agreement with the study of Belandur Lake, Bangalore (Chanakya et al., 2006). Varthur Lake behaves like a highly anoxic system mostly at the initial reaches, which makes ammonia the predominant N form with low nitrification and ultimately results in very low nitrate values. Anoxic conditions do not favour NH_4 to be nitrified to a large extent. On the other hand, low DO (0 mg/l) and negative redox (−220 to −180 mV) conditions favour denitrification. Similar values were reported for urban lakes in Hosurs (16.25–30 mg/l) (Karibasappa et al., 2009), Varthur Lake (>3 mg/l during October) (Ramachandra et al., 2006) and at the inlets and outlets of Bellandur Lake (31 mg/l during November) (Chanakya et al., 2006).

Phosphorus, an essential part of the biological system, is present mostly in the form of inorganic phosphates, which is taken up by the biota (Martin, 1987) and also constitutes a limiting factor to eutrophication (Vollenweider et al., 1980). Phosphate values ranged from 0.14 (October) to 3.51 mg/l (April) (Figure 7q). Appreciable differences were found in the inlet and outlet P concentrations (Figure 5n) during the summer months. Higher values during dry seasons may be attributed to lower algal activities (due to macrophyte cover) and to resuspension of sediment phosphorus leading to release of mineral phosphate accumulated in sediments (Ryding and Rast, 1994) Lower levels of phosphate are reported in lakes with higher phytoplanktonic biomass (Parinet et al., 2004).

Lower P concentrations during the monsoon could be attributed to dilution (due to runoff) and enhanced algal activities in the absence of macrophyte cover. Higher P values in July may be due to runoff. Higher values of phosphates were observed during the pre-monsoon (Bharali et al., 2008; Kapil and Bhattacharya, 2009), implicating evaporation losses coupled with the release of P from sediments (Hujare, 2008) and decayed plankton (phyto and zoo) wastes (Heron, 1961). Higher values were reported in Madivala Lake (Ramachandra et al., 2001) and urban lakes in Hosur (0.2–3 mg/l; Karibasappa et al., 2009).

BOD decreased from the inlet to the outlet (Figure 5o) in the monsoon and post-monsoon period (six months) highlighting the decline of organic content. This coincides with the low macrophyte coverage and availability of large oxic zone (evident from DO at midday as well as in the evening). Also, aerobic decomposition coupled with functioning of algal photosynthetic activities enhanced DO levels while lowering BOD. On the other hand, BOD reduction is very poor with dense macrophyte cover (late winter and summer months), with higher anaerobic conditions. This illustrates that lake would function as an anaerobic (upper reaches)–aerobic (lower reaches) lagoon system while bringing the desirable utility of sewage treatment to an appreciable level. Attempts, therefore, need to be made to increase the efficacy of conversion as well as water purification, leading finally to a sustainable technology that is applicable to a large part of India and the developing world.

It may be estimated that at about 100 g TS of waste/capita/d entering the sewage system the loading rate may be estimated to be 0.125 g TS/l/d and about 0.2 g BOD/l/d at the inlet, which is close to the functional limit for typical lagoons. On the other hand, when one considers the maximum potential of the anaerobic–aerobic systems, higher loading rates and higher conversion rates are possible. There is, thus, a need to further examine the potential for higher quality of water at the outlet to enable the recycling and reuse of water in the future. In order to make this more sustainable, the extent of the harvest and the reuse of plant nutrients for the system need to be examined. The macrophytes and the algae together with wetland vegetation have an important role in regulating the amount of nutrients. The contribution of macrophytes and phytoplankton in removing nutrients in these sewage-enriched systems varies with the nature of the effluent and the age of the wetland, in addition to other environmental factors like sunlight.

4 Conclusion

The water quality of sewage-fed Varthur Lake, Bangalore, India has been measured at five different locations. A BOD removal of 70% (filterable) was achieved when the lake functioned as an anaerobic–aerobic lagoon for 6 months at an estimated residence time of 5 d. During this period, the biota of the lake, especially primary producers (phytoplankton, algae), treated the water to nearly standard water quality levels. The growth and spread of macrophytes (water hyacinth) renders the lake anaerobic and reduces its capacity to treat the water. Keeping an open surface and permitting microalgal growth provides a high level of water treatment, and it may be used in a larger number of small towns to enable local reuse of water.

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BIOFUEL PROSPECTS OF MICROALGAL COMMUNITY IN URBAN WETLANDS

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Abstract: Microalgae are emerging as one of the most promising sources of biofuel because of their high photosynthetic efficiency and faster replication as compared to any other energy crops. Although, the concept of using microalgal lipid as a source of fuel is very mature, its approach in benefiting both environmental and energy-related is a frontier research area today. Algal community for the production of lipid depends on the physical, chemical as well as biological variables of aquatic ecosystems. This communication focuses on achieving the lipid characterization of the microalgal community collected from four wetlands and one agricultural field of Bangalore, Karnataka with a wide range of environmental characteristics. Results reveal significant change in lipid component with change in algal community and chlorophyll content which was explained by community structure analysis and chlorophyll estimation. The presence of Triacyl glycerol (TAG) was examined through thin layer chromatography (TLC). The profile of TAG was further confirmed through Gas chromatography – mass spectroscopy (GC-MS). This study confirms the potential of algal community towards meeting growing demand for alternate sustainable fuel.

Keywords: Microalgae, Community structure, Lipid, Gas chromatography – mass spectroscopy.

I. INTRODUCTION

Water occupies most part of the Earth's surface amounting to a volume of 1.38X109 km^3 of which freshwater contributes to approximately 0.0013% of the global water[1]. Freshwater ecosystems encompass an extensive range of habitats viz., rivers, lakes, and wetlands, with constant interaction of biotic with abiotic components. Studies have revealed that the use of freshwater in agricultural purposes is ~ 4000 km^3 of water by 2050[2], for domestic purposes (during 1987– 2003) is estimated to be 325 billion cubic meter[3] while industrial consumption was 665 billion m^3 during the same period[4]. However, in the 21[st] century, freshwater ecosystems are vulnerable to and by climate change[5,6,7], increase in burgeoning human population coupled with growing food requirements, industrialization and urban sprawl[8]. This turns fresh water into wastewater polluting the environment and creating health hazards to the aquatic life in the freshwater bodies making it unfit for human consumption. These polluted aquatic ecosystems are neglected owing to decline in water quality and quantity, nutrient and hence impeding species' diversity, photosynthesis, chlorophyll and the biochemical composition which includes lipids, carbohydrates and proteins. This has directed towards the threshold of water crisis and the urgent need for developing appropriate water management plans. Along with water management the utilization of biotic components like macrophytes[9,10], micro[11,12] and macrolage[13] as sources of energy has gained prominence in recent years in an era of global warming in addressing production and utilization of renewable energy while dealing with the social and ecological problems.

Biodiesel is a proven fuel and the technology for more than a decade now[14]. Water is the primary factor in the development of biofuel feedstock production[15]. Numerous researches have been carried out on the production of biodiesel through vegetable oils[16] and other plant oils[17,18]. But due to the high cost of these oleaginous materials, the commercial production of biodiesel is hindered. Therefore, finding cheaper way of producing biodiesel is the need of the hour.

Lipids, the important secondary metabolite owing to specific cell functions and cell signaling pathways play a role in biodiesel production[19]. Major feedstock of biodiesel include soybeans, canola oil, animal fat, palm oil, corn oil, waste cooking oil and jatropha oil[20]. These crop based biofuels have limitations like low biomass productivity (Table 1), requirement of large land area and its non renewability[21]. The other limitation includes the inadequacy of these crops and animal fats oil to meet the existing demand for fuels[21]. Micro algae are efficient biological factories capable of taking zero-energy form of carbon and synthesize it into a high density liquid form of energy (natural oil) and are capable of storing carbon in the form of natural oils or as a polymer of carbohydrates[22]. Microalgae as primary producers form the basis of the food web and play a significant role in the biotic and abitoic interactions of any aquatic ecosystem. The variation in water chemistry and biotic components of an aquatic ecosystem consequent to anthropogenic stress attributes to changes in the structure of microalgae at community level. The concept of using microalgal lipid as a source of fuel is very mature, but its approach in benefiting multiple needs—both environmental and energy-related is an upcoming area of research. Hence characterizing the microalgal community is critical for better understanding of the ecological as well as biogeochemical processes[23]. Over the past few decades, several thousand algae and cyanobacterial species have been screened for high lipid content of which several hundred oleaginous species have been isolated and characterized under laboratory and or outdoor conditions[12,21,24,25]. The current investigation focuses on lipid characterization of the micro algal community in Bangalore collected from 4 wetlands with a wide range of environmental characteristics and an agricultural field.

TABLE 1
BIOFUEL SOURCE COMPARISON[21, 37]

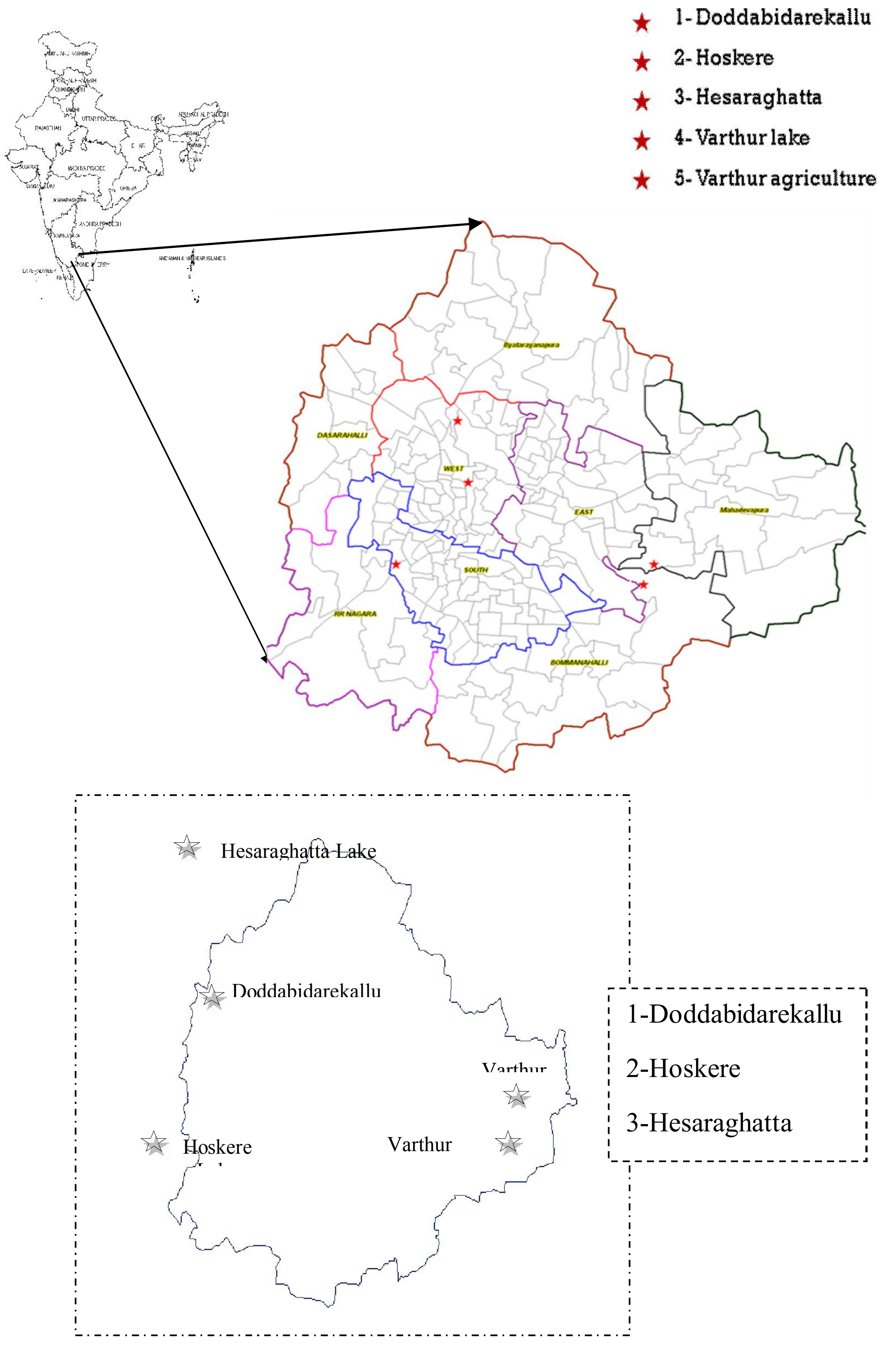
Feedstock	Oil Yield (l/Ha)
Corn	172
Soybean	446
Canola	1190
Jatropa	1892
Coconut	2689
Oil palm	5950
Microalgae a	136900
Microalgae b	58700

a= 70% oil (by wt) in biomass and b= 30 % oil (by wt) in biomass

II. STUDY AREA

Selected four lakes and an agricultural field for the Microalgal community and lipid characterization investigation fall within Bangalore (Fig. 1), the capital city of Karnataka and is the fifth largest city in India. Bangalore city is located at 12.940699^{0}N and 77.746596^{0}E geographic position, at an elevation of 900 meters and a surface area of 741 sq. km (as per 2007). Mean annual temperature being 24 ºC with extremes ranging from 15 ºC (in winter) to 37 ºC (in summer). The average annual rainfall is 859 millimeters[26].

The selection of lakes for the study was based on the levels of anthropogenic stress upon the lake, covering different environmental condition. Samples from each lake were sampled at inlet channel so as to record the pollution level on microalgal lipid content. The Doddabidarekallu lake (Nagasandra lake) with an area of 13.07 ha is situated in the industrial area (peenya industrial area), receives industrial effluents representing the industrial waste sample. Hesaraghatta (371.24 ha) and Hoskere lake (also known as Soolekere) with a surface area of 15.54 ha is situated on the city boundary (as per BBMP) and is relatively clean without any sewage and industrial waste into the lake channel while, Varthur with an area of 180.4 ha receives about 40% of the city's sewage. Agriculture field was selected near the Varthur lake to see the effects of inorganic fertilizers with high phosphates and nitrates.



Note: Sampling sites are 1- Doddabidarekallu, 2- Hoskere, 3- Hesaraghatta, 4- Varthur lake, 5- Varthur agriculture)

Fig 1. Sampling locations in Bangalore, Karnataka, India

III. MATERIALS AND METHODS

A. *Water sampling and analysis*

Four Lakes (Fig. 1) were selected based on the exploratory survey of 15 lakes during eight months (September 2009- April 2010) which includes water quality analysis of both Inlet and outlet channels. Water samples were collected from four lakes and one agricultural field in Bangalore during May 2010. They were selected based on the anthropogenic stress (industrial runoff, sewage runoff, unpolluted, high nutrient load) influencing on it. Triplicates were collected at each sampling point in 1L polythene bottle. On site physical parameters like pH, water temperature (WT), electric conductivity (EC), salinity and total dissolved solids (TDS) were analyzed using pH/EC probe. Dissolved oxygen (DO) was estimated following Wrinkler's method. Samples were brought to Aquatic ecology laboratory for further analysis of chemical variables such as Nitrates, Phosphates, Alkalinity, Total hardness, Calcium hardness, Magnesium hardness, Chlorides, Sodium, Potassium, Biological oxygen demand (BOD) and Chemical oxygen demand (COD). These variables were estimated as per standard procedure[27].

B. *Microalgae sampling*

Microalgae were sampled from aquatic plant at all sampling points by shaking vigorously and then squeezed in the plastic bag. The resulting brown suspension is transferred into a polythene sample bottle and preserved. Community structure analysis: 0.5 ml of the preserved microalgal sample was observed under light microscope (100X magnification). The entire coverslip was covered to record the presence/absence data of the taxa and photographed for identification.

C. *Chlorophyll estimation*

25 ml of the microalgal sample was centrifuged t 300 rpm and was filtered. The filtered sample was then processed for chlorophyll estimation following APHA method (APHA 10200 H).

D. *Lipid characterization*

25 ml of the microalgae sample was sonicated[28] in water bath for 2 hours at room temperature in order to disrupt the cell membranes, chloroform: methanol (2:1) was added as the extraction solvent. The chloroform layer was evaporated using rotary evaporator (Eppendorf Vacuum Concentrator 5301) to obtain lipids. Thin layer chromatography: All samples were reconstituted in chloroform to make stock solutions. The stock solutions were spotted in bands onto silica gel TLC plates (Merck KGaA). The mobile phase consisted of a solvent system of hexane/diethyl ether/acetic acid (70:30:1 by volume)[29]. The plates were developed by exposing the vapors of iodine crystals to stain the plates for visualizing neutral lipids. The samples were extracted and stored in -20 ºC until further analysis[30].

E. *Gas chromatography–mass spectrometry analysis*

After the initial thin layer chromatography (TLC) lipid screening, the extracts were converted into fatty acid methyl esters (FAME) using Boron trifluoride-methanol and was heated in water bath at a temperature of 60 ºC for 1 hour. The methylated sample was then purified further for GC-MS. The main focus of using GC-MS was purely for lipid identification rather than quantification. The injector and detector temperatures were set at 250 ºC while the initial column temperature was set at 40 ºC for 1 min. A 1μL sample volume was injected into the column and ran using a 50:1 split ratio. After 1 min, the oven temperature was raised to 150 ºC at a ramp rate of 10 ºC min^{-1}. The oven temperature was then raised to 230 ºC at a ramp rate of 3 ºC min^{-1}, and finally the oven temperature was increased to 300 ºC at a ramp rate of 10 ºC min^{-1} and maintained at this temperature for 2 min. The total run time was programmed for 47.667 min. The mass spectra were acquired and processed using Agilent Chem Station (5975 C; Agilent, USA).

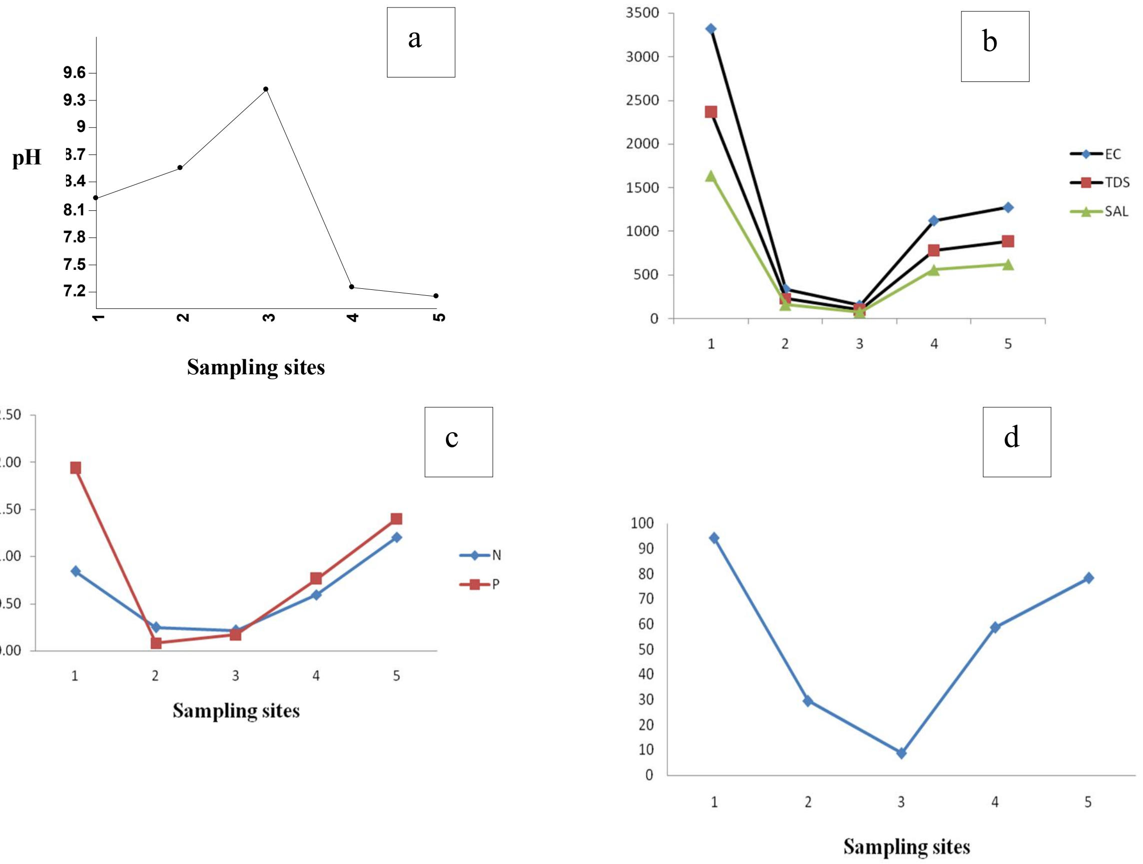


Fig. 2 Variation in water physical and chemical variables [a): pH, b)EC,SAL and TDS, c) N and P, d) chlorophyll composition across sites (mg/l)]

IV. RESULTS AND DISCUSSION

A. *Water quality*

Physical and chemical variables analyzed across the sampling sites (lakes) are listed in Table 2. The pH ranged from neutral to alkaline (7.13 – 9.42 as in Fig. 2a), highest being in the Hesaraghatta lake (9.42) due to the increased acid neutralizing capacity. Ionic concentration was low at Hesarghatta lake (150.7 µS), Hoskere lake (337 µS) and fairly high at Doddabidderakallu lake (3320 µS) owing the industrial pollution. Difference between Hesarghatta and Doddabidderakallu lakes was significant by EC, SAL and TDS (Fig. 2b). Among water chemistry variables, phosphates, chlorides, hardness and alkalinity showed a high value in Doddabidderakallu followed by Varthur akin to conditions in agriculture site while Hesarghatta and Hoskere showed low range reflecting clean water compared to the former sites. Nitrate levels of agricultural field (1.203 mgL^{-1}) encompassed the low range as observed in Doddabidderakallu (0.84 mgL^{-1}), Varthur (0.594 mgL^{-1}), Hoskere (0.246 mgL^{-1}) and Hesarghatta (0.215 mgL^{-1}) lakes. High amount of phosphate was sensible in Doddabidderakallu (1.93 mgL^{-1}) compared to other lakes (Fig. 2c). This high amount of nutrients and ionic concentrations, mainly alkalinity and hardness in Doddabidderakallu can be attributed to the untreated industrial effluents and sewage into the inlet channel. Even though Varthur showed moderate water quality, high amounts of contamination has been reported in the past[31]. Hoskere and Hesarghatta showed a negligible amount of anthropogenic activities except for few local disturbances. The elevated nitrate and phosphate concentrations in agriculture site were evident from the intrusion of fertilizers.

TABLE 2:
WATER QUALITY VARIABLES OF 5 SAMPLING SITES (1-5 AS DESCRIBED IN STUDY AREA)

	1	2	3	4	5
pH	8.21	8.55	9.42	7.23	7.13
WT (^{o}C)	27.00	30.3	33.1	32.50	29.80
EC (µ S)	3320	337.	150	1122	127
TDS (mgL^{-1})	2370.0	230.0	102.7	781.00	886.00
SAL (mgL^{-1})	1640.0	159.0	75.70	560.00	623.00
TURBIDITY (ntu)	139.00	13.20	15.00	71.70	44.30
DO (ppm)	0.00	9.35	12.20	13.33	9.35
COD (mgL^{-1})	240.00	213.3	117.3	128.00	250.67
BOD (mgL^{-1})	1.5	6.2	5.5	2.53	3.52
N (mgL^{-1})	0.84	0.246	0.215	0.594	1.203
P (mgL^{-1})	1.93	0.08	0.17	0.76	1.40
Chlorides (mgL^{-1})	610.60	62.48	22.72	187.44	249.92
Total Ha (mgL^{-1})	680.00	96.00	80.00	232.00	332.00
Ca. Ha (mgL^{-1})	439.81	67.98	39.97	59.86	147.85
Mg (mgL^{-1})	107.31	16.59	9.75	14.61	36.08
Alkalinity (mgL^{-1})	1080.0	160.0	380.0	440.00	540.00

B. *Community structure analysis*

The community structure of microalgae through microscopic analysis resulted with 27 genus belonging to 4 classes with 2 unidentified filamentous algae (Table 3). The class Bacillariophyta (diatoms) and Chlorophyta dominated at Hoskere and Varthur lake as well as agricultural sample with *Achnanthidium* Kützing, *Gomphonema* Ehrenberg, *Nitzschia* Hassall, *Navicula* Bory de Saint-Vincent, *Chlamydomonas* Ehrenberg, *Scenedesmus* Meyen and *Anabaena* Bory de Saint-Vincent ex Bornet & Flahault accounting more in number (occurrence number in microscopic field). Dodabidarekallu was represented by *Nitzschia* sp. alone, whose presence justifies high ionic and organic nutrients load. Hoskere was well occupied by diatoms viz., *Fragiallria* Lyngbye, *Sellaphora* Mereschowsky, *Surirella* Turpin along with the former species. Significant relation of ecology of microalgae such as *Nitzschia* sp., *Sellaphora* sp., *Chlorella* M.Beijerinck and *Phacus* Dujardin (varthur and agricultural field samples) with the extent of pollution load was observed.

TABLE 3
COMMUNITY STRUCTURE OF 5 SAMPLING SITES (1-5 AS DESCRIBED IN STUDY AREA. + INDICATES PRESENCE AND – INDICATES ABSENCE OF SPECIES)

Sampling sites	1	2	3	4	5
BACILLARIOPHYTA					
Achnanthidium Kützing	-	+	-	-	-
Cyclotella (Kützing) Brébisson	-	+	-	+	-
Cymbella C.Agardh	-	+	-	-	-
Diploneis Ehrenberg ex Cleve	-	+	-	-	-
Fragillaria Lyngbye	-	+	-	-	-
Gomphonema Ehrenberg	-	+	+	-	+
Navicula Bory de Saint-Vincent	-	+	+	-	+
Nitzschia Hassall	+	+	-	+	+
Rhopalodia Otto Müller	-	-	+	-	-
Sellaphora Mereschowsky	-	+	-	+	+
Surirella Turpin	-	+	-	-	-
CHLOROPHYTA					
Chlamydomonas Ehrenberg	-	-	-	+	-
Chlorella M.Beijerinck	-	+	+	+	+
Chlorogonium Ehrenberg	-	-	-	+	-
Closterium Nitzsch ex Ralfs	-	-	+	+	-
Cosmarium Corda ex Ralfs	-	+	-	-	-
Monoraphidium Komárková-Legnerová	-	+	-	+	-
Pandorina Bory de Saint-Vincent	-	+	+	-	-
Scenedesmus Meyen	-	-	-	+	-
EUGLENOPHYTA					
Euglena Ehrenberg	-	-	-	+	-
Phacus Dujardin	-	-	-	+	+
Trachelomonas Ehrenberg	-	-	-	+	-
FILAMENTOUS ALGAE					
Filamentous algae 1	-	-	-	+	-
Filamentous algae 2	-	-	-	+	-
CYANOPHYTA					
Anabaena Bory de Saint-Vincent ex Bornet & Flahault	-	+	+	-	-
Cylindrospermopsis Seenayya & Subba Raju	+	-	-	-	-
Merismopedia Meyen	-	+	-	+	-

C. *Water Quality and Community structure*

Nitzschia sp. was prevalent in Doddabidderakallu with the high quantum of nutrients and ionic concentrations. Compared to this Varthur showed moderate water quality, while, Hoskere and Hesarghatta showed a negligible amount of anthropogenic activities except for few local disturbances. The elevated nitrate and phosphate concentrations is observed in agriculture sites. The class Bacillariophyta (diatoms) and Chlorophyta dominated at Hoskere and Varthur lake as well as agricultural sample. Occurrence of microalgae such as *Nitzschia* sp., *Sellaphora* sp., *Chlorella* M.Beijerinck and *Phacus* Dujardin with the extent of pollution load show significant correlation ($p<0.05$).

D. *Lipid analysis*

The neutral lipid profile of the microalgal community revealed characteristic profile of the given community. The neutral lipid profile of each lake which is characteristic feature of the thriving microalgal community is given in Table 4. Agricultural field with *Gomphonema* sp. and *Nitzschia* sp. as dominant also reflected more fatty acids as of Doddabidarekallu sample due to inhibition of cell cycle and which causes TAG accumulation. Hoskere and Hesaraghatta (unpolluted water) had relatively less chlorophyll (Fig. 2d)and fatty acids in lipid profile. This is due to the inability of the diatoms to accumulate more TAG due to lack of any stress. In freshwater, lipid productivity, the mass of lipid that can be produced per day is dependent upon plant biomass production as well as the lipid content of this biomass[21]. The pattern of fatty acids varies according to the internal and external factors working on the algal cell[32,33] which concludes that growth rate and the mixed population which competes for the resources, influences on fatty acid composition. Although there are many microalgae as evident from Table 4 that have the ability to accumulate oils under some special cultivation, they have different prospects for biodiesel production in terms of oil yield lipid coefficient and lipid volumetric productivity[34]. However lipid production varies with variation in algal species with reference to both quantity and quality of lipids[35].

In the current investigation, Doddabidarekallu, Varthur and agriculture field samples were represented by diatoms, which are lipid-rich and have been demonstrated to be an important source for biodiesel[36,37]. *Nitzschia* species at Doddabidarekallu site (industrial waste) was prevailing with high organic and ionic content resulted with high lipid profile and chlorophyll content. This supports that environmental condition are decisive variables for lipid in microalgae. However, this has to be explored further through in situ experiments (like axenic culture, synchronous inoculums for bioreactors etc.). For further evidence, role of each keystone micoalgae species in the contribution towards lipid production with its ecological preference has to be studied.

V. CONCLUSION

The polluted lake water Doddabidarekallu supported growth of Bacillariophyceae members. The lipid profile obtained from this lake also had relatively higher proportion of fatty acid methyl esters (12 types) which highlights that diatoms are rich in TAG accumulation. The changes in neutral lipid emphasize the importance of knowing how nutrient levels play an important role in each of the microalgae for an enhanced accumulation of neutral lipids. Therefore this study proposes the use of lakes for sustained biodiesel production with the further research concentrating on transesterification process of lipid to biofuel characteristics.

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TABLE 4
LIST OF POLYUNSATURATED FATTY ACIDS

POLYUNSATURATED FATTY ACIDS	Formula	1	2	3	4	5
9- octadecenoic acid (Z)- methyl ester	C18:1	-	+	-	-	-
10- octa decanoic acid methyl ester		+	-	-	-	-
Decanoic acid methyl ester	C10:0	+	-	-	-	+
Docosonoic acid methyl ester	C22:0	+	+	-	-	-
Dodecanoic acid methyl ester	C12:0	+	+	-	-	+
Dodecanoic acid, 1- methyl ethyl ester	C15:1	+	+	-	+	+
Eicosanoic acid methy ester	C20:4	-	+	-	+	+
Heptadecanoic acid methyl ester	C17:0	+	-	-	+	+
Hexadecanoic acid methyl ester	C16:0	+	+	+	+	+
Hexadecanoic acid 14 - methyl ester	C17:1	-	-	+	-	-
Isopropyl myristate		-	+	-	-	-
Isopropyl palmitate	C19:1	-	+	-	-	-
Methyl tetradecanoate	C14:1	+	+	+	+	+
Nona decanoic acid methyl ester	C20:1	+	-	-	-	-
Octadecanoic acid methyl ester	C18:0	+	+	+	+	+
Octanoic acid methyl ester	C8:0	+	+	+	+	-
Pentadecanoic acid methyl ester	C15:1	+	-	-	+	+
Tetradecanoic acid, methyl ester	C14:0	-	-	+	+	-

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ALGAL PHOTOSYNTHETIC DYNAMICS IN URBAN LAKES UNDER STRESS CONDITIONS

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ABSTRACT

Urban lakes form vital ecosystems supporting livelihood with social, economic and aesthetic benefits that are essential for quality life. This depends on the biotic and abiotic components in an ecosystem. The structure of an ecosystem forms a decisive factor in sustaining its functional abilities which include nutrient cycling, oxygen production, etc. A community assemblage of primary producers (algae) plays a crucial role in maintaining the balance as they form the base of energy pyramid in the ecosystem. Algae assimilate carbon in the environment via photosynthetic activities and releases oxygen for the next level of biotic elements in an ecosystem. Besides these, algal cells rich in protein serve as food and feed, used as manure and for production of biofuels. Understanding algal photosynthetic dynamics helps in assessing the level of dissolved oxygen (DO), food (fish, etc.), waste assimilation, etc. Algal chlorophyll content, algal biomass, primary productivity and algal photosynthetic quotient are some of the parameters that helps in assessing the status of urban lakes. Chlorophyll content gives a measure of the growth, spread and quantity of algae. Unplanned rapid urbanization in Bangalore in recent times has resulted in either disappearance of lake ecosystems or deteriorated the lake water quality impairing the ecological processes. This paper computes algal growth, community structure, primary productivity and composition for three major lakes (T G Halli, Belandur and Varthur lakes) under contrast levels of anthropogenic influences.

Keywords: Algae, photosynthesis, lakes, community assemblage, relative abundance, physico-chemical

1. Introduction

Urban lakes play a pivotal role in maintenance of the homeostasis in the system. These water bodies modulate temperature, regulate local hydrological cycle, detoxify water, increases the primary productivity of the system through algal photosynthesis and help in improving environmental conditions for life. Water is an essential component for life on earth, which contains minerals extremely important in human nutrition. Small water bodies are abundant (Downing et al., 2006) and have disproportionately high hydrologic and nutrient processing rates (Smith et al., 2002). However, in recent times, dramatic increase in the population and unplanned urbanization had led to deterioration of water bodies through varying degrees of environmental stress due to encroachments, eutrophication (especially from domestic effluents), and siltation. Urbanization inculcates alteration in natural ecosystem's integrity, litho-morphological characteristics, surrounding air and water quality in that particular microclimate. In Bangalore, the impact of urbanization in the last three decades has resulted in either disappearance of lake ecosystem or deteriorated the lake water quality impairing the ecological processes. The main causes for the impaired conditions of the lakes are pollutants from fixed point sources (like nutrients from wastewater, municipal and domestic effluents, organic, inorganic, and storm water runoff, etc) and pollutants from non-point sources (such as nutrients through fertilizers from agricultural areas as run off, organic pollution from human settlements located along the periphery of the lakes and reservoirs (Reddy and Char, 2006)). Contamination of water bodies also happens through atmospheric pollution, effluent discharges, use of agricultural chemicals, eroded soils, and land use (Sillanpaa et al., 2004).Freshwaters receive most inorganic nutrients and other toxic substances generated by both the domestic and industry as waste and released into the environment.

Although aquatic ecosystems are operational with a variety of physicochemical and biological mechanisms to eliminate or reduce adverse effects of such compounds, toxicants may evoke changes in development, growth, reproduction, and behavior and may even cause death of freshwater organisms (Rand et al., 2003). The water bodies as lakes, tank and reservoirs proves to be an excellent candidates for evaluating the health of the ecosystem and proved to be a good material for the study of functional aspects of the ecosystem in terms of photosynthetic productivity under varying levels of anthropogenic stress. There has been a lot of work ascribing the diversity of plankton with relation to water quality, but the photosynthetic dynamic's of the urban lake systems is seldom mentioned. Objectives of this work are:

(i) to study the nutrient status with reference to physicochemical parameters
(ii) to analyse the community structure together with determination of the day net photosynthesis

in two urban lakes - Varthur and Bellandur in the Bangalore city and a reservoir at the outskirts of the city - T. G. Halli. The study addresses the difference in photosynthetic productivity in terms of measurable variables between the lakes at varied anthropogenic stress and compares organic and nutrient stress conditions in lakes during Jan-Aug 2010.

2. Materials and Methods

2.1 Study Area:

The study areas comprises three main water bodies - Bellandur Lake , Varthur Lake and TG Halli of Greater Bangalore as depicted in Figure 1.

Bellandur Lake is the largest lake in the Bangalore city situated in the southern part of Bangalore. The lake is 130 years old and spreads across an area of 365 ha [Figure 1 b)]. Sewage from residential areas near the old Bangalore international airport is directly allowed into the lake through the main drain. Dense weeds have occupied a major portion of the lake, thus affecting the photosynthesis process by obstructing penetration of sunlight. Objectionable froth has been developed at the overflow region (at the outflows).

Varthur Lake is the second largest fresh water body in Bangalore built by the Ganga Kings over a thousand years ago [Figure 1 c)] for domestic and agricultural uses. It is part of a series of connected and cascading water bodies. The Varthur lake catchment has seen large scale land use changes after 2000, consequent to the rapid urbanization process in the region. Now the lake receives inadequately treated sewage of about 595 million liters per day (MLD).

The lake had a varying extent of floating macrophytes during different seasons. The sampling locations are shown by yellow tags in the lakes. Table 1 shows the characteristics of the studied lakes.

TG Halli is situated at the peripheral region, approximately 25 km from Bangalore city on the way to Magadi [Figure1 a)]. Water from this reservoir is pumped to a water treatment plant located nearby, which is one of the main sources that provide drinking water to the residents of Bangalore city (35 MLD). The main source of water to the reservoir is the river Arkavati and domestic discharge from North part of Bangalore including Peenya, Dasarahalli and Jalahalli connections.

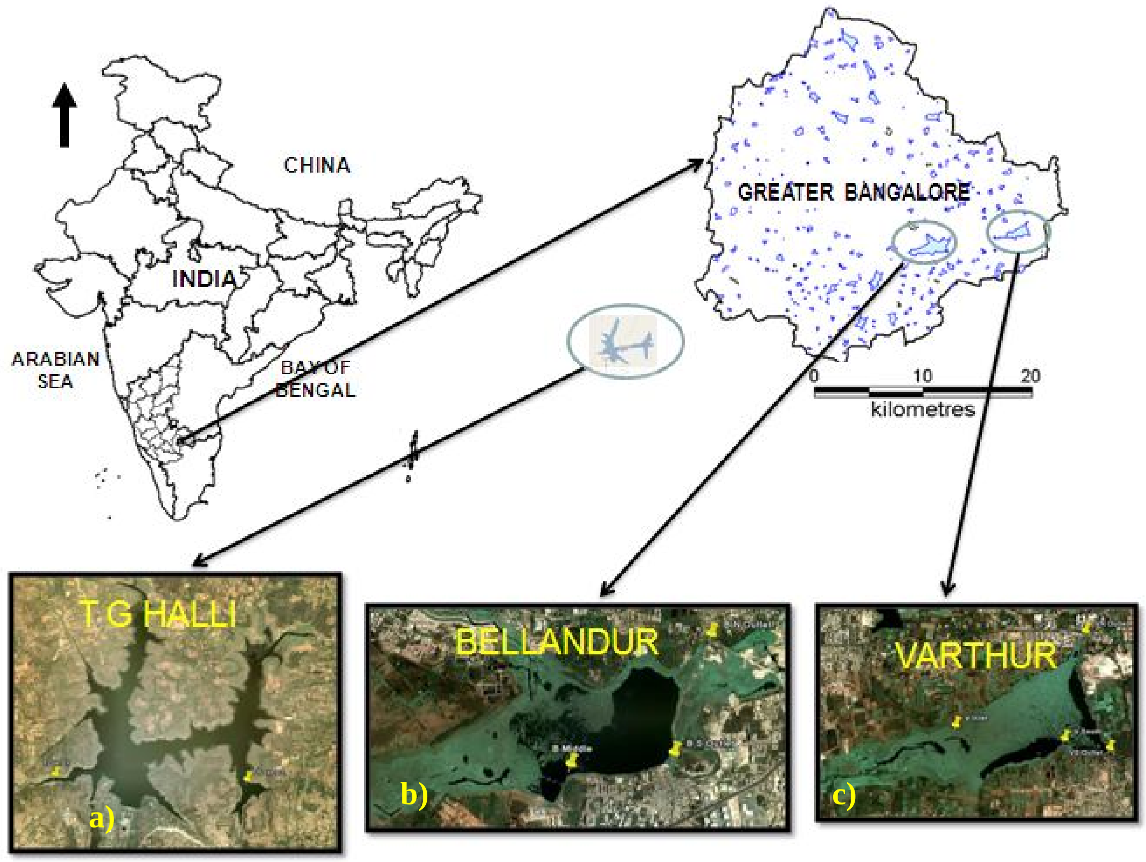

Figure 1: Study Area: Bangalore city, Greater Bangalore; 3 lakes of Bangalore.

Table 1: Characteristics of the Study area

Lakes	Varthur	Bellandur	T.G.Halli
Location	SE of Bangalore	SE of Bangalore	35 km West of Bangalore
Coordinates	12.956683° – 12.941499° N 77.745378° - 77.72805° E	12.943917° - 12.927959° N 77.638344° - 77.680167° E	12.995103° -12.963357° N 77.362962° -77.327291° E
Primary inflows	Bellandur	Sewage from Bangalore	Arkavathy river
Primary outflows	To river Pennar	Varthur lake	Dammed
Catchment area (sqkm)	1.8	148	1453
Max. length (km)	2	3.6	3.3
Max. width (km)	1.1	1.4	2.8
Surface area (sqkm)	2.2	3.6	4.2

Mean depth (m)	1.1	2.1	7.5
Surface elevation (m)	919	921	914.4
Water colour	Greenish (intense)	Greenish	Transparent
Odur	Yes	Yes	No
Macrophyte cover	*Eicchornia, Alternanathera Typha, Lemna*	*Eiccheornia, Alternanthera, Cyperus*	*Hydrilla*

2.2 Experimental Design

Samples were collected from the inlet and outlets considering the inflow and outflows of the lake. Parameters like pH, temperature, salinity, electric conductivity and total dissolved solids were analysed in-situ with the help of probes. Dissolved Oxygen, Free Carbon dioxides were recorded in situ following the Winklers iodometric method and titrimetry respectively. Further other physico-chemical analyses were carried out in lab following standard methods (APHA, 1998). Algal samples were collected with the help of Planktonic net in 100 ml polythene bottles and preserved in 70% alcohol. Algae attached to aquatic plants and stones were also collected in separate containers and preserved in 70 % alcohol. With the help of a pipette samples were mounted on the slide and observed under microscope. 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. Chlorophyll analysis was carried out by the spectrophotometric method. (APHA, 98). The day net photosynthetic productivity was calculated by measurement of dissolved oxygen in the stystem at frequent intervals (Os wald et al., 1957 and Odum and Hoskin et al., 1958).

3. Results and discussions

3.1 Physico-chemical analysis

3.1.1 Dissolved oxygen: Dissolved oxygen (DO) in the lakes ranged from 0-1.62 mg/l in Bellandur lake, 0.81-4.22 mg/l in Varthur lake and 8.13-10.97 mg/l in T.G.Halli (Table-1). The values indicate that Bellandur had anoxic conditions at the outlets due to the passage of water course underneath the floating bed of debris and macrophytes which had covered about 40 % of the surface of the lake towards the outlet areas. This anaerobic condition is due to deprivation of the air-water interface and also the decline of the algal growth under the plant cover. Varthur lake is undergoing hypoxic conditions with very low DO concentrations at the inflow region however the outlets have comparably higher DO values (4.22 mg/l). However in the case of T.G.Halli D.O.at saturated levels were observed at both the sites indicative of a lower organic load and thence lower oxygen demand in the system. There exists a positive relationship of DO with temperature. These results are in conformity with earlier studies (Srivastava et al., 2003; Masood and Krishnamurthy, 1990) which showed a positive relation between temperatures, duration of sunlight, and soluble gases like DO. The decrease in oxygen may be the result of the high load of organic substances in the inflow from the storm water drains. The deprivation of oxygen is an indicator of the present trophic status of the lakes, which is congested with inorganic and organic matter making the conditions incearsingly eutrophied. The primary production and input of degradable organic substances create's a tremendous demand for oxygen in case of Bellandur and Varthur lakes.

3.1.2 Biochemical oxygen demand: In the present investigation, the biological oxygen demand in varied from Bellandur 35.85-68.88 mg/l, Varthur lake, 99.95 - 40.78 mg/l and T.G.Halli, 12.69-15.02 mg/l. In Varthur higher BOD values were found near the inflow region, which substantially decreased towards the outlets, showing around 60% of BOD removal. However in case of Bellandur BOD levels were still lower compard to Varthur and showing better treatability of wastewater. The higher levels of BOD in the urban lakes can be attributed to sewage influx through stormwater drains, reduced circulation in water bodies. The biochemical oxygen demand levels indicate higher levels of biodegradable organic matter, high oxygen consumption by heterotrophic organisms, and a high rate of organic matter remineralization. The studies were similar to that of the shallow tropical waterbodies in Mexico (North) (Zavala et al., 2000), the lakes in urban areas increasingly serve as sinks for domestic sewage and other municipal wastes. However in case of T.G.Halli the BOD values were very low compared to the urban lakes, which showed a lower organic load and therefore a lesser demand for oxygen.

3.1.3 Alkalinity: Total alkalinity values ranged from 260-1010 mg/l in Bellandur, 300-520 mg/l in Varthur Lake and from 340-360 mg/l in T.G.Halli. High alkalinity values are indicative of the eutrophic nature of the urban lakes like Bellandur and Varthur. High alkalinities in eutrophic waters were also recorded in earlier studies (Munawar, 1970; Singh, 2000). With an increase in DO there is an increase in the Alkalinity values. Essentially the bicarbonates buffering was the prime source of alkalinity in surface waters of Bangalore. Higher values of total alkalinity is due to the presence of excess of CO_2 produced as a result of decomposition processes coupled with mixing of sewage and other domestic effluents. Only T.G.Halli showed carbonate's (40 mg/l) compared to the urban lakes.

3.1.4 Phosphates (PO_4): Phosphate values ranged from 0.5-1.2 mg/l in Bellandur, 1.3-2.1 mg/l in Varthur Lake and 0.08-0.4 mg/l in T.G.Halli. Three urban lakes Bellandur and Varthur have higher concentrations of phosphates primarily due the inflow of sewage, sediment resuspension during high turbulence period and anaerobic conditions in the bottom of the lake and agricultural runoff from the immediate cultivated lands. These results are in conformity with earlier studies (Ravi Kumar et al., 2006). Phosphates are critical nutrients in the productivity of water in reservoir. The phosphate content in Bellandur and Varthur were well beyond the eutrophic levels. Phosphates enter the lakes through domestic wastewater, accounting for the condition of eutrophication. Phosphorus concentrations were increased by sewage input. In the present investigation, phosphate concentration is more when oxygen content is less (Table 1). However comparatively lower phosphate values were found in T.G.halli showing its healthy trophic status.

3.1.5 Nitrates: Nitrogen entering aquatic systems arises from a variety of sources that include point and non-point sources of pollution, biological fixation of gaseous nitrogen, and the deposition of nitrogen oxides and ammonium (Stoddard, 1994). Nitrate nitrogen in water in Indian reservoirs is mostly in traces and seldom exceeds 0.5 mg/L. Water with 0.2–0.5 mg/L of nitrates is of high productive reservoirs, up to 0.2 mg/L nitrates of medium productive reservoirs, and in low productive reservoirs, the nitrates are negligible (Jhingran and Sugunan 1990).The Nitrate concentration ranged from 0.02-0.03 mg/l in Bellandur, 0.03 – 0.05 mg/l in Varthur and 0.02 – 0.3 mg/l in T.G.Halli. Maximum values were recorded in T.G. Halli due to more oxidizing condition and lower organic load. The main Nitrogen sources in urban lakes are the domestic sewage, agricultural runoff and decomposition of autochthonous vegetative matter. However reactive Nitrogen forms were mostly found in the form of ammonia in the lakes pertaining to anaerobic conditions and scant oxidation. The lakes covered by the aquatic weeds are deficient of nitrates, due to persistence of anaerobic conditions (Durga Madhab et al, 2010). Moderately low nitrate values were reported in earlier studies (Chanakya et al, 2006). A positive relation was found between Nitrates and phosphates indicative of trophic status.

3.1.6 Chlorophyll-a

The chlorophyll content was more or less similar to the pattern of phytoplankton distribution and abundance. (Table 1). Maximum value of Chlorophyll-a was found in T.G.Halli (18.35 µg/l) owing to greater light penetration and higher growth of benthic microalgae and the lowest were found near the inflow region of Varthur lake (which in connected to the storm water drains that brings in 595 MLD of wastewater. However the surficial water samples had a very less micro-algal content. Table 2 gives the results for various physico-chemical parameters at selected sites in the sampled lakes.

3.2 Phytoplankton Standing Crop

3.2.1 Community composition: The total number of identified and recorded benthic phytoplankton species at all the investigated sites in the lakes during the period of study were found to be 24, belonging to 7 genera and 3 classes namely; Bacillariophyceae, Cyanophyceae and Chlorophyceae. Bellandur lake was dominated by *Chlorella* sp. populations (80%), filamentous algae (3%) comprising of *Oscillatoria* sp. and *Lyngbya* sp. were present at the outlet reaches showing N deprivation and rest comprised of the diatoms. In Varthur lake the algal community was dominated by *Chlorella* sp. member of Chlorophyceae which comprised of *C. vulgaris*, *C. pyrenoidosa* and *C. minutissima*., followed by members of Bacillariophyceae (18%) as *Nitszchia palea* and *Gomphonema parvulum. Microcystis auregonosa* a member of Cyanophyceae were found in minor proportions (1%). In earlier studies 25 algal genera were observed at Varthur lake. In T.G.halli the community composition was rather very contrasting comprising of dominant diatom species (80 %) as *Gomphonema* sp. > *Nitszchia* sp. > *Navicula* sp. > *Acnanthes* sp.> *Cymbella* sp. 21 algal genera were observed at T.G.Halli in earlier studies the dominant being the diatoms. The chlorophycean members comprised of *Chlorella* sp. (13%) followed by *Scenedesmus* sp. Member of Cyanophyceae (7%). The dominance of diatom sp. in T.G.Halli is indicative of a good water quality, under low stress conditions. However the spur of Chlorophyceae and Cyanophyceae members is an indicator of Organic pollution and nutrient accumulation in the urban lakes as in Bellandur and Varthur. The productivity of the lakes are directly linked with the type and the abundance of the algal community. The turbidity values suggest very high algal abundance in Varthur and Bellandur lakes which is attributed to algal bloom which coincides with the high inorganic nutrient values and high BOD values in these lakes. The maximum concentration of micro-benthic algae was > 1.5×10^4 cells/ml. The lowest being few hundred cells /ml in case of T.G.Halli. Table 2 illustrates the relative abundance of the microlagal population at the various sampling locations. It was observed that the maximum number of counted species belonged to class Chlorophyceae in urban lakes. For example, presence of Chlorella is an indication nutrient rich eutrophic waters that can also act potential organism for nutrient bioremediation. Bacillariophyceae in case of T.G.Halli represent the most productive group at all sites during the period of study. In addition, the distribution and frequency of algal species along all sites showed that Bacillariophyceae together with some species of Chlorophyceae were always dominant especially at depending upon the nutrient load and trophic status of the lake. The algal compositions in sampled lakes are depicted in Figure 3.

Table 2: Physico-chemical parameters of the sampled locations of the Lake

Parameters	Varthur Lake				Bellandur Lake			T.G. Halli	
	Inflow	South Outlet	North Outlet	South	North Outlet	South Outlet	Middle	Near Outflow	Near Inflow
	1	2	3	4	5	6	7	8	9
pH	8.54	8.06	9.03	8.13	9.02	9.42	7.91	7.81	8.12
Temperature (^{0}C)	24.40	26.30	25.60	282.00	25.40	23.00	24.80	23.70	24.00
Electrical Conductivity (µScm^{-1})	1098	1057	1068	1038	980	1009	981	309	255
Total Dissolved Solids (mg/l)	868.00	840.00	849.00	826.00	770.00	808.00	781.00	214.00	190
Salinity (mg/L^{-1})	538.00	522.00	527.00	514.00	483.00	507.00	487.00	215.00	152
Turbidity (NTU)	216.00	96.50	90.60	76.00	127.00	108.00	102.00	9.05	25
Dissolved Oxygen (mg/l)	0.81	0.81	4.22	4.06	0.00	0.00	1.62	8.13	10.97
Free CO_2 (mg/l)	176.00	17.60	17.60	17.60	120.56	14.08	9.68	352.00	0.00
Chemical Oxygen Demand (mg/l)	293.33	229.33	325.33	282.66	192.00	224.00	282.66	48.00	44
Biochemical Oxygen Demand (mg/l)	49.95	40.78	41.68	57.72	46.28	35.85	68.88	15.02	12.69
Nitrates (mg/l)	0.05	0.04	0.04	0.03	0.03	0.02	0.03	0.02	0.03
Phosphates (mg/l)	2.10	1.80	1.70	1.30	0.50	0.90	1.20	0.80	0.40
Carbonates (mg/l)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	40.00	40.00
Bicarbonates (mg/l)	520.00	300.00	420.00	360.00	260.00	300.00	1010.00	320.00	300.00
Alaklinity (mg/l)	520.00	300.00	420.00	360.00	260.00	300.00	1010.00	40.00	40.00
Ca Hardness (mg/l)	204.16	344.27	176.14	392.31	232.18	168.13	196.15	79.97	55.97
Mg Hardness (mg/l)	30.25	102.40	106.38	61.48	71.24	67.34	68.32	19.51	13.66

Total Hardness (mg/l)	124.00	420.00	436.00	252.00	292.00	276.00	280.00	116.00	96.00
Chlorides (mg/l)	136.32	88.04	144.84	130.64	119.28	127.80	150.52	42.60	45.44
Sodium (mg/l)	19	23.2	19.4	18.3	20.9	13.9	16.5	64.8	53.4
Potassium (mg/l)	3.6	4.3	3.5	3.2	4.1	2.8	3.5	5.9	5.7
Chlorophyll-a (µg/l)	3.73	8.32	6.25	13.55	10.29	16.03	15.70	18.35	16.20

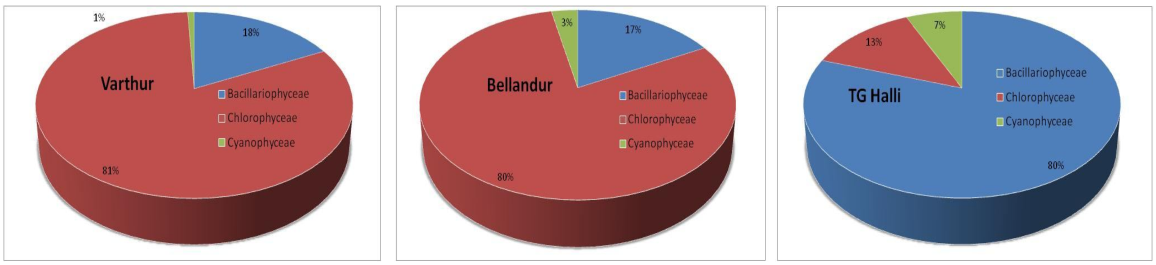

Figure 3: Algal composition in sampled lakes.

3.2.2 Distribution and relation with water quality: Study of phytoplankton population at the selected sites in all three lakes revealed that the communities were affected by the physico-chemical conditions of water, seasonal fluctuations, in addition to the different sources of pollution. In varthur, the total phytoplanktons were dominated by bacillariophyceae and were recorded in high counts due to the flourish of pollution tolerant diatom taxa namely *Nitszchia palea* and *Gomphonema parvulum*, representing the most dominant among diatoms population at this site due to the heavy load of organic pollution and nutrient salts discharged from drain to the strom water drains. This observation coincided with Abdalla et al.(1991) who reported that this species developed in Lake Mariut with the increase of the organic load. The dominance of diatoms in T.G. Halli especially indicates proper silica mineralization and pollution free conditions which is evident from the water quality paramates. Hence the presence of a high percentage and number of Bacillariophyceae represented the first productive group as mentioned before. Furthermore, the shallow lake water leads to a rapid change in the productivity with the change in physico-chemical conditions of water. These effluents enhance the biological activities of bacteria, especially in summer months due to the decomposition of organic matter, in agreement with earlier studies (El-Sherif and Aboul Ezz 1988) where the lowest standing crop area were reported due to the high density of zooplankton in addition to the low counts of phytoplankton in some sites resulting from the grazing effect of zooplankton on phytoplankton. The relative abundance of the studied algae is as listed in Table 3.

Table 3: Percentage Relative abundance of microalgae present in all sampling sites.

Algal genera	Varthur Inflow	Varthur South Outlet	Varthur North Outlet	Varthur South	Bellandur North Outlet	Bellandur South Outlet	Belandur Middle	T.G. Halli Outflow	T.G. Halli Inflow
Chlorella sp.	90.55	68.81	94.83	72.12	82.57	71.43	88.98	9.02	19.74
Nitzschia sp.	4.72	3.67	5.17	8.65	0.92	0.00	3.39	31.58	38.16
Microcystis sp.	3.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gomphonema sp.	1.57	27.52	0.00	19.23	3.67	14.29	7.63	32.33	39.47
Filamentous algae	0.00	0.00	0.00	0.00	12.84	14.29	0.00	0.00	0.00
Navicula sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.80	0.00

Achnanthes sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.51	0.00
Cymbella sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.26	2.63
Scenedesmus sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.00

3.3 Measurement of Day-Net Photosynthetic Productivity: The amount of oxygen released during the daylight hours minus simultaneous community respiration may be called day-net photosynthesis. Os wald et al., (1957) used the day-net photo synthesis to estimate the photosynthetic production of sewage oxidation ponds. To determine day-net photo synthesis in g-O_2/day/cu.m the minimum DO concentration were subtracted from the maximum DO concentration. The day net photosynthesis was multiplied by the depth of the euphotic zone in. meters to obtain day-net productivity in g O_2/day/sq.m (Table 4).

Table 4: Day Net Photosynthetic Productivity in the studied lakes.

Sampling sites	Turbidity (NTU)	Transparency (Euphotic Zone)	O_2 Conc. mg/l		Day Net Photosynthesis O_2/d m^3	Day Net Productivity O_2/d m^2
			Max	Min		
Varthur						
Inflow	216	0.12	0.81	0	0.81	0.09
N Oulet	96.5	0.25	0.81	0	0.81	0.20
S Outlet	90.6	0.28	4.22	0	4.22	1.18
South	76	0.18	4.06	0	4.06	0.73
Bellandur						
N Outlet	127	0.23	0	0	0	0
S Outlet	108	0.28	0	0	0	0
Middle	102	0.22	1.62	0	1.62	0.36
T.G.Halli						
Inflow	9.05	5	8.13	5	3.13	15.65
Outflow	25	3.4	10.97	5	5.97	20.29

The Day net productivity values indicates higher productivity in T.G. Halli and lower productivities in urban lakes as Bellandur and Varthur which can be attributed to decreased transparency and hence lesser sunlight penetration due to microalgal bloom.

4. Summary and Conclusion

Urban lakes of Bangalore has been subjected during the last century to a drastic rate of sewage pollution due to the high loads of discharges leading to a prominent changes in physico-chemical conditions and phytoplankton community. The study of physico-chemical parameters and their impacts on the standing crop of phytoplankton and primary production indicated that the maximum number of phytoplankton species counted, belonged to class Chlorophyceae (Chlorella blooms) in case of Urban lakes, which is an indicator of eutrophication. The stations nearby the inflow regions at Varthur receiving sewage from drains recorded the lowest content of chlorophyll-a. On the other hand, in T.G.Halli, the Bacillariopyceae taxa dominated owing to a healthy trophic status. Chlorophyll-a content is more or less similar to the pattern of phytoplankton counts. However the T.G.Halli reservoir had the highest Chlorophyll-a levels attributed by benthic chloroplast levels showing higher light penetration and photosynthetic productivity. The Day net photosynthesis was found to be higher in case of T.G.Halli compared to the urban nutrient stressed lakes varrying from site to site depending on the characteristics of water and its microclimate.

Transparency exhibited significant positive relation with the total count of phytoplankton. Chlorophyll-a, phosphates, nitrates and dissolved oxygen showed a negative relationship with the day net photosynthetic productivity. The relation of total alkalinity with the total count of phytoplankton and chlorophyll-a, was positive. From this study, we conclude that Bellandur and Varthur are undergoing a high nutrient stress resulting in anaerobic conditions with the lakes becoming increasingly eutrophied while T.G.Halli is considered as a pristine water body with a healthy trophies status which is least stressed.

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STATUS OF VARTHUR LAKE: OPPORTUNITIES FOR RESTORATION AND SUSTAINABLE MANAGEMENT

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SUMMARY

Lake ecosystems vital functions such as recycling of nutrients, purification of water, recharge of groundwater, augmenting and maintenance of stream flow and habitat provision for a wide variety of flora and fauna along with their recreation values necessitates their sustainable management through appropriate conservation mechanisms. Failure to restore these ecosystems will result in extinction of species or ecosystem types and cause permanent ecological damage.

In Bangalore, lakes have played a prominent role serving the needs of agriculture and drinking water. But the burgeoning population accompanied by unplanned development has led to the drastic reduction in their numbers (from 262 in 1976 to 81 at present). The existing water bodies are contaminated by residential, agricultural, commercial and industrial wastes/effluents.

Varthur lake is situated in the south taluk of Bangalore district. It has a large surface area and is the main irrigation source to the nearby agricultural fields and supports a wide variety of flora and fauna. The main aim of undertaking the present study was to evaluate the ecological status of the Varthur lake, the results of which would help in restoration efforts.

The study consisted of three parts (i) Morphometric survey – to provide the information on the depth, surface area, width, etc of the lake; (ii) Water quality survey – to elucidate the quality of lake water and the nearby groundwater; (iii) Socio-economic survey – to assess the dependency of the nearby residents on the lake ecosystem.

The morphometric survey consisting of depth profiling, contour mapping, volumetric calculations and other general parameters (surface area, shoreline, maximum length, maximum width, and mean width) were estimated by field studies supplemented with GIS software and statistical calculations. Several physico-chemical parameters of both the lake and nearby groundwater were analysed according to standard methods of APHA. A random socio-economic survey was conducted in the nearby villages of Varthur, Baligere and Ramagondanahalli using a standard questionnaire.

The results of the above studies revealed the following:

(i) The morphometric survey showed that the lake occupies an area of 1 478 000 m^2 with a mean depth of 1.05m. The morphometric results emphasise the fact that the whole of Varthur Lake is shallow in relation to its surface area.

(ii) The results of the water quality analysis show that the lake is eutrophic with high concentrations of phosphorous and organic matter. All the parameters analysed were above the standards prescribed for surface waters. The lake was also subjected to faecal contamination. The groundwater analysis did not reveal any contamination by lake water, but further analysis has to be undertaken to rule out the possibility of groundwater pollution.

(iii) The socio-economic aspects of Varthur lake showed that local residents continue to rely heavily on the lake for cattle fodder and irrigation of crops.

The total land irrigated by the lake water amounts to 1537 acres. Various crops like paddy, arecanut, bananas, greens, vegetables, flowers and coconuts are grown using the lake water. There is a possibility that contamination of water supplies is having a negative effect on the quality and quantity of crops produced using the lake water. This poses a threat to the primary source of income for people living near the lake and warrants further investigation.

The results reveal the need and importance for the restoration and management of the Varthur lake. Restoration can be brought about in many ways, the important ones being pollution abatement, desilting of the tank and educating the stakeholders and the local population on the importance for restoring the lake ecosystem. All the conservation measures should have a holistic approach with watershed management practices.

1. Introduction

Though, the majority of our planet is covered by water, only a very small proportion is associated with the continental areas to which humans are primarily confined. Of the water associated with the continents, a large amount (more than 99%) is in the form of ice or groundwater and is difficult for humans to use. Human interactions with water most often involve fresh streams, marshes, lakes and shallow ground waters; thus completely relying on a relatively scarce and rare commodity.

Lake ecosystems are one of the most productive ecosystems in the biosphere and play a significant role in the ecological sustainability of the region. They constitute an essential component of human civilization, meeting crucial needs to sustain life on earth, such as water (agriculture, drinking, etc.), food (protein production, fodder, etc), biodiversity (diverse flora and fauna), energy (fuel wood, etc), recreation (tourism), transport, water purification, flood control, pollutant sink and climate stabilisers. The values of wetlands though overlapping (like cultural, economic and ecological factors) are inseparable. The geomorphological, climatic, hydrological and biotic diversity aspects have contributed to wetland diversity.

Anthropogenic activities including deforestation, agriculture, and watershed development are known to affect the input rates of nutrients and organic matter into lakes, often increasing the overall productivity of lake biota. Lakes are under increasing threat due to the separate, but often combined impact of identifiable point sources such as municipal and industrial wastewater, and non-point degradation like urban and agricultural run-off within a lake's watershed. Major degrading factors include excessive eutrophication due to nutrient and organic matter loading; siltation due to inadequate erosion control in agriculture, construction, logging and mining activities; introduction of exotic species; acidification from atmospheric sources and acid mine drainage; and contamination by toxic (or potentially toxic) metals such as mercury and organic compounds such as poly-chlorinated biphenyls (PCBs) and pesticides. In addition, physical changes at the land-lake interface (eg. draining of riparian wetlands) and hydrologic manipulations (eg. Damming outlets to stabilise water levels) have major impacts on the structure and functioning of these ecosystems.

Lakes have played a major role in the history of Bangalore serving as an important drinking and irrigation source. They occupy about 4.8% of the city's geographical area (640 sq. km) covering both urban and non-urban areas. Bangalore has many man-made wetlands but has no natural wetlands. They were built for various hydrological purposes and mainly to serve the needs of irrigated agriculture. The spatial mapping of water bodies in the district revealed the number of waterbodies to have decreased from 379 (138 in north and 241 in south) in 1973 to 246 (96-north and 150-south) in 1996 and 81 at present. This overall decrease of 35% was attributed to urbanisation and industrialisation (Deepa et.al., 1997). The tanks were reclaimed for various purposes such as residential layouts, commercial establishments, sport complexes, etc. Only 30% of the lakes are used for irrigation at present. Fishing is carried out in 25% of the lakes surveyed, cattle grazing in 35%, agriculture in 21%, mud-lifting in 30%, drinking in 3%, washing in 36% and brick-making in 38%. This highlights the need for appropriate conservation, restoration and management measures.

The following Table 1provides the distribution of tanks by taluks in Bangalore.

TABLE 1: TALUKWISE DISTRIBUTION OF TANKS

S no	**Name of the Taluk**	**No. of tanks**
1	Bangalore North	61
2	Bangalore South	98
3	Hoskote	23
4	Anekal	44
5	Magadi	11
6	Nelamangala	13
7	Devanahalli	12

1.1 Background

Varthur Lake is an artificial lake, or *tank*, located in the Bangalore South taluk of the Bangalore District in Karnataka. This lake has played an important role in maintaining water resources for irrigation since its construction during the Ganga Empire over 1,000 years ago (Karnataka State Gazetteer, 1990). Over the centuries, it has developed into a complex ecosystem that provides habitat for a variety of plant and animal species, including resident and migratory waterfowl. The lake also endows the local community with a pleasant microclimate and considerable aesthetic appeal.

The lake is surrounded by small farms that grow rice, raggi, coconut, flowers, and a variety of fruits and vegetables. The largest town in the immediate area is Varthur, which had a population of 5,431 as per 1981 census (Census of India, 1981). Several smaller villages are also located near the periphery of the lake. Figure 1.1 presents a view of southeastern Bangalore and Varthur Lake's catchment area as surveyed in 1970 to 1974. Human settlements and the roadways are marked in red; the outskirts of Bangalore city proper can be seen in the upper left-hand corner.

Figure 1.1 Varthur Lake and Surrounding Area

Source: Survey of India, 1980. Bangalore District. 1st Edition No. 57 H/9.

Varthur Lake is part of a system of interconnected tanks and canals that receive virtually all the surface runoff, wastewater, and sewage from the Bangalore South taluk. Rapid development and population expansion, both within Bangalore and in the surrounding towns and villages, have taken a heavy toll on many of the tanks in the area, and Varthur is no exception. The Bangalore South taluk alone has experienced a surge in its population from 2,84,556 to 4,45,581 between 1971 and 1981 (Census of India, 1981). Pollution loading has exceeded the lake's ability to assimilate contaminants, leading to visible degradation of the quality of water in the lake. Examining the current ecological status and economic value of the lake is crucial for developing appropriate remediation strategies. Figure 1.2 presents the interconnectivity of lakes as per the satellite image.

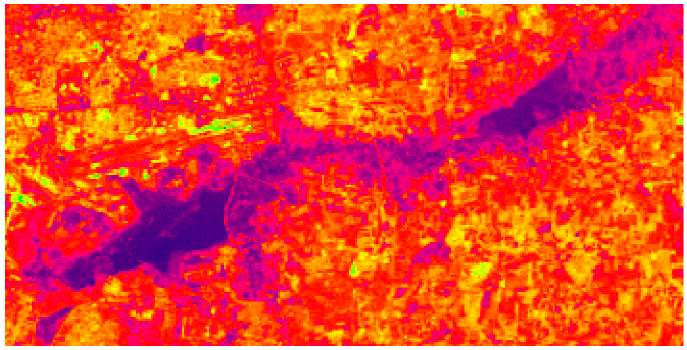


Figure 1.2: Interconnected lakes

1.2 Objective

The purpose of the study was to identify the most immediate threats to the ecological status of the Varthur Lake and to evaluate the necessity of undertaking restoration efforts in order to maintain the benefits provided by this tank. The results of this study will also provide a base for future analysis of the ecology of the lake and its importance to local residents.

1.3 Scope

The study was composed of the following components:

- **Morphometric Survey of Varthur Lake**, including depth profiling and calculation of volume, to evaluate the risks posed by sedimentation and to provide general morphometric information for future analysis of Varthur Lake.

- **Water Quality Survey** of lake water to determine the extent of the pollution in Varthur Lake during the post-monsoon and dry winter seasons and analysis of groundwater to detect potential contamination from lake seepage.

- **Socio-Economic Survey** of the stakeholders living in close proximity to Varthur Lake to determine their dependency on the lake, how their use of the lake has changed over time, and their willingness to support restoration efforts.

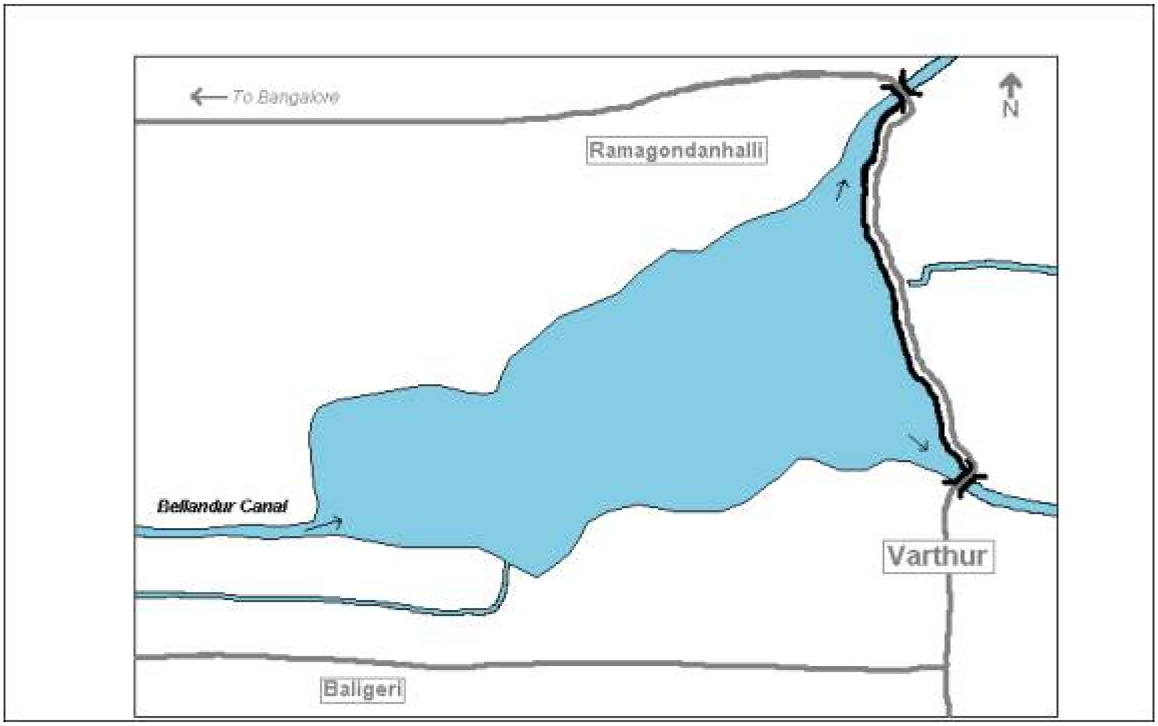
2. Morphometric Survey

2.1 Methodology

Verification of the Shoreline

A 1:50,000 scale map of Varthur Lake published by the Survey of India (SI) in 1980 was scanned, georeferenced, and digitised using MapInfo Professional 5.0. The digitised shoreline of the lake was then overlapped with a geometrically-restored LISS II satellite image of the lake from 1998 using Idrisi 32 software (Eastman, J. Ronald. 1999). From the image, it is seen that the general shape and surface area of the lake is virtually the same in 1998 as it was between 1971 and 1974, when the SI map was completed. The SI map was used as a reasonable approximation of the current shoreline of the lake for the remainder of the study under the assumption that the outline of the lake has not changed significantly since 1998.

Figure 2.1 LISS image and SI map



Depth Sampling

The depth of the lake was measured at randomly distributed points around the lake. The location of these points was recorded using a handheld GPS (Geographic Positioning System). The depth of the lake was sampled on two occasions, November, 2001, and February, 2002, corresponding to the post-monsoon and dry seasons, respectively. The position of the GPS points taken in the field were rectified to fit the map of the lake by comparing the GPS coordinates for two landmarks (the bridge over the northeast outlet and the main irrigation canal) to previously established coordinates published by the Survey of India, 1980.

The November depth samples were measured with a weighted line and measuring tape. A total of 31 sample points were recorded using this method. February samples were taken from a coracle boat using a graduated aluminum pole with a flat disc attached to the bottom. A total of 46 sample points were recorded with this method. The data collected during the February sampling is presented in Appendix A.

Contour Mapping

The depth data collected in February were converted into data points on the georeferenced map of Varthur Lake using MapInfo Professional 5.0 software. The initial bathymetric map was hand contoured using a 0.25 meter contour interval. The shoreline contour was truncated at the spillovers that transect the two primary outlets. All lines were drawn using the polyline tool incorporated in the software.

Volumetric Calculations

Estimations of the February volume of Varthur Lake were made using two methods, (A and B), based on the data used in the calculations. Method A was a simple manual calculation based on surface area slices at the .25 meter intervals used on the initial digitized map. Method B was a more accurate computer-assisted analysis that used a grid file of the lake extrapolated from the original data points and the contour map.

Method A:

This method subjected data from the contour map to two separate volume computations labeled formulas 1 and 2, respectively (Mutreja, K. N. 1986). The maximum depth of the lake is represented by the 2.0 m contour. Table 2.1 summarizes the application of formula 1. This procedure involved finding the volume of each layer between the contours (Vol. 1) and subtracting the volume of each layer that is lost due to the slope of the bottom of the lake (Vol. 2). Vol. 2 assumes a slope factor of 0.5.

Table 2.1 Volume Calculation Using Method A: Formula 1

Cont. ID	Area (m^2)	Depth (m^3)	Vol. 1 (m^3) (Depth of prev. cont.-Depth of cont.)*Area of cont.	Vol. 2 (m^3) (Area of cont.-Area of prev. cont.)*0.5	Vol. 1-Vol. 2	Comment
1	11,680	2.00	0	0	0	Vol. interval assumes 2 m contour represents max. depth
2	166,900	1.75	41,725	19,403	22,323	normal interval slope calculation
3	382,200	1.50	95,550	26,913	68,638	normal interval slope calculation
4	644,100	1.25	161,025	32,738	128,288	normal interval slope calculation
5	862,000	1.00	215,500	27,238	188,263	normal interval slope calculation
6	1,025,000	0.75	256,250	20,375	235,875	normal interval slope calculation
7	1,134,000	0.50	283,500	13,625	269,875	normal interval slope calculation
8	1,253,000	0.25	313,250	14,875	298,375	normal interval slope calculation
9	1,478,000	0.00	369,500	28,125	341,375	normal interval slope calculation

		total:	1,736,300	183,290	1,553,010	est. total volume of lake is 1,540,589 m^3

$$V = \frac{50 * \max.depth * \sqrt{\pi}}{\sqrt{A}}$$

Formula 2 (presented below) involves the summation of truncated irregular cones delineated by the contour lines on the map. Max. *depth* represents the maximum estimated depth of the lake and *A* represents the surface area of the lake.

Method B:

The second method for calculating the volume of the lake used the same data points and contour map incorporated into Method A to create a computer-generated model of the lake. Volume calculations were based on this second model. Data points were expressed as UTM coordinates the digitized data was created with MapInfo Professional 5.0. The gridding calculations, contouring, and graphics were completed using Surfer 7 contouring software.

The first step involved digitizing the hand contoured map of Varthur Lake, thus converting each contour into a data file composed of a series of points expressed as X, Y, and Z (east, north, and depth) coordinates. The data points from the February field sampling were also entered directly into the data file. All data points were referenced using coordinates taken from the 1980 SI map of Varthur Lake. The resulting data was treated using the Kriging formula option, which analyses the given data and extrapolates information for areas where no data is available. This analysis produced a grid file of the lake with data points spaced at 5-meter intervals. The resulting grid file was then subjected to a blanking file representing the shoreline of the lake in order to reduce any data that the Kriging program had extrapolated outside the boundary of the lake to a nil value. All volume calculations were derived using options incorporated into the software, including computations based on the Trapezoidal Rule, Simpson's Rule, and Simpson's 3/8 Rule.

General Parameters

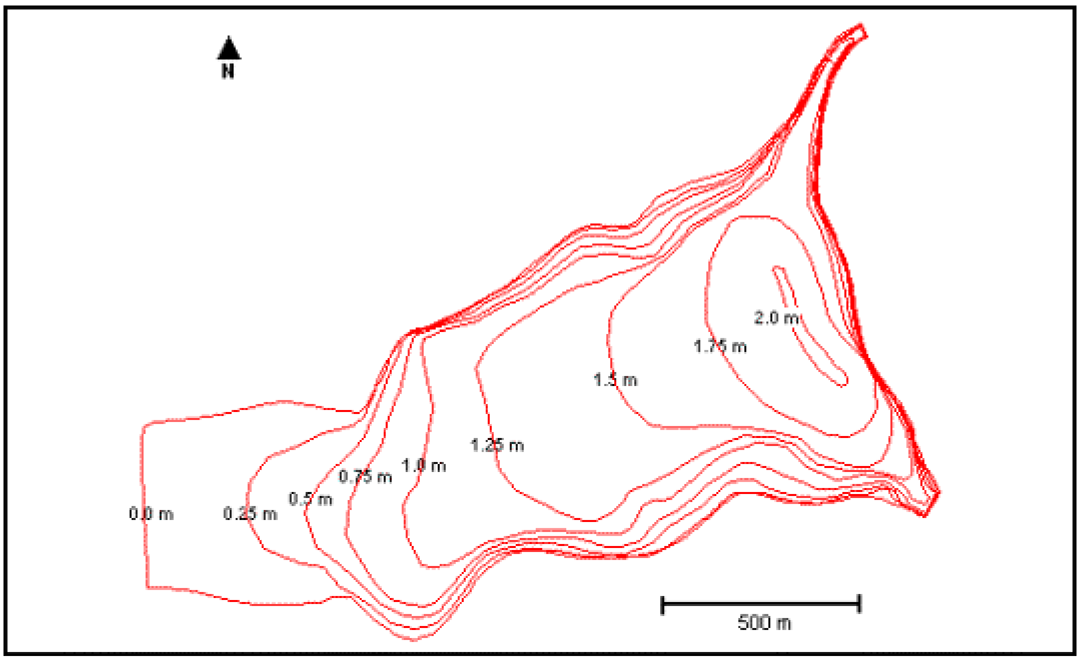
Surface area (area), shoreline, maximum length, maximum width, and mean width of the lake were estimated using a geo-referenced image of Varthur Lake from the SI map and MapInfo Professional 5.0 software. For details on the calculation of mean depth, relative depth, mean width, and shoreline development, see the glossary provided near the end of this document.

2.2 Results

Varthur is an extremely shallow lake, with a very large surface area in relation to its depth. The total area of the lake is estimated to be 1,478,000m^2.The shoreline of Varthur Lake does not appear to have changed considerably between the early 1970's and present day, unlike many other tanks in the district that have decreased drastically in size due to encroachment.

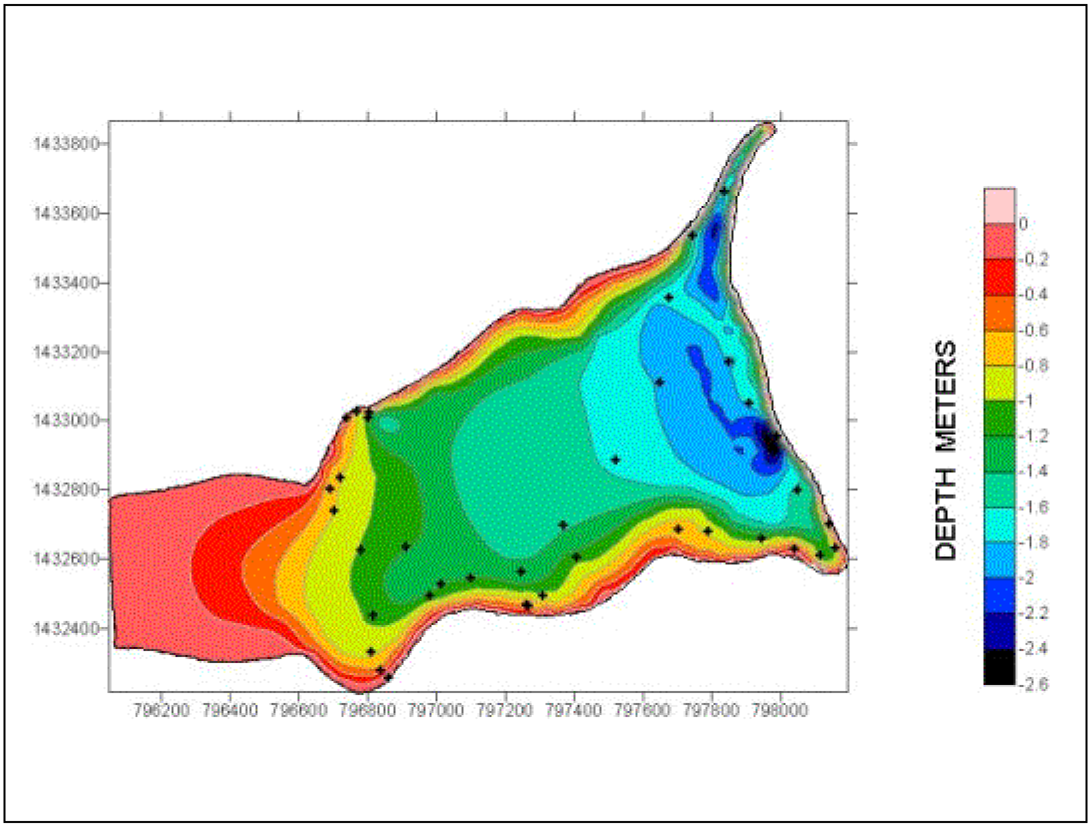
Two methods were used to calculate the volume of the lake. Method A employed standard formulas for calculating the volume of a reservoir using data from the contour map presented in Figure 2.2. Figure 2.2 is a bathymetric map of Varthur Lake and shows the lake has an estimated maximum depth of approximately 2.0 meters. The mean depth is estimated to be 1.05 m and the lake bottom exhibits a very gradual downward slope from west to east, with maximum observed depth occurring near the dam wall. These results are consistent with sedimentation patterns common to dammed reservoirs.

Figure 2.2 Bathymetric Map of Varthur Lake, February 2002



Method B involved software-assisted volumetric analysis incorporating the same contour map as well as the actual data points collected in the field to extrapolate a depth profile of the lake in grid form. This profile produced a maximum estimated depth of 2.55 m, which is 0.55 m greater that that of the previous contour map. The following figure presents a visually enhanced image of the depth profile produced using method B.

Figure 2.2 Gridded Depth Profile of Varthur Lake, February 2002



Three standard calculus-based formulas were applied to the above profile, resulting in three separate but highly similar estimates of the volume. The results of these calculations are summarized below in Table 2.2.

Table 2.2 Results of Volume Calculations: February 2002

Method	Information Source	Application	Estimated Volume
A	Contour map	Formula 1	1 553 010 m^3
		Formula 2	1 667 588 m^3

B	Depth profile in grid form	Trapezoidal Rule	1 574 494 m^3
		Simpson's Rule	1 574 473 m^3
		Simpson's $^3/_8$ Rule	1 574 519 m^3

The widest variation in volume estimates lies between the two formulas used in method A. This is likely due to the large horizontal intervals found between the contour lines. The values calculated using method B fall in between those derived using method A. The mean average of method B values is 1,574,495 m^3, with a standard deviation of 19 m^3. These values are more consistent, in part because the depth profile provides more detail than the contour map.

The remainder of the morphometric parameters for Varthur Lake is listed on Table 2.3. These results emphasize the fact that the whole of Varthur Lake is shallow in relation to its surface area. The lake exhibits low shoreline development consistent with the lack of topographical diversity in the region; this factor contributes to the regularity of the sedimentation patterns within the lake as there are few formations to interfere with the water currents.

Table 2.3 Morphometric Parameters of Varthur Lake, February 2002

Parameter	Values from Contour and SI Map	Alternate Values from Depth Profile in Grid Form
Area	1 478 000 m^2	1 477 196 m^2
Maximum observed depth	1.85 m	
Maximum estimated depth	2.0 m	2.55 m
Mean depth	1.05 m	1.07 m
Relative depth	0.15%	0.19%
Shoreline	6 560 m	
Shoreline development	1.52	
Maximum length	1 810 m	
Maximum width	1 040 m	
Mean width	117 m	

2.3 Observations

As silt and sediment-laden water enters Varthur Lake from the Bellandur Canal, the velocity and turbidity of the water decreases considerably due to the increase in cross-sectional area and the presence of large mats of water hyacinth. At this point, the water no longer contains sufficient energy to displace or carry larger suspended particles. These particles are deposited on the lake bottom near the inlet, forming a delta. Smaller suspended particles are deposited further away from the inlet where the velocity and turbulence decrease further. This forms a gradual downward-slope along the length of the reservoir, with the deepest section occurring near the dam. The velocity of the water increases as its approaches the northeast and southeast outlets, and these areas appear to accumulate less sediment that the main body of the lake.

Varthur may have a slightly less silt than the other tanks in the area due to desilting performed by local residents around the edges of the lake. This activity was observed in several areas along the northern shoreline while conducting field sampling. Varthur Lake has a catchment area of 1.8 km^2, the second largest in the Bangalore South taluk (Govt. of Karnataka, 1990). This catchment area contains a substantial human population engaged in agriculture and various industries and, therefore, the potential for accelerated sedimentation due to anthropogenic causes is substantial. Without previous depth profiles of the lake, it is difficult to estimate the rate of sedimentation. However, even if the historical depth of Varthur is very shallow, its lack of depth makes it highly susceptible to increases in sediment loading caused by human development within the catchment area.

Loss of depth and volume would reduce the water supply available to local farmers who continue to use Varthur as a primary water source. It would also have a detrimental effect on the quality of water in the reservoir and degrade habitat for fisheries and wildlife. The ability of the lake to moderate the local climate would be reduced, as the amount of energy absorbed and released by the lake would decline along with its depth and volume. Accumulation and impaction of silt on the lake bottom also has the potential to impede the infiltration of rainwater into the aquifers below. This infiltration is the main water source of groundwater recharging in the Bangalore area. Varthur Lake represents a major local reservoir of rainwater and a reduction in the permeability of its benthic layers would decrease the water resources available from local open and bore wells. These wells are the primary source of domestic, potable, and agricultural water, and their decline would be detrimental to the people living in the area. The method of volume calculation based on hand-drawn contour maps and formula 1 yielded results very similar to those obtained using sophisticated software programs and is a more practical approach for volume estimation when the resources employed in method B are not available.

2.4 Conclusions and Recommendations

Varthur Lake is a shallow, artificial reservoir with a mean depth of approximately 1.1 m as of February 2002. The pattern of sedimentation in the lake is consistent with that of a typical dammed reservoir. The western portion of Varthur located near the primary inlet is extremely shallow. The depth gradually increases moving towards the eastern portion of the lake, reaching maximum depth, estimated from 2.0 to 2.55 m, near the dam wall. Varthur Lake, like many tanks in the Bangalore area, is suffering from rapid sedimentation that poses a threat to the ecology and very existence of the lake. In order to gauge the rate at which it is filling in, studies measuring the sediment loading of the reservoir should be undertaken. Comparing the amount of suspended solids present in the inflow and outflow would not yield an accurate estimate of the amount of sediment actually settling in Varthur because much of the sediment is organic debris from autotrophic organisms living in the lake itself. The feasibility of using sediment traps as an alternate means of measuring sediment loading of the lake should be investigated. Analysis of the composition and permeability of the underlying sediment through core sampling would be very useful in determining the impact of sedimentation on the recharging of groundwater supplies. Removal of accumulated sediment has historically been a regular aspect of tank maintenance. Records referring to the desilting of Bangalore tanks date back to the early 16th century. Some form of desilting will eventually have to take place in Varthur in order to retain the water-holding capacity of this reservoir.

Monitoring of the morphology and sedimentation patterns is an important, but often neglected, aspect of the limnological analysis of Bangalore's tanks. In order to preserve and enhance the substantial benefits provided by Varthur Lake, information regarding these parameters should be expanded and employed to prevent the unnecessary loss of this valuable resource.

3. Water Quality Survey

3.1 Methodology

Collection of samples

Water samples from Varthur Lake were collected on three occasions: October, November, and January 2002. October samples were collected from the shoreline nearest to the following locations: Bellandur Canal, the south-southwest portion of the lake, and the northeast and southeast outlets. Water samples were collected from 10 to 30 cm below the surface of the water during the morning hours. These samples were collected and stored in white, 500 ml polyethylene containers, with the exception of those collected in borosilicate glass bottles for dissolved oxygen analysis. No preservatives were added as the samples were transported to the laboratory within six hours and either refrigerated or analysed immediately.

Bore well water samples were collected in January from four locations closest to the southern shore of the lake. These samples were collected and stored in clean, white, 500 ml polyethylene containers that had not been used for lake sampling. No preservatives were added, as samples were taken to the lab and analysed immediately.

Analysis of Samples

On-site analysis of lake water included air and water temperature, transparency and, in the case of October and November sampling, dissolved oxygen. Laboratory analysis included: acidity, alkalinity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), chloride, chlorine residual, coliform bacteria, dissolve oxygen (DO), electrical conductivity (EC), fluoride, hardness, iron, nitrate, pH, phosphate, potassium, sodium, sulphate, solids (total, total dissolved, and total suspended) and turbidity.

The majority of lake water analyses followed standard procedures published by the Indian National Environmental Engineering Research Institute (NEERI, 1998) and the American Public Health Association (APHA, 1985). Ammonia, coliform bacteria, fluoride, iron, pH (in the field), phosphorus, residual chloride, and turbidity for October and November samples were tested using a Jal-Tara Water Quality Testing Kit produced by Development Alternatives in New Delhi (Development Alternatives 2000).

Bore well samples were tested for ammonia, chloride, coliform bacteria, EC, fluoride, nitrate, and pH. EC and pH were measured using an electrical conductivity meter and a pH meter, respectively. All other parameters were tested using a Jal-Tara Water Quality Testing Kit.

3.2 Results

3.2.1 Lake Water Samples

A complete set of results from analysis of October, November and January water samples is provided in Appendix B. The following is a brief summary of these findings.

General Parameters

Dissolved oxygen (DO) levels in Varthur Lake were extremely low. Water temperature ranged from 22 to 26°C prior to 9:00 AM on all sampling dates. The pH of the water was found to be slightly alkaline (approximately 7.5 to 8.0) for all water samples. November water samples exhibited a strong ability to neutralise acids in solution due to the presence of bicarbonate. The acidity of the samples was much less than their alkalinity. Total hardness showed little variation during the sampling period, indicating that the overall concentration of calcium and magnesium salts is fairly constant; hardness due to calcium carbonate ranged from 59 to 68% of total hardness for November and January samples.

In November, light was able to penetrate the upper 19 to 24 cm of the water column. Transparency was substantially reduced during January. Further examination of physical properties revealed high concentrations of suspended and dissolved solids. The concentration of total dissolved solids (TDS) showed substantial seasonal variability, increasing three-fold between November and winter sampling periods. This increase in TDS corresponds to a similar increase in electrical conductivity. Moderate to high concentrations of total suspended solids (TSS) were also present in January samples. Water from the middle of the lake exhibited the highest concentration of TSS by far.

Nutrients

Nitrate concentrations present in October samples were low, averaging only 0.24 mg/l. The average concentration of nitrate increased to 1.00 mg/l and 1.27 mg/l in November and January, respectively. Ammonium was estimated to be in excess of 3.0 mg/l for three of the four October samples. Phosphorus concentrations from January samples were very high, averaging 15.1 mg/l.

Organic Matter

The BOD of water samples was extremely high and nearly equivalent to COD.

Microbial Contaminants

Bacterial culturing confirmed the presence of the bacteria *E. coli* in the lake.

Inorganic Constituents

The concentration of chloride ions in November samples averaged 102 mg/l. In January samples, these values increased 60 to 70 percent. October lake water samples contained less than 0.2 mg/l of residual chlorine, which is the minimum detection level of the Jal-Tara kit. Sulfate concentrations in the lake were consistently low, however, a substantial decrease in sulfate occurred between November and January sampling dates. Sodium concentrations for November were only moderately high. Elevated levels of potassium were observed in November samples. January samples were well within standard range for unpolluted surface waters.

3.2.2 Groundwater Samples

Results from the groundwater survey are presented in Table 3.1. Two of the samples tested positive for minor concentrations of coliform bacteria. These well were located at opposite ends of the lake, approximately 250m and 750 m from the southeastern and southwestern shorelines, respectively.

Table 3.1 Groundwater Survey Results

Parameter	Site 1	Site 2	Site 3	Site 4
Ammonia (mg/l)	<0.2	<0.2	<0.2	<0.2
Coliform bacteria	negative	positive	positive	negative
Chloride (mg/L)	0.8	1.1	0.9	0.8
EC (μS/cm)	896	1120	928	832
Fluoride (mg/l)	0.6	0.6	0.6	0.6
Nitrate (mg/l)	<10.0	<10.0	<10.0	<10.0
PH	7.40	7.28	7.41	7.55

3.3 Observations

3.3.1 Lake Water Samples

Results of the analysis for samples taken near the northeast outlet during October, November and January are presented in Table 3.2. This table also includes standard values for unpolluted water bodies as well as regulations and guidelines.

Table 3.2 *Comparison of Water Quality Data and Various Pollution Standards*

Parameter	Results *from the* Northeast Outlet			Standard value for unpolluted surface waters[1]
Sampling Date	Oct-11	Nov-11	Jan-31	
General Parameters				
Acidity, total (mg/l)	n/a	92.0	n/a	
Alkalinity, total (mg/l)	n/a	332.0	n/a	
Alkalinity as HCO3 (mg/l)	n/a	332.0	n/a	
D.O. (mg/l)	2.0	3.0*	2.9	
EC (μS/cm)	460	474	1420	10-1000
Hardness, Total (mg/l)	213.6	209.3	232.5	
Hardness, $CaCO_3$ (mg/l)	132.0	124.0	158.1	
Hardness, $MgCO_3$ (mg/l)	n/a	77.6	62.7	
pH (*in situ*)	7.5-8.0	n/a	n/a	
pH (*ex situ*)	7.61	7.55	7.68	
Air Temperature (°C)	28.5	26.0	21.0	
Water Temperature (°C)	27.0	26.0	23.0	
Total Diss. Solids (mg/l)	332.4	370.8	1246	
Total Solids (mg/l)	n/a	n/a	1258	
Total Susp. Solids (mg/l)	n/a	n/a	12	
Transparency (cm)	n/a	27.0	11	
Turbidity (NTU)	50	50	25	
Nutrients				
Ammonia (mg/l)	>3.0	n/a	n/a	<3.0
Nitrate (mg/l)	nil	1.074	1.40	≤0.1
Phosphorus (mg/l)	n/a	>1.0	15.54	.005-.020
Organic Matter				
BOD (mg/l)	n/a	n/a	74.2	≤2.0
COD (mg/l)	n/a	n/a	82.2	≤20.0

Microbial Contaminants				
Coliform bacteria	positive	positive	n/a	
Inorganic Constituents				
Chloride (mg/l)	n/a	100.0	170.0	≤10.0
Chlorine, residual (mg/l)	<0.2	n/a	n/a	
Fluoride (mg/l)	<0.3	n/a	n/a	<0.1
Iron (mg/l)	~0.3	n/a	n/a	
Potassium (mg/l)	130*	20.2	2.2	<10.0
Sodium (mg/l)	907*	32.8	n/a	<50.0
Sulfate (mg/l)	n/a	14.5	8.48	2.0-80.0

* values subject to interference. See section 3.2

** total ammonia, depends on pH

[1,] UNESCO, WHO, UNEP 1996 Water Quality Assessments: A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring. Second Edition. E & FN Spon, Madras.

The wide variation between TSS concentrations for various sampling sites could be due to the presence of organic floatables observed during collection of the samples. The presence of these clumps of matter could significantly increase the TSS value for a sample in comparison to a similar sample without clumps.

> Turbidity from organic and inorganic suspended matter in Varthur has the potential to impact the ecology of the lake in several ways. Many toxic contaminants, such as heavy metals and some pesticides, could potentially find their way into Varthur by adhering to solids in solution. Eventually, much of the suspended matter will settle in the bottom of the lake where they smother benthic organisms and contribute to siltation. Turbidity is also the most important factor in prolonging the survival of faecal coliform in water bodies because the particulate matter shelters bacteria from harmful solar radiation (DWI, 1995).

The bacterium *Escherica coli* is indigenous to the intestines of animals, including humans. Its presence in Varthur indicates that faecal matter contaminates the lake. Faecal contamination is often associated with other types of pathogenic bacteria and viruses found in untreated sewage. The turbidity of the lake water, along with its warm temperature, mildly alkaline pH, and low oxygen levels, could lead to prolonged survival of pathogenic bacteria for up to several days.

Varthur contains significant amounts of the macronutrients required by aquatic plants in large quantities in order to survive and grow, especially phosphate. Excess amounts of phosphorus could be the result of contamination from sewage and/or fertilisers. Both the population of Bangalore and the availability of fertilizers have increased in recent years. Eutrophication has resulted in large populations of algae to develop in Varthur, which imparts a green colour. This process has also assisted in the intrusion of Eichhornia crassipes *(water hyacinth). Although the amount of lake surface occupied by this plant fluctuated dramatically between sampling dates, the western portion of the lake was consistently covered with mats of hyacinth, as were the two main outlets. Overall, coverage by water hyacinth increased during the winter months.*

The concentration of nitrate was slightly higher than standard values for unpolluted waters in October samples, but increased substantially in November and January. The relatively low nitrate concentrations observed in Varthur could be a result of several biological processes. Loss of nitrate in Varthur could be the result of *ammonification*, the conversion of organic nitrogen to ammonium during the decomposition of organic matter. High concentrations of ammonia observed in October samples support this explanation. Under anoxic conditions, nitrate may also be converted to nitrite; it is likely that such conditions exist near the bottom sediments of Varthur lake, given the extremely low oxygen levels of the surface layers, and that this process may be partly responsible for the lower concentrations of nitrate in the water. Loss of nitrate also occurs through uptake by macrophytes and algae; during periods of high plant growth, this process may significantly reduce nitrate concentrations in the lake.

November ammonia concentrations in Varthur were high enough to be toxic to many forms of aquatic life. Given the warm temperature, alkaline pH of the water, and organic pollution present in Varthur, these concentrations may have been substantially greater than 3.0 mg/l, which is the maximum detection of the Jal-Tara kit. When water samples from January were viewed under a microscope, the most dominant zooplankton by far was Daphnia, a species that is highly tolerant of ammonia.

Potassium is also an essential element for plant growth. Elevated levels of potassium were observed in November samples, indicating potential contamination from industrial effluents or fertilizer. Potassium concentrations dropped substantially in January, possibly due to uptake by the increasing macrophyte population. A similar trend was observed for sulfate and could be caused by winter plant uptake as well.

The high BOD of the water samples indicates that decomposition of organic matter is one of the main factors leading to the low DO concentrations observed in the lake. Much of the remaining oxygen is likely consumed through nighttime respiration by aquatic plants. Eutrophic lakes similar to Varthur often experience a daily cycle of hyper- and hypo-oxygenation due to the high concentration of photosynthetic algae that produce oxygen during daylight hours and consume oxygen at night. However, the data collected is insufficient to confirm these diurnal-nocturnal fluctuations in DO.

The low DO content of Varthur limits diversity of animal life that can survive in the lake. Anoxic conditions also affect many other chemical processes within the lake that can be detrimental to organisms, such as the conversion of organic nitrate to toxic ammonia.

The high BOD values imply that virtually all of the organic matter contained in the samples was biologically degradable, and that the combined concentrations of sulphates, nitrates, ferrous iron, and other organic components that cannot be oxidized by bacteria are comparatively low. Based on these findings, only a small proportion of the organic pollution in Varthur could have its origin in industrial effluents. The majority of organic pollution likely comes from animal and plant sources, such as sewage and plant death within the lake. In addition to sewage, several aquaculture ponds are seasonally drained into the lake also have the potential to contribute substantial amounts of nutrient-rich organic debris.

Elevated chloride values could be due to many factors, including sewage, industrial effluents, and agricultural runoff. The seasonal variation may due to the fact that January concentrations were not diluted by monsoon rainwater.

The water sample taken from the Bellandur Canal in November was very similar in composition to those taken from Varthur Lake, and it is likely that many of the contaminants that enter Bellandur Lake from its own substantial catchment area eventually make their way to Varthur.

3.3.2 Groundwater samples

The following groundwater parameters were found to be within the limits set by the 1983 Indian Standards Specification for Drinking Water: ammonia, chloride, electrical conductivity, fluoride, nitrate, and pH. There is a possibility that coliform bacteria present in two if the sample could have originated from sewage effluent in the lake, however, these bacteria could also have been present on the pump itself due to human contact.

3.4 Conclusions

The water quality survey for Varthur Lake indicates that it is a eutrophic lake containing high concentrations of organic wastes and phosphorus. Nutrient enrichment has allowed substantial populations of water hyacinth and algae to develop in the lake. The decay of organic matter present in the lake, much of which comes from plant life growing in the lake itself, has resulted in extremely low concentrations of dissolved oxygen and elevated ammonia content.

The pollution entering Varthur Lake comes mainly from non-point sources that are, by nature, difficult to identify with certainty. The tank is part of a large network of interconnected canals and reservoirs, the largest of which is Bellandur Lake, which receives all of the overflow sewage and wastewater from central, eastern, and southeastern Bangalore city. A variety of industries, sewage outlets, urban wastewater, and agricultural runoff contribute to the current condition of these water bodies and it is, therefore, very difficult to determine the most significant sources of pollution. Any restoration efforts for Varthur Lake must address the interconnected nature of these sources contaminating the lake.

Pesticides have become readily available through government-sponsored programs in Bangalore area, increasing the potential for contamination of local water bodies.

4. Socioeconomic Survey

4.1 Methodology

Sample households from the town of Varthur and the villages of Baligeri and Ramagondanhalli were interviewed using a standard questionnaire. Questions were presented to the participants orally and answers were recorded onto a survey form. A copy of the original survey form is provided in Appendix C. Interviews were conducted from October 14th to November 10th. 22 households took part in the survey, representing a total of 217 people. The questions posed during the interviews were classified under the following headings:

- ✓ Demographic Information
- ✓ Domestic Water Usage
- ✓ Groundwater Recharge
- ✓ Irrigation
- ✓ Other Commercial Uses
- ✓ Water Usage for Livestock
- ✓ Livestock Fodder
- ✓ Family History
- ✓ Aesthetic Value & Recreation
- ✓ Fishing & Aquaculture
- ✓ Waterfowl
- ✓ Spiritual Value
- ✓ Health Effects
- ✓ Community Involvement in Restoration

Questions regarding domestic water usage, irrigation, other commercial uses, water usage for livestock, livestock fodder, and fishing and aquaculture attempted to quantify residents' direct economic reliance on lake and groundwater resources. Other direct uses, such as recreation and, in some cases, spiritual value, were investigated using qualitative questions regarding use of the lake. Any changes in lifestyle, such as a change in occupation, that may have been caused by deterioration in the quality of the lake were investigated in the family history section of the questionnaire.

The use of groundwater resources was included in the survey to identify trends in the overall reliance on lake resources compared to groundwater. Usage of groundwater may be indirectly associated with lake water resources as the Varthur lake could be responsible for recharging local aquifers. Questions regarding groundwater recharge were intended to detect changes in the local water table that could be the result of reliance on bore wells.

Questions pertaining to waterfowl and fish populations pertained to qualitative information about changes in the ecology of the lake, especially the biodiversity and abundance of wildlife. These topics, along with questions regarding aesthetic value, sought information on less tangible benefits provided by the lake that may be affected by a decline in its overall condition. Potential harm to the local population as a result of this deterioration was also investigated through questions regarding mosquito populations and incidents of insect and water-borne diseases.

The heritage value of the lake as well as family commitment to remaining in the area were investigated through questions regarding both family history and their desire to see future generations remain near Varthur. Determining residents' overall concern for the future of the lake was the motivation behind the question regarding support for future reclamations efforts.

4.2 Results

The survey revealed that the total land area irrigated using Varthur lake water is 1537 acres and the total number of farmers dependent on the lake water for irrigating their lands is 1159. In Varthur, Sorahumase and Valepura village, the land irrigated by the lake water amounts to 796, 551.27, 189.13 acres respectively. The type of crops grown in Varthur village and the area under each crop is as follows: Paddy – 771.31 acres, coconuts – 8.22 acres, bananas – 9.26 acres, Beetle leaf – 0.26 acres, arecanut – 0.10 acres and Floriculture – 5.31 acres. In Siddapur village the main crops grown are vegetables and floriculture whereas in the nearby Ramagondanahalli it is vegetables, greens and flowers.

All respondents used bore wells to meet their domestic water needs. 9 of the 22 households interviewed purify their drinking water with a filtration system, and one household boiled the water prior to drinking.

20 of the households, representing 83% of the survey population, relied on agriculture as their primary source of income. 12 of these households relied exclusively on lake water to irrigate their crops, and 2 more used both the lake and bore wells for this purpose. 10 of the houses that use the lake for irrigation reported a decline in both the quality and quantity of crops due to pollution of the lake water.

14 households raise cattle, primarily for milk. At least 11 of these farms rely exclusively on plants growing on and around Varthur Lake to feed their cattle. 9 of these 11 farms rely on the sale of dairy products for part of their income; the percentage of total income derived from dairy products for these farms ranged from 1 to 74%, with mean and median averages of 32% and 40%, respectively.

None of the households were involved in fishing the lake, however, one was actively engaged in aquaculture of carps in lake-water-filled dugouts near the shore. Another respondent indicated a desire to start a similar operation.

86% of the respondents indicated that they had noticed deterioration in the quality of the lake. Although estimates of when this deterioration began varied widely, (from 6 to 40 years), over half of the estimates ranged from 15 to 20 years ago. 10 of the farms reported a reduction in the quality and quantity of their crops as a consequence of polluted lake water. 18 of the respondents indicated that the mosquito population around Varthur has increased in recent years. One respondent indicated that family members had suffered from malaria and dermatitis. Another household that did not filter or boil their drinking water reported problems with viral fever. The smell given off by the lake in winter months was considered to be a nuisance by 16 of the households involved in the survey.

All of the residents surveyed indicated that their families had lived in the area for one generation or more. Duration of residency ranged from 30 years to more than 200 years and at least 60% of the families had lived in the area for over 100 years. 19 of the 22 households surveyed would actively support reclamation efforts for Varthur Lake. 16 of the 22 households visit the lake on an annual basis to submerge idols during Ganesh festival.

4.3 Observations

The effect of polluted lake water on crop production could very well be detrimental due to factors such as pathogens contained in the water (see section 3.4). It is unclear whether aquaculture has become popular because of a decline in the population of fish in the lake or because of its comparative convenience and increased yield. Several residents lamented the fact that fish stocks have declined and they are no longer able to enjoy this resource.

Water hyacinth is often classified as a nuisance species in Bangalore tanks. However, it provides a significant and inexpensive source of cattle fodder for farmers around Varthur as well as a source of income for residents who gather and sell the water hyacinth. The majority of households in the villages surveyed maintain dairy cattle to feed their families and, in most cases, to supplement their income. While estimates of income derived from dairy varied widely, this income would be reduced if farmers had to purchase fodder outside the lake area.

Many residents relied on bore wells or open wells for all their water needs, a trend that increases rapidly as distance from the lake increases. Reliance on bore wells does not necessarily negate their reliance on Varthur Lake, however, because Varthur could play an important role in recharging local aquifers in the area. 50% of the population represented in the survey does not filter well water prior to drinking. This makes them more susceptible to potential contamination of groundwater supplies by pollutants in the lake water.

Contaminated water in Varthur lake has led to the increase in mosquito populations reported by local residents, including consistently warm water temperatures and large populations of water hyacinth that provide breeding habitat for these insects (see section 3.3). Mosquitoes constitute both a nuisance and a public health risk in the vicinity of the lake, as they are carriers of diseases such as malaria, encephalitis, and dengue fever.

Few of the people living near Varthur have direct contact with the lake either for annual submersion of Ganesha idols or recreation. Many respondents were generally unaware of changes in the ecology of the lake unless they pertained to sight, smell, or mosquito populations. Some respondents were unable to provide information on wildlife populations, especially fish. Despite these observations, most respondents indicated a willingness to support efforts aimed at restoring Varthur Lake to a less polluted state and hoped that their children would remain in the area around the lake to raise their families.

4.4 Conclusions and Recommendations

It is obvious from the survey that local residents continue to rely heavily on the lake for cattle fodder and irrigation of crops. There is a possibility that contamination of water supplies is having a negative affect on the quality and quantity of crops produced using lake water. This poses a threat to the primary source of income for people living near the lake and warrants further investigation.

The degradation of the lake has affected residents in several ways. The smell emanating from the lake during winter months and increased mosquito populations pose a considerable nuisance to those living in the vicinity of the lake. Mosquitoes are also a potential health risk as they accommodate the transmission of many tropical diseases. Contamination of groundwater by pollutants originating from the lake poses a substantial risk to people living near Varthur. Loss of potable water supplies would be grossly detrimental to the economic well being of the community and efforts should be made to continue monitoring drinking water supplies for local towns and villages.

The degradation of Varthur Lake has lead to the loss of both direct and indirect benefits from the lake. However, a strong majority of residents are committed to remaining in the area and are willing to support community-based lake rehabilitation. In order to reclaim lost benefits and enhance the existing use of lake resources, efforts should be undertaken to improve the water quality and ecological health of Varthur Lake while keeping in mind the primary uses of the lake resources.

5. General Summary

The current shallow depth of Varthur is of primary concern, as loss of depth will eventually jeopardize the very existence of the reservoir. Further analysis and monitoring is necessary to determine the rate at which Varthur is filling with sediments. Eventually, desilting must take place in order to maintain the water-holding capacity of the reservoir. In order to do this, the Jala Samvardhane programme needs to be undertaken immediately. Beyond desilting, efforts must be made to reduce the amount of sediment entering the reservoir as well as the amount organic sediments accumulating due to a cycle of nutrient enrichment, plant growth, and plant decay.

Nutrient enrichment is largely responsible for the poor quality of water in the reservoir. Varthur Lake displays many features common to eutrophic water bodies, such as low dissolved oxygen levels and high ammonia content, which result in a reduction in the diversity and number of animal species that can inhabit a lake. Nutrient and organic pollution is likely exacerbating problems like plant overgrowth, pathogenic bacteria, increased mosquito populations, and unappealing smell. The most significant source of this pollution remains unknown due to the complex nature of the catchment area and the limited water quality parameters incorporated in this study. However, results of this study consistently indicated that sewage, wastewater, and agricultural runoff are the most likely sources of contamination.

It is obvious that Varthur Lake continues to provide substantial economic benefits to the local population, despite the tendency of some locals to avoid direct contact with the lake due to the previously mentioned health risks and aesthetic concerns. Factors that elude quantification through a socio-economic surveying, such as microclimate regulation, biodiversity, and the rich heritage associated with the lake, add to the value of this resource. All of these benefits are being eroded by contamination of the lake and, therefore, lake restoration must take place in order to maintain and, perhaps, improve the quality of life currently available to residents of the Varthur Lake area. A majority of residents in the area recognize the importance of the lake and are willing to offer their support for such efforts.

6. Opportunities and Initiatives for Restoration

Efforts towards Lake Restoration and conservation in Bangalore are piecemeal and reactive, as evidenced by the state of Varthur lake water. Conservation efforts could be far more effective if we could avoid habitat degradation. This approach would require an ability to predict the elements of the lake biota that are most vulnerable to extinction and to identify their ecological attributes (bird migration, fish diversity, etc.). A related point is the need to assess the health of the lake community and to monitor changes in it over time.

The preliminary step that has to be implemented in restoring lake for their long-term sustenance includes:

Pollution impediment:

Wastewater, solid and semi solid wastes entering in to the lake from external sources must be stopped before any restoration work is implemented.

Harvesting of Macrophytes:

Water hyacinth and other nuisance vegetation present in the lake, causing eutrophication, must be removed manually or mechanically. Weed infestation can also be controlled by applying chemicals like methyl-chlora-phenoxy-acetic acid, hexazinore, etc., and biological control by means of introducing *Pila globosa* (trophical snail), Chinese grass carp (fast growing fish) etc. that feed on many aquatic plants.

Desiltation:

Dredging of the sediments in the lake to improve the soil permeability, water holding capacity and ground water recharge. Recent technological developments do permit wet dredging. Studies in Kolar district reveal that desilting of waterbodies helps in lowering fluorosis in borewell water (ground water).

Rain water harvesting:

The lake can also be used as rainwater harvesting structure. After desiltation or dredging, the storage capacity i.e., the water holding capacity of the lake would increase and as Varthur lake has a large catchment area, it would prove to be an effective rainwater harvesting structure. The bunds surrounding the lake can be strengthened and fencing should be provided around the lake. A draw well can be constructed at one end of the tank with an underground filter media connecting the well and tank bed to fetch clear water.

Watershed Management:

Watershed management is the rational utilization of land and water resources for the optimum production with minimum hazard to natural resources. As an extension of the restoration programme, watershed management practices are essential for proper land use, protecting land against all forms of deterioration, conserving water for farm use, proper management of local water for drainage, flood protection and sediment reduction and increasing productivity from all land uses.

Best Management Practices:

The restoration programmes with an ecosystem approach through Best Management Practices (BMPs) helps in correcting point and non-point sources of pollution.

Key steps for best management practices include:

- Pollution alleviation practices to reduce the engendering of non-point source of pollution (mainly agricultural and storm runoff) through source reduction, waste minimisation and process control.

- Promoting public education programmes regarding proper use and disposal of agricultural hazardous waste materials and regular monitoring of lakes, which are rudimentary. The local schools can undertake the periodic monitoring of water bodies and educating the stakeholders on the importance of restoration and maintenance of the Varthur lake. The education programmes are already underway (funded by the Commonwealth of Learning, Canada), the students of KK English High School periodically monitor the lake water quality along with the soil quality of the catchment area. The Energy and Wetlands Research Group, Centre for Ecological Sciences teach the 8^{th} and 9^{th} standard students on various aspects of the lake ecosystem and help in the water quality analysis.

- Afforestation with native species in desolate areas around the wetland (catchment area) to control the entry of silt from run off.

- The shorelines of the lakes should be lined with bricks or stones to control shoreline erosion.

- Constructed wetlands for the purpose of stormwater management and pollutant removal from the surface water flows.

- Infiltration trenches for reducing the storm water sediment loads to downstream areas by temporarily storing the runoff.

- Extended detention dry basins for removing pollutants primarily through the settling of suspended solids.

- Gyration of crops rather than monocultures to reduce the need for N and assist with pest control and help in aeration of soil.

These restoration goals require profound planning, authority and funding along with financial resources and active involvement from all levels of organisation (Governmental and Non-Governmental Organisations (NGOs), research organisations, media, etc.) through interagency and intergovernmental processes all made favourable in innovating and inaugurating the restoration programs. Network of educational institutions, researchers, NGO's and the local people are suggested to help restore the fast perishing Varthur Lake ecosystem and conserve it by formulating viable plans and management strategies.

7.0 Acknowledgement

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9.0 Glossary

BOD – (biochemical oxygen demand) the amount of oxygen required by microorganisms to oxidize all the biologically degradable organic matter present in a sample to an inorganic form. High BOD values indicate large concentrations of organic matter that is susceptible to bacterial degradation.

COD – (chemical oxygen demand) the amount of oxygen consumed while oxidizing biologically and non-biologically degradable organic matter in a sample using a strong chemical oxidant. High COD values indicate large concentrations of organic matter.

Digitization – converting an existing paper map into a digital form that can be stored as a database. This process normally involves scanning the original map and then tracing the desired features using digitizing software.

Geometric restoration – correcting distortions found in a satellite image by correlating points on the image with control points of specified locations using a series of polynomial equations.

Georeferencing – defining the location of an image using an established coordinate referencing system. This process normally requires the user to specify a coordinate system (eg., latitude/longitude), the reference units (eg., degrees), and the positions of the edges of the image.

Hardness – an expression of the total concentration of dissolved calcium and magnesium salts present in a body of water.

Mean depth – defined as the volume of a lake divided by its surface area.

Mean width – defined as the surface area of a lake divided by the maximum length of open water between shorelines.

Relative depth – a term that expresses the maximum depth of a lake or reservoir as a percentage of the average (mean) diameter.

relative depth =

$$\frac{50 * max\ depth * \sqrt{\pi}}{\sqrt{area}}$$

Shoreline development ratio – the ratio of the shoreline the circumference of a circle whose area is equal to that of the lake. High values indicate an irregular shoreline that deviates substantially from a smooth circular shape.

$$\text{shoreline development ratio} = \frac{\text{length of shore line}}{2\sqrt{\pi * area}}$$

Transparency – the distance to which light can penetrate a body of water.

Turbidity – describes the degree to which incident light is scattered by particulate matter suspended in a body of water. As turbidity increases, transparency decreases.

UTM – (Universal Transverse Mercator) a grid coordinate system that employs metric units of distance. UTM grid coordinates are expressed as distance in meters to the north, referred to as the "northing", and distance in meters to the east, referred to as the "easting".

Bathymetry – The analysis of depth profile of the lake.

Watershed - All land and water areas that drain toward a river or lake, also called drainage basin or water basin.

Morphometry - Relating to the shape of lake basin; includes parameters needed to describe the shape of the lake such as volume, surface area, mean depth, maximum depth, maximum length and width, depth versus volume etc.

Eutrophic lake - A very biologically productive lake due to relatively high rates of nutrient input.

Eutrophication - The process by which lakes and streams are enriched by nutrients (usually phosphorous and nitrogen) which leads to excessive plant growth – algae in the open water, periphyton (attached algae) along the shoreline and the higher plants in the near shore.

Dissolved oxygen (DO) - The concentration of molecular oxygen (gas) dissolved in water; usually expressed in milligrams/litre or parts per million. Adequate concentration of dissolved oxygen is essential for fish and other aquatic organisms. DO levels are considered the most important and commonly employed measurement of water quality and indicator of a water body's ability to support desirable aquatic life.

Appendix A – Bathymetric Data Points: Febr uary 2002

Reference Points	GPS Coordinates		Map Coordinates	
	Latitude	Longitude	Latitude	Longitude
NE Bridge	77.74564	12.95691	77.74564	12.95691
Irrigation Canal	77.74429	12.95458	77.74559	12.9527
Data Points	GPS Coordinates		Corrected Coordinates	
Depth (cm)	**Latitude**	**Longitude**	**Latitude**	**Longitude**
72	77.74243	12.94627	77.74369	12.94533
85	77.74323	12.94619	77.74449	12.94525
100	77.74472	12.94599	77.74598	12.94505
13	77.74565	12.94571	77.74691	12.94477
98	77.74629	12.94548	77.74755	12.94454
84	77.7467	12.94569	77.74796	12.94475
64	77.74655	12.94637	77.74781	12.94543
0	77.74655	12.9464	77.74781	12.94546
156	77.74568	12.94734	77.74694	12.9464
185	77.74514	12.9488	77.7464	12.94786
175	77.74431	12.94968	77.74557	12.94874
182	77.7438	12.95088	77.74506	12.94994
163	77.37437	12.99547	77.37563	12.99453
148	77.743	12.95396	77.74426	12.95302
175	77.7424	12.95227	77.74366	12.95133
82	77.74193	12.95025	77.74319	12.94931
166	77.74086	12.94824	77.74212	12.9473
143	77.73938	12.94644	77.74064	12.9455
90	77.73886	12.94447	77.74012	12.94353
64	77.73884	12.73884	77.7401	12.7379
59	77.73839	12.94423	77.73965	12.94329
41	77.73839	12.94423	77.73965	12.94329
38	77.73839	12.94423	77.73965	12.94329
118	77.73535	12.94587	77.73661	12.94493
113	77.7343	12.94926	77.73556	12.94832
88	77.7343	12.9493	77.73556	12.94836
76	77.73432	12.94942	77.73558	12.94848
92	77.73402	12.94943	77.73528	12.94849
58	77.73372	12.94923	77.73498	12.94829
78	77.73353	12.9478	77.73479	12.94686
73	77.73328	12.94748	77.73454	12.94654
80	77.73334	12.94688	77.7346	12.94594
105	77.73407	12.94581	77.73533	12.94487

102	77.73423	12.94402	77.73549	12.94308
80	77.73418	12.94302	77.73544	12.94208
34	77.73448	12.94257	77.73574	12.94163
0	77.73448	12.94255	77.73574	12.94161
108	77.73484	12.73484	77.7361	12.7339
118	77.73581	12.94456	77.73707	12.94362
118	77.73612	12.94489	77.73738	12.94395
121	77.73694	12.94507	77.7382	12.94413
130	77.73824	12.94519	77.7395	12.94425
115	77.73975	12.94557	77.74101	12.94463

Appendix B – Water Quality Survey Data

Collection Info												
Date of Sampling	**Oct 11**	**Oct-11**	**Oct-11**	**Oct-11**	**Nov-11**	**Nov-11**	**Nov-11**	**Nov-11**	**Jan-31**	**Jan-31**	**Jan-31**	**Jan-31**
Time of collection	AM	AM	AM	9:00 AM	~12:00 PM	10:24 AM	9:40 AM	8:37 AM	8:15 AM	8:45 AM	9:15 AM	10:00 AM
Order of collection	3	2	4	1	4	3	2	1	S1	S2	S3	S4
Location	Bellandur Canal	Main Inlet	NE Outlet	SE Outlet	Main Inlet	Center	NE Outlet	SE Outlet	Center	NE Outlet	SE Outlet	NE Irrigation Canal
Sampling depth (approx.)	< 15 cm	< 15 cm	< 15 cm	< 15 cm	30 cm	30 cm	30 cm	30 cm	30 cm	30 cm	30 cm	30 cm
Comments	sampled from shore. grassy.	sampled from shore, s.side. muddy.	sampled from shore	sampled from shore	sampled from boat	sampled from boat	sampled from boat	sampled from boat	sample from boat	from boat, 50 ft from hyacinth	from boat, clear from weeds	from boat, hyacynth present
Parameters (in situ)												
D.O. (ppm)	2.8	3.4	2.0	2.8	6.3*	5.2*	3*	5.5*	1.8	2.9	2.2	1.8
Air Temperature (C)	30.0	26.0	28.5	30.0	32.5	26.0	26.0	21.0	21.0	21.0	23.0	na
Water Temperature (C)	26.0	26.0	27.0	26.0	21.0	24.0	26.0	23.0	22.0	23.0	22.0	na
Transparency (cm)	n/a	n/a	n/a	n/a	19	n/a	27	25	10	11	10	12
Apparent color (estimated)	green	Brown	brown	green	green	green	green	green	dark green	dark green	dark green	green
PH	8.0	7.5-8.0	7.5-8.0	8.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	N/a
Parameters (ex situ)												
Acidity, total (mg/l)	n/a	n/a	n/a	n/a	64.0	64.0	92.0	140.0	n/a	n/a	n/a	N/a
Alkalinity, total (mg/l)	n/a	n/a	n/a	n/a	336.0	336.0	332.0	348.0	n/a	n/a	n/a	N/a
Alkalinity as HCO3 (mg/l)	n/a	n/a	n/a	n/a	336.0	336.0	332.0	348.0	n/a	n/a	n/a	N/a
Ammonia (mg/l)	>3.0	1.0-3.0	>3.0	>3.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	N/a
BOD (mg/l)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	76.4	74.2	74.2	74.2

Chloride (mg/l)	n/a	n/a	n/a	n/a	108.0	104.0	100.0	96.0	160.0	170.0	170.0	170.0
Chlorine, residual (mg/l)	<0.2	<0.2	<0.2	<0.2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	N/a
Coliform bacteria	positive	positive	positive	positive	positive	positive	positive	positive	n/a	n/a	n/a	N/a
EC (microseimens/cm)	480	470	460	460	493	490	474	474	1460	1420	1470	1480
Flouride (mg/l)	<0.3	<0.3	<0.3	<0.3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	N/a
Hardness, Total (mg/l)	209.3	405.5*	213.6	383.7*	209.3	213.6	209.3	218.4	251.1	232.5	251.1	241.8
Date of Sampling	**Oct-11-01**	**Oct-11-01**	**Oct-11-01**	**Oct-11-01**	**Nov-11-01**	**Nov-11-01**	**Nov-11-01**	**Nov-11-01**	**Jan-31-02**	**Jan-31-02**	**Jan-31-02**	**Jan-31-02**
Location	Bellandur Canal	Main Inlet	NE Outlet	SE Outlet	Main Inlet	Center	NE Outlet	SE Outlet	Center	NE Outlet	SE Outlet	NE Irrigation Canal
Hardness, CaCO3 (mg/l)	136.0	136.0	132.0	132.0	128.0	136.0	124.0	140.0	148.8	158.1	158.1	158.1
Hardness, MgCO3 (mg/l)	n/a	n/a	n/a	n/a	78.4	85.3	77.6	81.3	78.4	62.7	78.4	70.6
Iron (mg/l)	~0.3	~0.3	~0.3	~0.3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Nitrate (mg/l)	0.11	0.63	nil	0.21	0.25	2.40	1.07	0.30	1.26	1.40	1.30	1.12
pH	7.71	7.64	7.61	7.68	7.70	8.18	7.55	7.64	7.74	7.68	7.70	7.64
Phosphate (mg/l)	n/a	n/a	n/a	n/a	>1.0	>1.0	>1.0	>1.0	1.5	1.5	15.06	14.74
Potassium (mg/l)	118*	125*	130*	115*	21.4	21.0	20.2	21.4	2.2	2.2	1.8	1.9
Sodium (mg/l)	1055*	1053*	907*	1046*	51.0	69.2	32.8	18.9	n/a	9	n/a	n/a
Sulphate (mg/l)	n/a	n/a	n/a	n/a	20.6	18.4	14.5	16.8	3.28	8.48	2.12	2.54
Total Diss. Solids (ppm)	355	349	332	335	347	365	371	358	1076	1246	1204	1178
Total Solids (ppm)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1148	1258	1218	1196
Total Susp. Solids (ppm)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	72	12	14	18
Turbidity (NTU)	50	25	50	n/a	50	50	25	50	27	25	24	25

* = possible interference/analytical error

Appendix C – Socio-Economic Survey Form

SOCIO-ECONOMIC STUDY OF VARTHUR LAKE AREA Primary Surveyor:

NAME OF RESPONDENT:___________________________ AGE:_____ M/F DATE:___________

VILLAGE/ ACREAGE/ RURAL NAME:_________________ VILLAGE TALUK:_______________

DEMOGRAPHIC INFORMATION

TOTAL NUMBER OF PERSONS IN HOUSEHOLD: ___
AGE 0-15 YEARS: ___ AGE 16-25 YEARS: ___ AGE 26-50 YEARS: ___ AGE 50+ YEARS: ___
OCCUPATION(S) OF HOUSEHOLD MEMBERS:
TOTAL HOUSEHOLD INCOME (Rs./yr):

DOMESTIC WATER USAGE (drinking, cooking, washing, bathing)

SOURCE:	BOREWELL	SPRING	LAKE	OTHER ________
QUANTITY USED				
WATER FILTER USED? YES/NO				

GROUND WATER RECHARGE

USE OF WATER	IS WELL COMMUNAL?	AGE OF WELL	DEPTH (m)	RE-DRILLED/ YEAR
DOMESTIC				
AGRICULTURE				

IRRIGATION

WATER SOURCE	CROP	AREA	PUMP CAPACITY	**HOURS OF USE/DAY**	**YIELD**	INCOME (Rs.)

HAS THE QUALITY OR QUANTITY OF CROPS CHANGED OVER THE YEARS? YES/ NO/ DON'T KNOW

AFFECTED CROP	QUAL	QUAN	YEAR 1	YIELD 1	YEAR 2	YIELD 2	YEAR 3	YIELD 3

OTHER COMMERCIAL USES (Cottage Industries)

ACTIVITY	WATER SOURCE	WATER USAGE	INCOME (Rs.)

WATER USAGE FOR LIVESTOCK

WATER SOURCE:	**TYPE OF ANIMAL**	**QTY OF ANIMALS**	**WATER CONSUMED**	**USE OF ANIMAL**	INCOME (Rs./Mo)
BOREWELL ___	COW/BUFFALO				
LAKE ___	SHEEP				
OTHER _______	POULTRY				
	OTHER _______				

LIVESTOCK FODDER

TYPE OF FODDER	**WATER SOURCE** (borewell, lake, spring, rain)	**QTY. OF FODDER (Kg/DAY)**
CUT / DRY GRASS		
HUSK (purchased)	**N/A**	
FRESH GRASS / PASTURE		
DUCKWEED		
HYACINTH		

FAMILY HISTORY

HOW LONG HAVE YOU/YOUR FAMILY LIVED IN THIS AREA? _________ YEARS

HAVE YOU WITNESSED THE QUALITY OF THE WATER IN THE LAKE CHANGE? YES/ NO FOR HOW LONG? ______

IF YES, HOW HAS THIS AFFECTED YOUR LIFESTYLE?

HAS THE PRIMARY OCCUPATION OF YOUR FAMILY CHANGED IN THE PAST 30 YEARS?   YES/ NO

IF YES, HOW?

AESTHETIC VALUE / RECREATION

ARE YOU CONCERNED ABOUT A DECLINE IN AESTHETIC VALUE OF THE LAKE (SIGHT/SMELL)? YES/ NO

HAS THIS DECLINE PREVENTED YOU FROM ENJOYING TRADITIONAL ACTIVITIES AROUND THE LAKE (eg. picnics)? YES/ NO

FISHING/ AQUACULTURE

GROWN OR CAUGHT	SPECIES	WATER SOURCE (IF GROWN) (lake, borewell, spring, surface)	YEILD	INCOME

HAVE YOU NOTICED A CHANGE IN THE NUMBER OR SIZE OF FARMED/ LAKE FISH?

NUMBER: (DECLINE/ INCREASE/ SAME/ DON'T KNOW)   SIZE: (DECLINE/ INCREASE/ SAME/ DON'T KNOW)

HAVE DIFFERENT TYPES OF LAKE FISH BECOME MORE/LESS COMMON? (YES/ NO/ DON'T KNOW)

IF SO, WHICH TYPE?

WATERFOWL

HAVE YOU NOTICED ANY CHANGE IN THE OVERALL NUMBER OF BIRDS? (DECLINE/ INCREASE/ SAME/ DON'T KNOW)

HAVE DIFFERENT TYPES OF BIRDS BECOME MORE/LESS COMMON? (YES/ NO/ DON'T KNOW)   IF SO, WHAT TYPE?

SPIRITUAL VALUE

DOES THE LAKE PLAY A ROLE IN RELIGIOUS PRACTICES? (YES/ NO/ DON'T KNOW)

SUBMERSION OF IDOLS (eg. Ganesh)? (YES/ NO/ DON'T KNOW)

HEALTH EFFECTS

HAS THE NUMBER OF MOSQUITOS CHANGED OVER THE YEARS THAT YOU HAVE LIVED HERE?

(INCREASE/ DECREASE/ SAME/ DON'T KNOW)

DOES YOUR FAMILY SUFFER FROM ANY DISEASES (RELATED TO WATER QUALITY)? (YES/ NO/ DON'T KNOW)

IF YES, PLEASE LIST:

COMMUNITY INVOLVEMENT IN RESTORATION

WOULD YOU LIKE YOUR CHILDREN TO REMAIN HERE AND CONTINUE USING THE LAKE? (YES/ NO/ DON'T KNOW)

WOULD YOU BE WILLING TO ASSIST WITH A PLAN TO REHABILITATE THE LAKE? (YES/ NO/ DON'T KNOW)

Annexure 10

Conservation of Bellandur Wetlands: Obligation of Decision Makers to Ensure Intergenerational Equity

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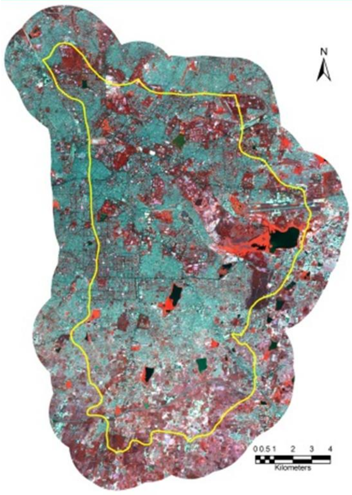

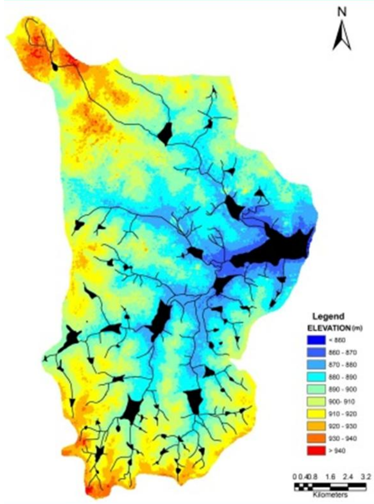

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CONSERVATION OF BELLANDUR WETLANDS: OBLIGATION OF DECISION MAKERS TO ENSURE INTERGENERATIONAL EQUITY

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Content

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CONSERVATION OF BELLANDUR WETLANDS: OBLIGATION OF DECISION MAKERS TO ENSURE INTERGENERATIONAL EQUITY

Executive Summary:

Bellandur lake catchment is located between 77° 35′ west and 77° 45′ east and latitude 12° 50′ south and 13° 00′ north (The Survey of India topographic map 57 H/9, scale: 1:50,000). The overall catchment area is about 287.33 sq. km with a water spread area of 361 ha. The terrain of the region is relatively flat and sloping towards south of Bangalore city. Relative slope of the region is found to be very gentle to gentle slope. The relative contour height is 930 m above mean sea level and the lowest is 880 m. The height is found to be 870 m above mean sea level near the tank. The drainage pattern is dendrite type and is characterized by gneiss and gneiss granite rocks. This water body has been a lifeline sustaining the livelihood of settlements in the catchment and command areas. Agriculture (rice and vegetables) practiced since many centuries in the downstream continues even today. Three main streams join the tank, which form the entire watershed. Three chain of lakes in the upstream joins Bellandur lake with a catchment area of about 148 square kilometres (14979 Hectares) and overflow of this lake gets into Varthur lake and from where it flows down the plateau and joins Pinakini river basin.

One of the streams originates at the northern part of the region, Jayamahal and known as eastern stream. Another stream originates from the central part of the city, Krishna Raja Market and covers the central part of the region before joining the tank and is called the central stream. Another stream commands southwestern part of the region called the western stream. Further, before the confluence with Bellandur Tank, all the streams come across two to three tanks. The rainfall data is available for the last 100 to 110 years. Rainfall varies from 725.5 mm to 844.8 mm. The district receives 51 % of the total annual rainfall in the southwest monsoon period, i.e. June to September. The average annual rainfall in the catchment was 859 mm in 1999. April is usually the hottest month with the mean daily maximum and minimum temperature of 33.4° C and 21.2° C respectively. December is generally the coolest month with the mean daily maximum and minimum temperature of 25° C and 15.3° C respectively. The temperature drops down to 8° C during January nights. Relative humidity is high from June to October (80 to 85 %). Thereafter, it decreases and from February to April becomes 25 to 35%. The relative humidity in the morning is higher than in the evening, giving rise to the formation of fog.

Unplanned rapid urbanisation during post 2000 witnessed large scale conversion of watershed area of the lake to residential and commercial layouts. This has altered the hydrological regime and enhanced the silt movement in the catchment. Declining vegetation cover has lowered water yield in the catchment, affecting the groundwater recharge. Alterations in ecological integrity is evident from reduced water yield, flash floods, contaminated water, obnoxious odour, copious growth of invasive floating macrophytes,

disappearance of native fish species, breeding ground for mosquito and other disease vectors, etc. A major portion of untreated city sewage (500+ million liters per day) is let into the lake, beyond the neutralizing ability of the lake, which has hampered the ecological functioning of the lake.

Significance of wetlands: Wetlands are lands transitional between terrestrial and aquatic eco-systems where the water table is usually at or near the surface or the land is covered by shallow water. **Wetlands are the most productive and biologically diverse but very fragile ecosystems. They function as kidneys of landscape due to remediation of contaminants (which include nutrients, heavy metals, etc.). These fragile ecosystems are vulnerable to even small changes in their biotic and abiotic factors. In recent years, there has been concern over the continuous degradation of wetlands due to unplanned developmental activities** (Ramachandra, 2002)**.**

Policy and legislative measures for Wetlands conservation in India are:

- The Indian Forest Act - 1927
- Forest (Conservation Act) - 1980
- Wildlife (Protection) Act - 1972
- Water (Prevention and Control of Pol1ution)Act - 1974
- Water (Prevention and Control of Pollution) Act - 1977
- Environmental (Protection) Act - 1986
- Wildlife (Protection) Amendment Act - 1991
- National Conservation Strategy and Policy Statement on Environment and I Development - 1992
- National Policy And Macro level Action Strategy on Biodiversity-1999
- Biological Diversity Act, 2002, areas rich in biodiversity, cultural importance, etc.
- Wetlands (Conservation and Management) rules 2010, Government of India

The proposed plan to set up SEZ by KIADB needs to be stopped and wetland to be restored considering

Activities	Norms
Location of the project (SEZ by Karnataka Industrial Areas Development Board (KIADB)) **in the valley zone**	This is contrary to sustainable development as the natural resources (lake, wetlands) get affected due to this decision. Eventually this kills the lake. This reflects the ignorance of the administrative machinery on the importance of ecosystems and the need to protect valley zones
The proposed activity is in valley zone	To be protected considering ecological function And are 'NO DEVELOPMENT ZONES' as per

	CDP 2005, 2015
Location of SEZ in flood prone zone of the lake and in wetland - 30 m buffer zone of the water body is to be no development zone	In case of water bodies a 30.0 m buffer of 'no development zone' is to be maintained around the lake (as per revenue records) ✓ As per BDA, RMP 2015 ✓ section 17 of KTCP Act, 1961 and sec 32 of BDA Act, 1976 ✓ Wetlands (Conservation and Management) rules 2010, Government of India
Alterations in topography	Adjacent localities would be vulnerable to floods
Removal of rajakaluve (storm water drain) and gradual encroachment of rajakaluve as well as lake bed	Removal of lake connectivity enhances the episodes of flooding and associated disasters The Hon'ble Supreme Court in Civil appeal number 1132/2011 at SLP (C) 3109/2011 on January 28,2011 has ex-pressed concern regarding encroachment of common property resources, more particularly lakes and it has directed the state governments for removal of encroachments on all community lands. Eviction of encroachment: Need to be evicted as per Karnataka Public Premises (eviction of unauthorised occupants) 1974 and the Karnataka Land Revenue Act, 1964.
The proposed action by KIADB to set up SEZ violates Hon'ble High Court of Karnataka's verdict to protect, conserve, rehabilitate and wisely use lakes and their watersheds in Bangalore all lakes in Karnataka and their canal networks (about 38,000)	High Court of Karnataka (WP No. 817/2008) • Protects lakes across Karnataka, • Prohibits dumping of Garbage and Sewage in Lakes • Lake area to be surveyed and fenced and declare a no development zone around lakes • Encroachments to be removed. • Forest department to plant trees in consultation with experts in lake surroundings and in the watershed region • Member Secretary of state legal services authority to monitor implementation of the above in coordination with Revenue and Forest Departments. • Also set up district lake protection committees

Additional 10000 to 14000 vehicles	Increases traffic bottleneck in the region and air pollution (with the increase in density of vehicles)
Increase in vehicular traffic and enhanced pollutants	Traffic congestion (due to additional vehicle movement). The density of traffic would increase, the road's current level of service (LOS) is under category **C** , the increase in vehicles upto 14000+ would worsen the traffic condition with LOS under category **F.** enhanced levels of vehicular pollutants; likely increase in respiratory diseases;
Water shortage The estimate shows that SEZ requires 4587 Kilo Liters per day (4.58 MLD – Million liters per day)	Bangalore is already experiencing severe water shortages as water yield in rivers (Cauvery, etc.) has come down due to large scale land cover changes. Neither Cauvery, T G Halli nor groundwater can sustain Bangalore's growing water demand. BWSSB has not given NOC and has indicated inability to supply such huge quantity of water on regular basis.
Pathetic water scenario and insufficient drinking water in Bangalore	At the 4% population growth rate of Bangalore over the past 50 years, the current population of Bangalore is 8.5 million (2011). Water supply from Hessarghatta has dried, Tippegondahanally is drying up, the only reliable water supply to Bangalore is from Cauvery with a gross of 1,410 million liters a day (MLD). There is no way of increasing the drawal from Cauvery as the allocation by the Cauvery Water Disputes Tribunal for the entire urban and rural population in Cauvery Basin in Karnataka is only 8.75 TMC ft (one thousand million cubic – TMC ft equals 78 MLD), Bangalore city is already drawing more water—1,400 MLD equals 18 TMC—than the allocation for the entire rural and urban population in Cauvery basin.

Ecological and Environmental Implications:

- *Land use change:* Conversion of watershed area especially valley regions of the lake to paved surfaces would alter the hydrological regime.
- *Loss of Drainage Network: Removal of drain (Rajakaluve) and reducing the width of the drain would flood the surrounding residential as* the interconnectivities among lakes are lost and there are no mechanisms for the excessive storm water to drain and thus the water stagnates flooding in the surroundings.
- *Alteration in landscape topography:* This activity alters the integrity of the region affecting the lake catchment. This would also have serious implications on the storm water flow in the catchment. The dumping of construction waste along the lakebed and lake has altered the natural topography thus rendering the storm water runoff to take a new course that might get into the existing residential areas. Such alteration of topography would not be geologically stable apart from causing soil erosion and lead to siltation in the lake.
- *Loss of Shoreline:* The loss of shoreline along the lakebed results in the habitat destruction for most of the shoreline birds that wade in this region. Some of the shoreline wading birds like the Stilts, Sandpipers; etc will be devoid of their habitat forcing them to move out such disturbed habitats. It was also apparent from the field investigations that with the illogical land filling and dumping taking place in the Bellandur lakebed, the shoreline are gobbled up by these activities.
- *Loss of livelihood:* Local people are dependent on the wetlands for fodder, fish etc. estimate shows that wetlands provide goods and services worth Rs 10500 per hectare per day (Ramachandra et al., 2005).

Decision makers need to learn from the similar historical blunder of plundering ecosystems as in the case of Black Swan event (http://blackswanevents.org/?page_id=26) of evacuating half of the city in 10 years due to water scarcity, contaminated water, etc. or abandoning of Fatehpur Sikhri and fading out of Adil Shahi's Bijapur, or ecological disaster at *Easter Island or* Vijayanagara empire

It is the responsibility of Bangalore citizens (for intergenerational equity, sustenance of natural resources and to prevent human-made disasters such as floods, etc.) to stall the irrational conversion of land in the name of development and restrict the decision makers taking the system (ecosystem including humans) for granted as in the case of Bellandur wetlands by KIADB.

Keywords: Wetlands, Urbanisation, wetlands, intergenerational equity, Bellandur

CONSERVATION OF BELLANDUR WETLANDS: OBLIGATION OF DECISION MAKERS TO ENSURE INTERGENERATIONAL EQUITY

Introduction

Wetlands constitute vital components of the regional hydrological cycle, highly productive, support exceptionally large biological diversity and provide a wide range of ecosystem services, such as food and fibre; waste assimilation; water purification; flood mitigation; erosion control; groundwater recharge; microclimate regulation; enhance aesthetics of the landscape; support many significant recreational, social and cultural activities, besides being a part of our cultural heritage. It was acknowledged that most of urban wetlands are seriously threatened by conversion to non-wetland purposes, encroachment of drainage, through landfill, pollution (discharge of domestic and industrial effluents, disposal of solid wastes), hydrological alterations (water withdrawal and inflow changes), and over-exploitation of their natural resources resulting in loss of biodiversity and disruption in goods and services provided by wetlands (Ramachandra, 2002; 2009a,b; Ramachandra et al., 2012a,b). This report addresses the implications of setting up SEZ in an ecologically fragile wetlands. Also, provides insights to the strategies considering the current trends in aquatic ecosystem conservation, restoration and management including the hydrological and the biophysical aspects, peoples' participation and the role of non-governmental, educational and governmental organisations' needs for the restoration, conservation and management.

Urbanisation is a form of metropolitan growth that is a response to often bewildering sets of economic, social, and political forces and to the physical geography of an area. It is the increase in the population of cities in proportion to the region's rural population. The 20th century is witnessing "the rapid urbanisation of the world's population", as the global proportion of urban population rose dramatically from 13% (220 million) in 1900, to 29% (732 million) in 1950, to 49% (3.2 billion) in 2005 and is projected to rise to 60% (4.9 billion) by 2030. Urban ecosystems are the consequence of the intrinsic nature of humans as social beings to live together (Ramachandra et al., 2012a; 2012b; Ramachandra and Kumar, 2008). The process of urbanisation contributed by infrastructure initiatives, consequent population growth and migration results in the growth of villages into towns, towns into cities and cities into metros. Urbanisation and urban sprawl have posed serious challenges to the decision makers in the city planning and management process involving plethora of issues like infrastructure development, traffic congestion, and basic amenities (electricity, water, and sanitation), etc. (Ramachandra and Shwetmala, 2009; Ramachandra, 2009c). Land use analyses show 584% growth in built-up area during the last four decades with the decline of vegetation by 66% and water bodies by 74%. Analyses of the temporal data reveals an increase in urban built up area of 342.83% (during 1973 to 1992), 129.56% (during 1992 to 1999), 106.7% (1999 to 2002), 114.51% (2002 to 2006) and 126.19% from 2006 to 2010 (Ramachandra et al., 2012a). The major implications of unplanned urbanisation are:

- **Loss of wetlands and green spaces:** Urbanisation has telling influences on the natural resources such as decline in green spaces (vegetation) including wetlands and / or depleting groundwater table (Ramachandra, 2002).
- **Floods:** Common consequences of urban development are increased peak discharge and frequency of floods as land is converted from fields or woodlands to roads and parking lots, it loses its ability to absorb rainfall. Conversion of water bodies to residential layouts has compounded the problem by removing the interconnectivities in an undulating terrain. Encroachment of natural drains, alteration of topography involving the construction of high rise buildings, removal of vegetative cover, reclamation of wetlands are the prime reasons for frequent flooding even during normal rainfall post 2000 (Ramachandra et al., 2012a).
- **Decline in groundwater table:** Studies reveal the removal of water bodies has led to the decline in water table. Water table has declined to 300 m from 28 m over a period of 20 years after the reclamation of lake with its catchment for commercial activities. Also, groundwater table in intensely urbanized area such as Whitefield, etc. has now dropped to 400 to 500m (Ramachandra et al., 2002).
- **Heat island:** Surface and atmospheric temperatures are increased by anthropogenic heat discharge due to energy consumption, increased land surface coverage by artificial materials having high heat capacities and conductivities, and the associated decreases in vegetation and water pervious surfaces, which reduce surface temperature through evapotranspiration (Ramachandra and Kumar 2009).
- **Increased carbon footprint**: Due to the adoption of inappropriate building architecture, the consumption of electricity has increased in certain corporation wards drastically. The building design conducive to tropical climate would have reduced the dependence on electricity. Higher energy consumption, enhanced pollution levels due to the increase of private vehicles, traffic bottlenecks have contributed to carbon emissions significantly. Apart from these, mismanagement of solid and liquid wastes has aggravated the situation (Ramachandra and Shwetmala, 2009; Ramachandra et al., 2012a; 2012b).

Bangalore Lakes and Bellandur

Greater Bangalore is the administrative, cultural, commercial, industrial, and knowledge capital of the state of Karnataka, India with an area of 741 sq. km. and lies between the latitude 12°39'00'' to 13°13'00'' N and longitude 77°22'00'' to 77°52'00'' E (Figure 1). Bangalore city administrative jurisdiction was redefined in the year 2006 by merging the existing area of Bangalore city spatial limits with 8 neighbouring Urban Local Bodies (ULBs) and 111 Villages of Bangalore Urban District. Bangalore has grown spatially more than ten times since 1949 (~69 square kilometres to 716 square kilometres) and is the fifth largest metropolis in India currently with a population of about 9 million (Ramachandra and Kumar, 2008; Ramachandra et al., 2012a; 2012b). Bangalore city population has increased enormously from 65,37,124 (in 2001) to 95,88,910 (in 2011), accounting for 46.68 % growth in a decade. Population density has increased from as 10732 (in 2001) to 13392 (in 2011) persons per sq. km. The per capita GDP of Bangalore is about $2066, which is considerably low with limited expansion to balance both environmental and economic needs.

Bangalore once a garden city, became garbage city and now in the verge of becoming a dead city due to consistent mismanagement of natural resources. The transition from garden city to dead city has taken place because of the unplanned rapid urbanisation involving concentrated growth. Bangalore witnessed the software industry boon during early 2000. Due to this, there is drastic increase in population with the enhanced demand for water and electricity. Apart from this, lack of infrastructure is evident from traffic bottlenecks, etc.

About 80% of water supplied as demand turns as liquid waste either as domestic waste water or industrial waste water that contain high amounts of toxic, organic, inorganic wastes. Most of the sewage and wastewater generated is discharged directly into storm water drains that ultimately link to water bodies. The undulating terrain in the region facilitated the creation of a large number of tanks in the past, providing for the traditional uses of irrigation, drinking, fishing and washing. This led to Bangalore having hundreds of such water bodies through the centuries. In 1961, the number of lakes and tanks in the city stood at 262. A large number of water bodies (locally called lakes or tanks) in the City had ameliorated the local climate, and maintained a good water balance in the neighborhood. Since Bangalore is located on a ridge with natural water courses along the three directions of the Vrishabhavaty, Koramangala-Challaghatta (K&C) and Hebbal-Nagavara valley systems (Figure 2), these water courses are today being used for the transport and disposal of the city's sewage. The shortfall or lack of sewage treatment facilities have contaminated the majority of surface and ground waters.

The Koramangala Chalaghatta valley (Figure 2, Figure 3), tributary of Periayar River, located towards the south east of Greater Bangalore. The following are lakes along the valley: Varthur, Bellandur, Agaram, Puttenahalli, Chalaghatta, Madivala, Sarakki, Hhulimavu, Lalbhag, Bayappanahalli, Vibuthipura, Kundalhalli, Ibburu, Ulsoor, Beguru, etc.

Bellandur Lake located in the south-eastern portion of Greater Bangalore is towards the upstream of Varthur lake, the drainage network for Bellandur lake has 3 drainage network:

i. In the north originating at Jayamahal covering eastern portion of the City;
ii. Drains originating from the central part near K R Market covering the central portion of the City;
iii. Originating from the southern part of the city near Hulimavu.

Bellandur lake has a history over 130 years, post 1980's the drainage chains feeding the lakes were broken due to unchecked industrial, residential as well as commercial development in the region, the lands near the lake were allotted for development of ring road post 1990 during which there was industrial development

The Bellandur catchment extends from $12^0$50'N to $13^0$1'47"N in latitude and $77^0$33'14" E to $77^0$41'1"E in longitude with an area of 171.17 $km^{2.}$. The Bellandur Lake itself encompasses an area of 338.29 hectares. Bellandur lake catchment and its drainage network are represented in figure 3. The false colour satellite composite of Bellandur catchment (Figure 4) highlight the heterogeneity of the landscape. The digital elevation model (figure 4) depicts the undulating terrain with interconnected water bodies. The terrain altitude gradually varies from City center (North western part of catchment) 962m to 850m above MSL at the lake. Population in the catchment given in Table 1 show an increase from 1425105 (1991) to 3410383 (2011)

The population density (figure 5) in the Bellandur catchment has shown a sharp increase from 100 persons per hectare (2001) to over 141.96 (2011) and 750 persons per hectare (in 2011) in certain wards, mainly due to migration.

Table 1: Population of all the wards under Bellandur catchment

Year	Population	Population density persons / ha
1991	1425105	59.32
2001	2417744	100.63
2011	3410383	141.96

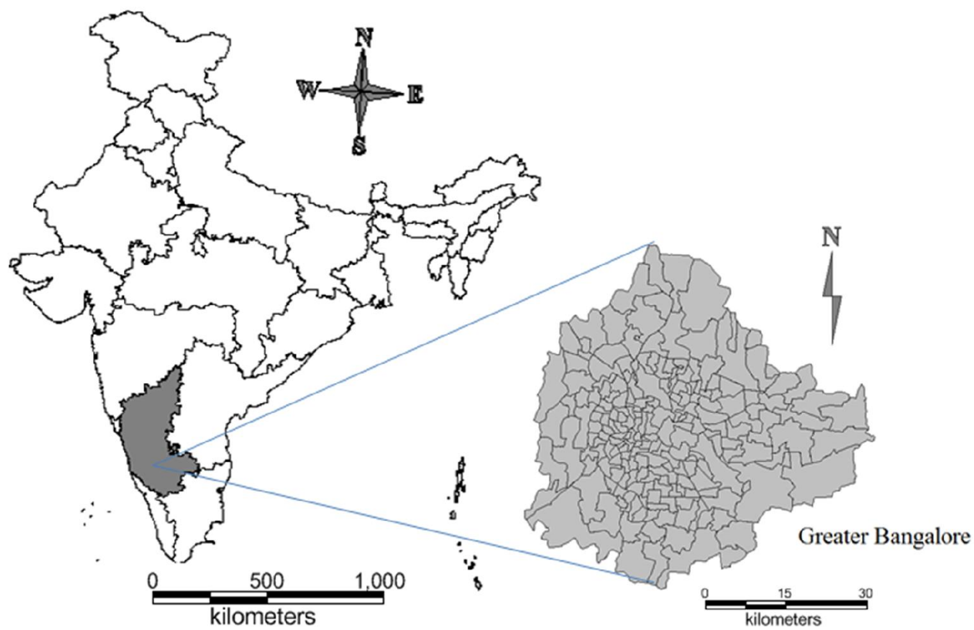


Figure 1: Greater Bangalore

Figure 2: Lake Series in Bangalore

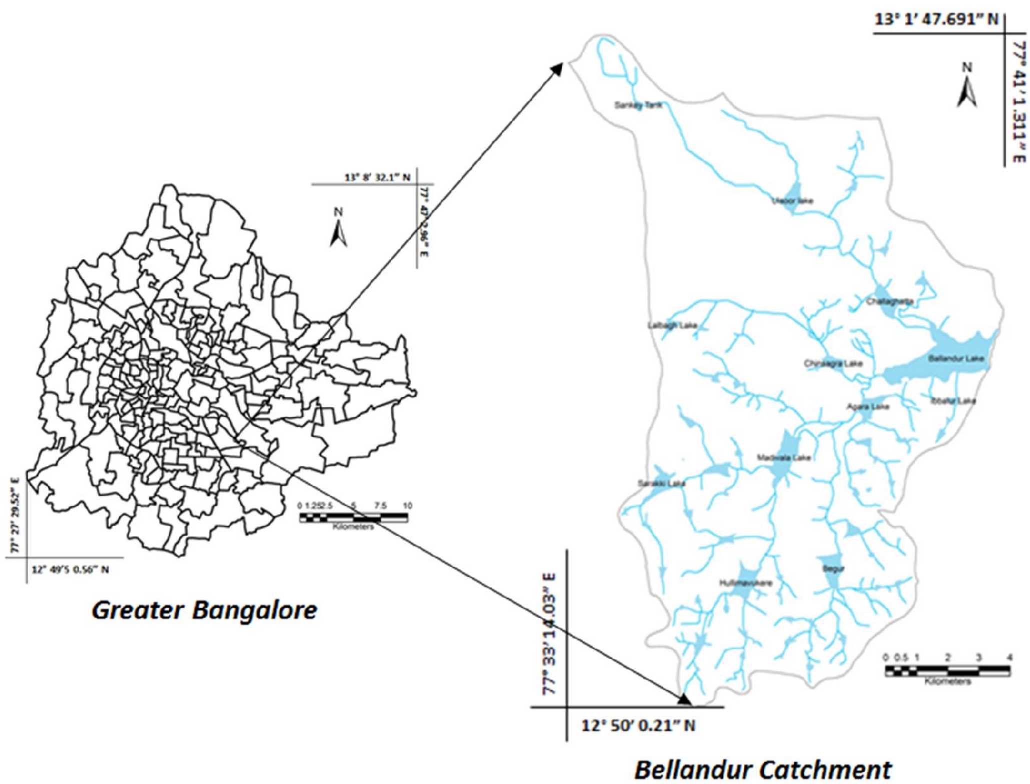


Figure 3: Bellandur Drainage Network

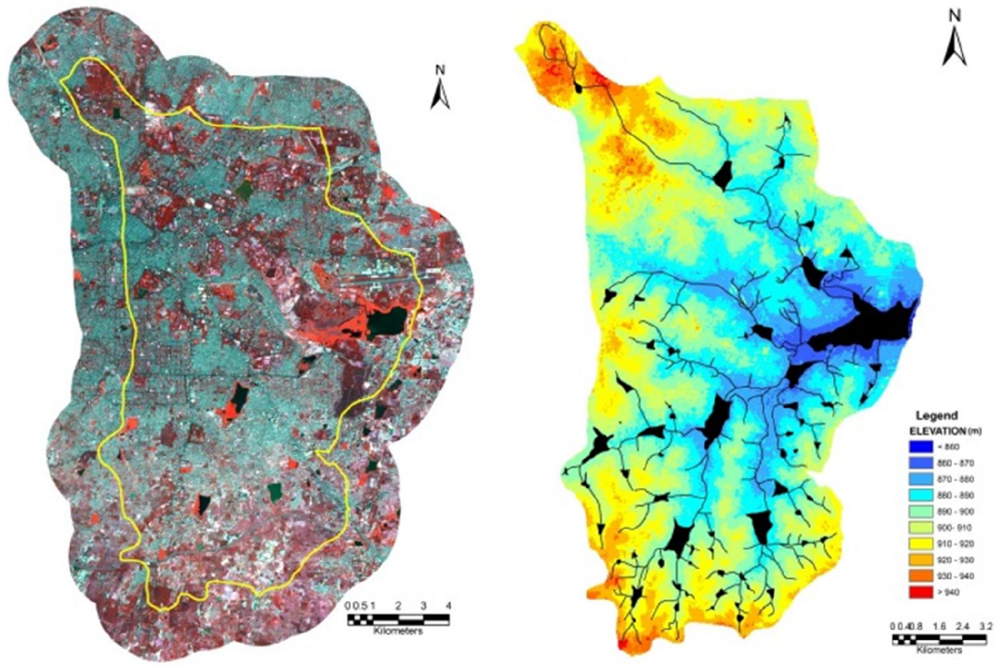


Figure 4: FCC and DEM

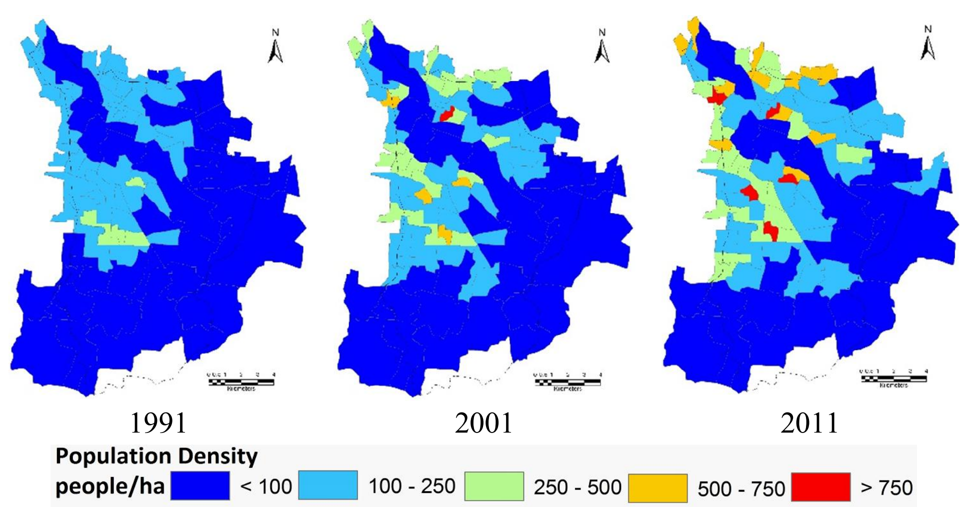


Figure 5: Population Density

Threats faced by Wetlands in Bangalore: Greater Bangalore had 207 water bodies in 1973 (Figure 6), which declined to 93 (in 2010). The rapid development of urban sprawl has many potentially detrimental effects including the loss of valuable agricultural and eco-sensitive (e.g. wetlands, forests) lands, enhanced energy consumption and greenhouse gas emissions from increasing private vehicle use (Ramachandra and Shwetmala, 2009). Vegetation has decreased by 32% (during 1973 to 1992), 38% (1992 to 2002) and 63% (2002 to 2010).

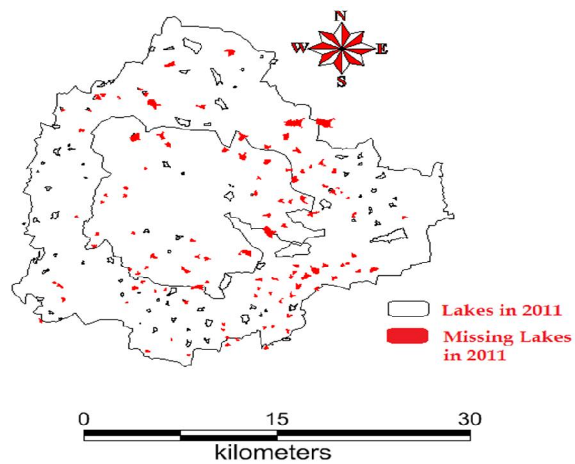


Figure 6: Lakes encroached by land mafia

Disappearance of water bodies or sharp decline in the number of water bodies in Bangalore is mainly due to intense urbanisation and urban sprawl. Many lakes (54%) were encroached for illegal buildings. Field survey of all lakes (in 2007) shows that nearly 66% of lakes are sewage fed, 14% surrounded by slums and 72% showed loss of catchment area. Also, lake catchments were used as dumping yards for either municipal solid waste or building debris (Ramachandra, 2009a; 2012a). The surrounding of these lakes have illegal constructions of buildings and most of the times, slum dwellers occupy the adjoining areas. At many sites, water is used for washing and household activities and even fishing was observed at one of these sites. Multi-storied buildings have come up on some lake beds that have totally intervene the natural catchment flow leading to sharp decline and deteriorating quality of water bodies. This is correlated with the increase in built up area from the concentrated growth model focusing on Bangalore, adopted by the state machinery, affecting severely open spaces and in particular water bodies. Some of the lakes have been restored by the city corporation and the concerned authorities in recent times. Threats faced by lakes and drainages of Bangalore:

1) Encroachment of lakebed, flood plains, and lake itself;
2) Encroachment of rajakaluves / storm water drains and loss of interconnectivity;
3) Lake reclamation for infrastructure activities;
4) Topography alterations in lake catchment;
5) Unauthorised dumping of municipal solid waste and building debris;
6) Sustained inflow of untreated or partially treated sewage and industrial effluents;
7) Removal of shoreline riparian vegetation;
8) Pollution due to enhanced vehicular traffic.

These anthropogenic activities particularly, indiscriminate disposal of industrial effluents and sewage wastes, dumping of building debris have altered the physical, chemical as well as biological integrity of the ecosystem. This has resulted in the ecological degradation, which is evident from the current ecosystem valuation of wetlands. Global valuation of coastal wetland ecosystem shows a total of 14,785/ha US$ annual economic value. Valuation of relatively pristine wetland in Bangalore shows the value of Rs. 10,435/ha/day while the polluted wetland shows the value of Rs.20/ha/day (Ramachandra et al., 2005). In contrast to this, Varthur, a sewage fed wetland has a value of Rs.118.9/ha/day (Ramachandra et al., 2011). The pollutants and subsequent contamination of the wetland has telling effects such as disappearance of native species, dominance of invasive exotic species (such as African catfish, water hyacinth, etc.), in addition to profuse breeding of disease vectors and pathogens. Water quality analyses revealed of high phosphates (4.22-5.76 ppm) levels in addition to the enhanced BOD (119-140 ppm) and decreased DO (0-1.06 ppm). The amplified decline of ecosystem goods and services with degradation of water quality necessitates the implementation of sustainable management strategies to recover the lost wetland benefits.

SEZ in Bellandur Wetlands: Irrational decision of setting up SEZ at Bellandur wetland would affect the lake. The Mixed Use Development Project - SEZ (figure 6) is proposed along Sarjapur Road in a wetland between Bellandur and Agara Lake, extending from 77°38’28.96” E to 77°38’57.99” E of Longitude and 12°55’24.98” N to 12°55’44.43” N of Latitude with an area of 33 hectare. The proposal of the project is to construct residential areas, offices, and retail and hotel buildings in this area.

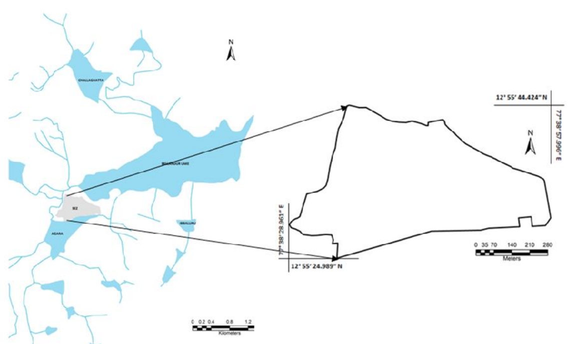


Figure 6: SEZ

Significance of the Region:

1. Wetlands with remediation functional ability (function as *kidneys* of the landscape). Removal of wetlands will affect the functional ability of the lake and would result in the death of Bellandur lake;
2. Considering severe water shortage to meet the drinking water requirement in Bangalore, there is a need to remove deposited silt in the Bellandur lake, which will enhance the storage capacity and in turn helps in mitigating the water requirement;
3. Wetlands aid in recharging groundwater as soil are permeable;

4. Belanduru lake provide food (fish, etc.) and fodder;
5. Retain the excess water and prevent flooding in the vicinity;
6. Large number of farmers in the downstream is dependent on Belanduru lake water for agriculture, vegetable, etc.

Realizing these, BDA has aptly earmarked these regions in CDP 2005 for "ENVIRONMENT PROTECTION AND HERITAGE CONSERVATION". The masterplan includes the protection of valleys and tanks as part of the vision and enforcing the ban on construction over protected areas. CDP 2015: As per CDP 2015, valley region are "No Development Zone"

1) In case of water bodies a 30.0 m buffer of 'no development zone' is to be maintained around the lake (as per revenue records) with exception of activities associated with lake and this buffer may be taken into account for reservation of park while sanctioning plans.
2) If the valley portion is a part of the layout/ development plan, then that part of the valley zone could be taken into account for reservation of parks and open spaces both in development plan and under subdivision regulations subject to fulfilling section 17 of KTCP Act, 1961 and sec 32 of BDA Act, 1976.
3) Rajakaluve/ storm water drains categorized into 3 types namely primary, secondary and tertiary. These drains will have a buffer of 50, 25 and 15m (measured from the centre of the drain) respectively on either side. No activities shall be permitted in the buffer zone.

SEZ in the wetland and assessment of damages

Drainage network and Land cover of the wetland region were mapped using temporal Google earth (http://www.googleearth.com) for the period 2007 to 2012, and the changes in land use and drainages (network as well as width of the channel/drain). Figure 7 depicts drastic land use changes evident from the conversion of wetland to open land (at the proposed SEZ site) during 2000 to 2012. Temporal change analysis done for the region is given in Table 1. Figure 8 illustrates land use changes between 2007 and 2012. Wetlands have decreased from 32.8 Ha to 5.95 Ha whereas the Open land (Conversion of Wetlands to SEZ Construction site) has increased from 0.6 Ha to 27.46 Ha.

Table1: Change in Land use

Year	Wetland in Ha	Open land in Ha
2007	32.80	0.60
2008	30.22	3.18
2009	24.31	9.10
2010	19.17	14.23
2011	16.63	16.77
2012	5.95	27.46

2000	2012

Figure 7: land use in the SEZ region during 2000 and 2012

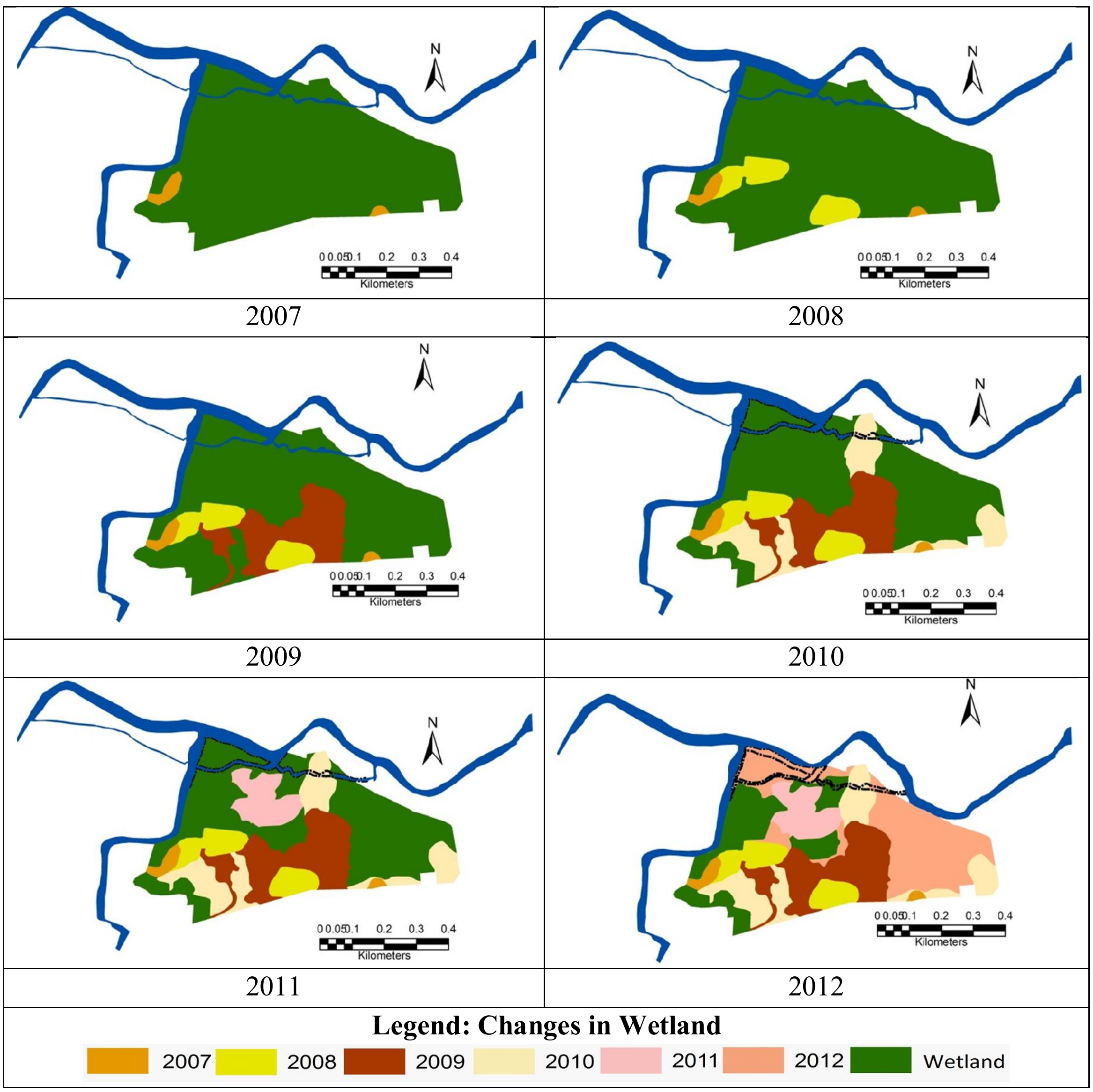


Figure 8: Change in wetland between 2007 to 2012

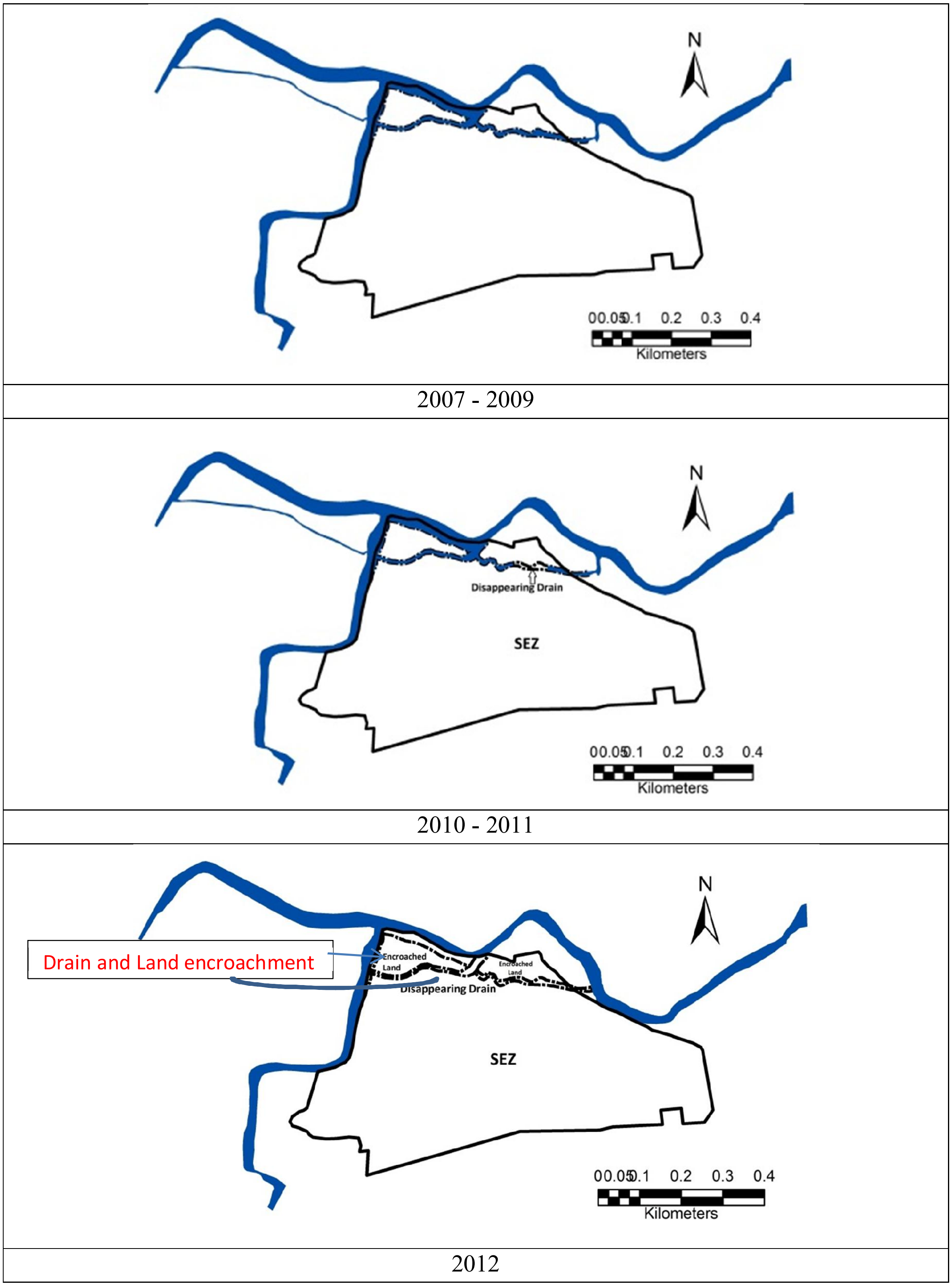


Figure 9: Change in drain network

The change in drainage pattern between 2007 and 2012 is shown in figure 9 and table 2 gives the extent of encroachment of drainage and wetland.

Table2: Encroachment of drainage and wetland

Description	Area in Ha	Length in m
Altered drain width and encroachment	0.5	390
Encroached a drain	0.56	586
Encroached Wetland	2.06	-

Effect on vehicle traffic in the region: Figure 10 gives the existing road network (Main Roads) in the region; the length between 2 signals on either side of the SEZ is approximately 1.88 km (Google Earth) the width of road is 15.5 m, 4 lanes and two ways. The capacity of urban roads is listed in table 3.

Table 3: Capacity of urban Roads as per IRC

No. of Traffic Lanes and width	Traffic Flow	Capacity in PCU per hour for traffic condition		
		Roads with no frontage access, no standing vehicles, very little cross traffic	Roads with frontage access, but no standing vehicle and high capacity intersections	Roads with free frontage access, parked vehicles and heavy cross traffic
Two lane 7.0-7.5 m	One way	2400	1500	1200
Two lane 7.0-7.5 m	Two way	1500	1200	750
Three lane 10.5 m	One way	3600	2500	2000
Four lane 14.0 – 15.5 m	One way	4800	3000	2400
Four lane 14.0 – 15.5 m	Two way	4000	2500	2000
6 lane 21 m	Two way	6000	4200	3600

Source: S.K.Khanna & C.E.G.Justo, (2005). Highway Engineering, 8th Edition, Table 5.8,pp 185-211

Road maximum capacity: As per IRC (*http://*www.irc.org.in - Indian Road Congress) for a 4 lane road with traffic flow on both sides, for roads with no frontage access, no standing vehicles, very little cross traffic (intersection) capacity is 4000 PCU/hour (PCU-Passenger Car Unit). The capacity for Sarjapur road was estimated to be **3500 PCU/hour**, on either side of the road, with average length of a PCU as 4 m at an average speed of 45 kmph and driver reaction time of 0.7 seconds. Along sarjapur road, during the highest peak hour traffic, the number of vehicles is approximately 2000 PCU's/hour. With this the level of service (LOS) based on the **ratio of observed to maximum capacity** is

$$V/C = 2000/3500 = 0.571$$

For the ratio of 0.57, the current Level of service in under category **"C" as per Table 4.**

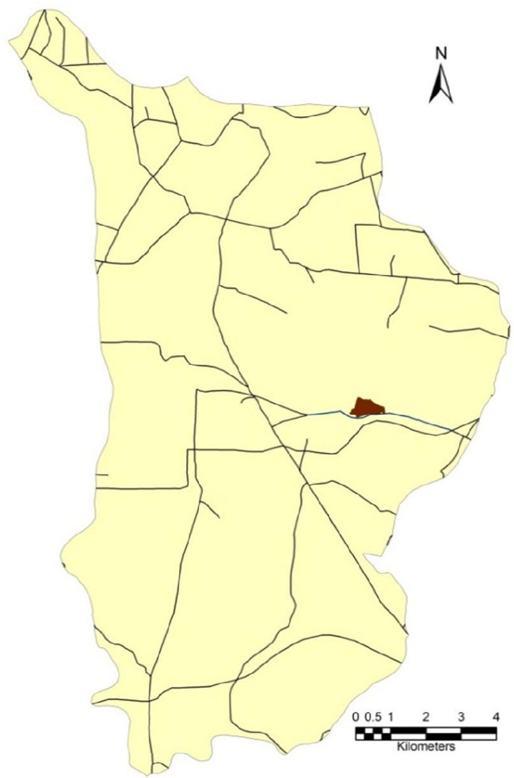


Figure 10: Bellandur Catchement Road Network

Table 4: Category of Roads based on traffic and service

V/C ratio	LOS	Performance
0.0 – 0.2	A	Excellent
0.2 – 0.4	B	Very Good
0.4 – 0.6	**C**	**Average / Fair**
0.6 – 0.8	D	Poor
0.8 – 1.0	E	Very Poor
1.0 – 1.2	**F**	**Very Very Poor**

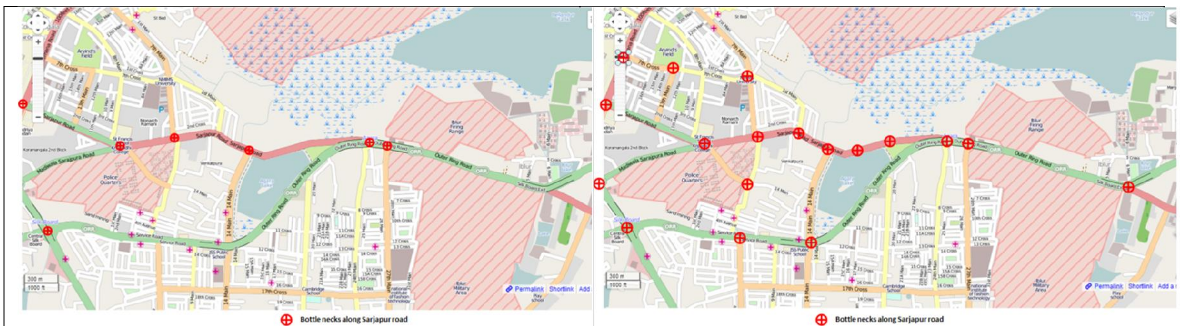
Source: IRC

The SEZ has a capacity of over 14000 Car units, in addition to this because of the Floating population that travel in their own mode of transit yields an additional vehicular population.

With added 14000 cars, assuming 8 hour of traffic in a day, the density of car units would increase by **1750** units per hour increasing the traffic to **3750PUC's/hour**. Then the V/C ratio is

$$V/C = (2000 + 1750) / 3500 = 1.07$$

The ratio of 1.07 is equivalent to an LOS category of **"F"** indicating very very poor traffic conditions indicating higher chances of traffic congestion. The current bottle necks along the Sarjapur Road is as depicted in figure 10(a) and likely bottleneck due to the addition of 14000+ vehicles, is depicted in figure 10(b). Traffic bottlenecks also have higher levels of pollutants such as particulate matter, CO_2, NO_x, SO_2.



a. Existing bottlenecks	b. Likely bottlenecks after SEZ

Figure 11: Traffic bottlenecks

Major Violations:

i). Development in the wetland - Violation of CDP 2015 as valley zone is supposed to be protected as the region is "No Development Zone";

ii). the wetland removal wit vegetation effects the ecological functioning. The plants and algae in wetlands aids in bioremediation by uptake of nutrient and heavy metals;

iii). this activity enchases flooding in the vicinity due to

a. Encroachment of drains / rajakaluves;

b. Alterations in topography;

c. encroachment of lakebed; and

d. encroaching of lake itself by dumping debris and filling up of same

iv). construction activity in the lake floodplain;

v). violation of 30 m buffer (lake floodplain);

vi). encroachment of a drain and land (2.06 hectares);

vii). gradual encroachment of another drain (by filling with building debris);

viii). filling of a portion of lake with building debris;

ix). alterations in topography;

x). traffic congestion (due to additional vehicle movement). The density of traffic would increase, the road's current level of service (LOS) is under category **C** , the increase in vehicles upto 14000+ would worsen the traffic condition with LOS under category **F.** enhanced levels of vehicular pollutants; likely increase in respiratory diseases;

xi). insufficient drinking water in Bangalore (how decision makers can make provision for large quantity of water requirement during construction and operation phase);

The proposed plan to set up SEZ by KIADB needs to be stopped and wetland to be restored considering

Activities	**Norms**
Location of the project (SEZ by Karnataka Industrial Areas Development Board (KIADB)) **in the valley zone**	This is contrary to sustainable development as the natural resources (lake, wetlands) get affected due to this decision. Eventually this kills the lake. This reflects the ignorance of the administrative machinery on the importance of ecosystems and the need to protect valley zones
The proposed activity is in valley zone	To be protected considering ecological function And are 'NO DEVELOPMENT ZONES' as per CDP 2005, 2015
Location of SEZ in flood prone zone of the lake and in wetland - 30 m buffer zone of the water body is to be no development zone	In case of water bodies a 30.0 m buffer of 'no development zone' is to be maintained around the lake (as per revenue records) ✓ As per BDA, RMP 2015 ✓ section 17 of KTCP Act, 1961 and sec 32 of BDA Act, 1976 ✓ Wetlands (Conservation and Management) rules 2010, Government of India
Alterations in topography	Adjacent localities would be vulnerable to floods
Removal of rajakaluve (storm water drain) and gradual encroachment of rajakaluve as well as lake bed	Removal of lake connectivity enhances the episodes of flooding and associated disasters The Hon'ble Supreme Court in Civil appeal number 1132/2011 at SLP (C) 3109/2011 on January 28,2011 has ex-pressed concern regarding encroachment of common property resources, more particularly lakes and it has directed the state governments for removal of encroachments on all community lands. Eviction of encroachment: Need to be evicted as per Karnataka Public Premises (eviction of unauthorised occupants) 1974 and the Karnataka Land Revenue Act, 1964.
The proposed action by KIADB to	High Court of Karnataka (WP No. 817/2008)

set up SEZ violates Hon'ble High Court of Karnataka's verdict to protect, conserve, rehabilitate and wisely use lakes and their watersheds in Bangalore all lakes in Karnataka and their canal networks (about 38,000)	• Protects lakes across Karnataka, • Prohibits dumping of Garbage and Sewage in Lakes • Lake area to be surveyed and fenced and declare a no development zone around lakes • Encroachments to be removed. • Forest department to plant trees in consultation with experts in lake surround ings and in the watershed region • Member Secretary of state legal services authority to monitor implementation of the above in coordination with Revenue and Forest Departments. • Also set up district lake protection committees
Additional 10000 to 14000 vehicles	Increases traffic bottleneck in the region and air pollution (with the increase in density of vehicles)
Increase in vehicular traffic and enhanced pollutants	Traffic congestion (due to additional vehicle movement). The density of traffic would increase, the road's current level of service (LOS) is under category **C** , the increase in vehicles upto 14000+ would worsen the traffic condition with LOS under category **F.** enhanced levels of vehicular pollutants; likely increase in respiratory diseases;
Water shortage The estimate shows that SEZ requires 4587 Kilo Liters per day (4.58 MLD – Million liters per day)	Bangalore is already experiencing severe water shortages as water yield in rivers (Cauvery, etc.) has come down due to large scale land cover changes. Neither Cauvery, T G Halli nor groundwater can sustain Bangalore's growing water demand. BWSSB has not given NOC and has indicated inability to supply such huge quantity of water on regular basis.
Pathetic water scenario and insufficient drinking water in Bangalore	At the 4% population growth rate of Bangalore over the past 50 years, the current population of Bangalore is 8.5 million (2011). Water supply from Hessarghatta has dried, Tippegondahanally is drying up, the only reliable water supply to Bangalore is from

	Cauvery with a gross of 1,410 million liters a day (MLD). There is no way of increasing the drawal from Cauvery as the allocation by the Cauvery Water Disputes Tribunal for the entire urban and rural population in Cauvery Basin in Karnataka is only 8.75 TMC ft (one thousand million cubic – TMC ft equals 78 MLD), Bangalore city is already drawing more water—1,400 MLD equals 18 TMC—than the allocation for the entire rural and urban population in Cauvery basin.

Ecological and Environmental Implications:

- *Land use change:* Conversion of watershed area especially valley regions of the lake to paved surfaces would alter the hydrological regime.
- *Loss of Drainage Network: Removal of drain (Rajakaluve) and reducing the width of the drain would flood the surrounding residential as* the interconnectivities among lakes are lost and there are no mechanisms for the excessive storm water to drain and thus the water stagnates flooding in the surroundings.
- *Alteration in landscape topography:* This activity alters the integrity of the region affecting the lake catchment. This would also have serious implications on the storm water flow in the catchment. The dumping of construction waste along the lakebed and lake has altered the natural topography thus rendering the storm water runoff to take a new course that might get into the existing residential areas. Such alteration of topography would not be geologically stable apart from causing soil erosion and lead to siltation in the lake.
- *Loss of Shoreline:* The loss of shoreline along the lakebed results in the habitat destruction for most of the shoreline birds that wade in this region. Some of the shoreline wading birds like the Stilts, Sandpipers; etc will be devoid of their habitat forcing them to move out such disturbed habitats. It was also apparent from the field investigations that with the illogical land filling and dumping taking place in the Bellandur lakebed, the shoreline are gobbled up by these activities.
- *Loss of livelihood:* Local people are dependent on the wetlands for fodder, fish etc. estimate shows that wetlands provide goods and services worth Rs 10500 per hectare per day (Ramachandra et al., 2005).

Decision makers need to learn from the similar historical blunder of plundering ecosystems as in the case of Black Swan event (http://blackswanevents.org/?page_id=26) of evacuating half of the city in 10 years due to water scarcity, contaminated water, etc. or abandoning of Fatehpur Sikhri and fading out of Adil Shahi's Bijapur, or ecological disaster at *Easter Island or* Vijayanagara empire.

It is the responsibility of Bangalore citizens (for intergenerational equity, sustenance of natural resources and to prevent human-made disasters such as floods, etc.) to stall the irrational conversion of land in the name of development and restrict the decision makers taking the system (ecosystem including humans) for granted as in the case of Bellandur wetlands by KIADB.

Acknowledgement

This report is prepared for Koramangala Residents Association in support of their noble cause to protect Bellandur lake, a life line for South East Bangalore. We thank Mr.Vijayan Menon, Major P. Kapoor, Muralidhar Rao, Nitin for suggestions during the discussion and field visit. This report is dedicated to the residents of Koramangala for their endless struggle against irrational decision of bureaucracy leading to senseless act of removing kidney of the landscape – wetlands, a fragile ecosystem.

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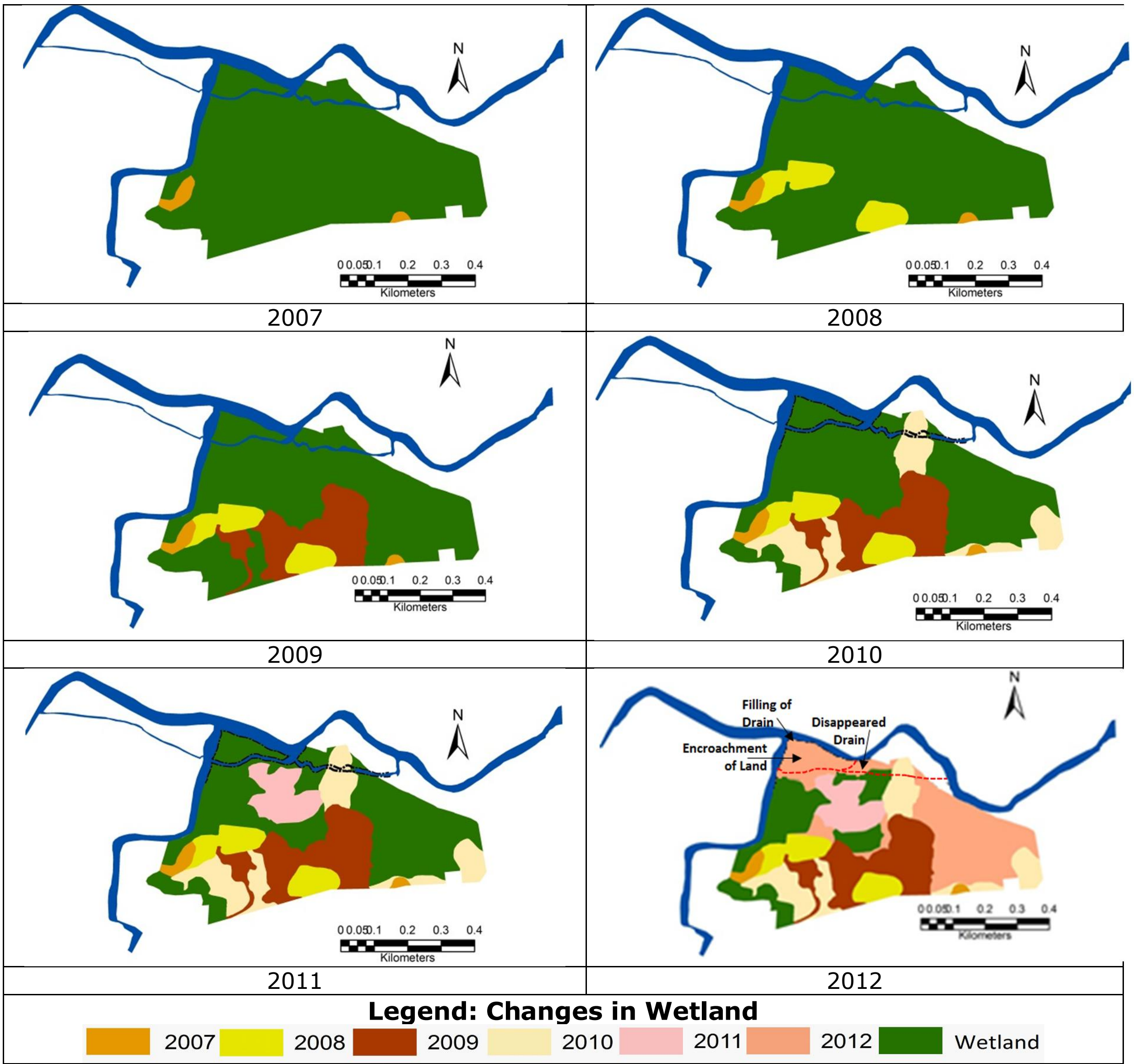

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Annexure 11

ENVIS Technical Report 76

INTEGRATED WETLANDS ECOSYSTEM: SUSTAINABLE MODEL TO MITIGATE WATER CRISIS IN BANGALORE

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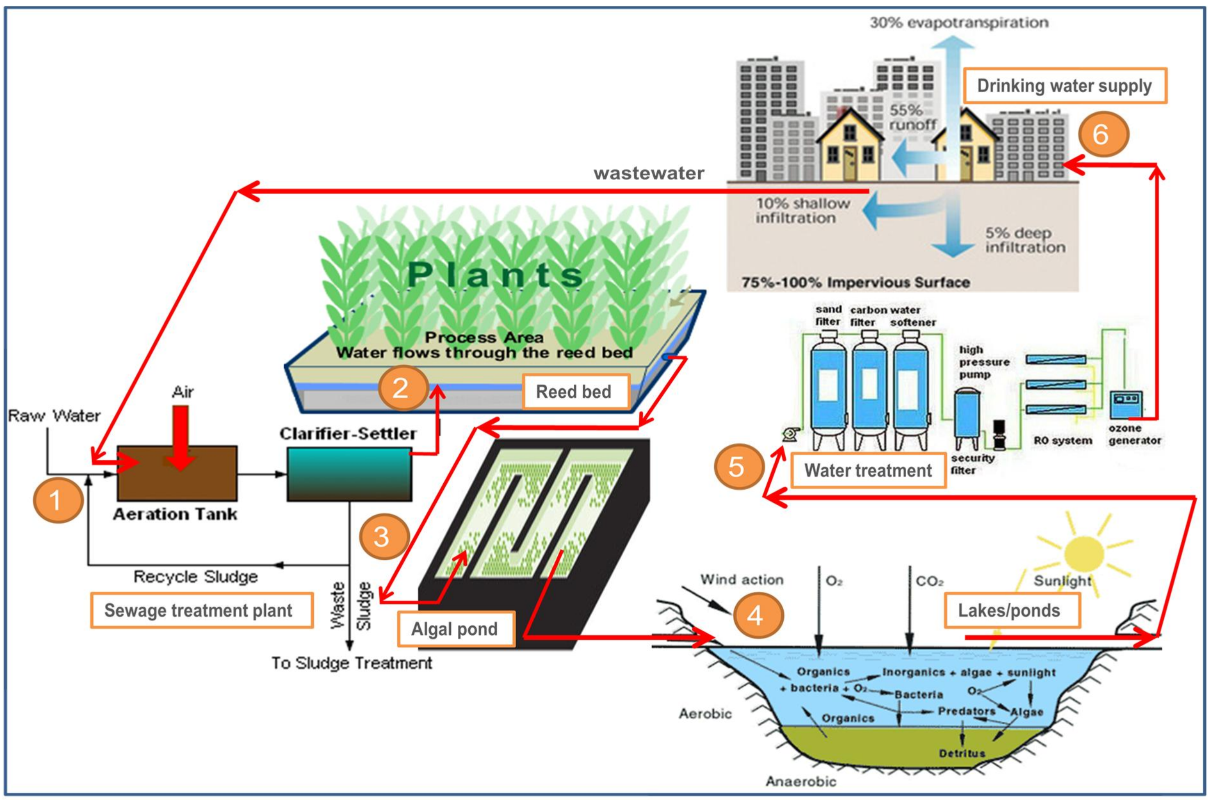
Asulabha K S	Sincy Varghese	Bharath H. Aithal



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INTEGRATED WETLANDS ECOSYSTEM: SUSTAINABLE MODEL TO MITIGATE WATER CRISIS IN BANGALORE

Summary

Urbanisation involves changes in vast expanse of land cover with the progressive concentration of human population. The urbanized landscape provides to its inhabitants the complex social and economic environment leading to further increase in population. Bangalore had flourished in earlier times owing to its salubrious microclimate, availability of water and other resources in the city. Unplanned urbanisation leads to haphazard growth altering the local ecology, hydrology and environment. Consequences of the unplanned urbanisation are enhanced pollution levels, lack of adequate infrastructure and basic amenities. This is evident in Bangalore with severe scarcity of water, frequent flooding, enhanced pollution levels, uncongenial buildings, mismanagement of solid and liquid wastes, etc. Sewage generated in urban households is either untreated or partially treated, which is finally let into water bodies through trunk sewers and storm water network. Although sustained inflow of sewage into water bodies has maintained the water levels in the system of interconnected lakes but it has also contributed to the contamination of surface as well as groundwater sources. Bangalore city is facing severe water shortages today due to insufficient piped supply coupled with the fast decline of groundwater table. Cauvery River caters to only 55% of over 9 million population and balance is met through groundwater. Plummeting groundwater table is due to poor infiltration because of increasing paved surface and also over exploitation. This study explores the feasibility of reuse of water through integrated wetlands ecosystem to mitigate the water crisis in the city.

Integrated wetlands system consists of sewage treatment plant, constructed wetlands (with location specific macrophytes), algal pond integrated with a lake. This model is working satisfactorily at Jakkur. The sewage treatment plant removes contaminants ~ 76 % COD (380 mg/l – 88 mg/l); ~78 % BOD (220-47 mg/l); and mineralises organic nutrients (NO_3-N, PO_4^{3-}P to inorganic constituents. Integration of the conventional treatment system with wetlands [consisting of reed bed (with typha etc.) and algal pond] would help in the complete removal of nutrients in the cost effective way. Four to five days of residence time helps in the removal of pathogen apart from nutrients. However, this requires regular maintenance through

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harvesting macrophytes and algae (from algal ponds). Harvested algae would have energy value, which could be used for biofuel production. The combined activity of algae and macrophytes helps in the removal of ~45% COD, ~66 % BOD, ~33 % NO_3-N and ~40 % PO_4^{3}-P. Jakkur lake acts as the final level of treatment that removes ~32 % COD, ~23% BOD, ~ 0.3 % NO_3-N and ~34 % PO_4^{3}-P. The lake water with a nominal effort of sunlight exposure and filtration would provide potable water. Replication of this model in Bangalore would help in meeting the water demand and also helps in recharging of groundwater sources without any contamination.

Keywords: Wetlands, algae, nutrient removal, bioremediation, Jakkur Lake

1.0 Introduction

Wetlands include a wide range of aquatic habitats such as marsh, fen, peat land/open water, flowing water (rivers and streams) or static (lakes and ponds). These ecosystems being the transition zone between land and water are ecologically important in relation to stability and biodiversity of a region and also in terms of energy and material flow. These ecosystems perform a vital function of uptake of nutrients and bioremediation of heavy metals, volatile organics and other xenobiotic compounds and are aptly referred as "Kidneys of the landscape". They also aid in recharge of groundwater aquifers and stabilization of shorelines. These transitional zones or ecotonal region are repository of rich biodiversity and support food chain. Wetlands act as giant sponges, which helps in slowing runoff, lower flood heights, reduce shoreline and stream bank erosion. The functional ability of wetlands is dependent on the type of trophic structure and material exchange. The trophic structure includes various trophic levels as producers (algae, etc.), primary consumers (zooplanktons and grazers), secondary consumers (small fish), tertiary (large fish, birds, etc.). Algae being the primary producers synthesize carbohydrates during photosynthesis and give out oxygen along with the production of other essential metabolites. Bulk of the CO_2 gets sequestered into algal biomass in these wetlands systems that aids in combating global warming through reductions of GHG (Greenhouse gases) in the environment. However the stability of every system depends upon the balance between production and consumption of energy and matter at different trophic levels in any system. The functional aspects of wetlands are tied to the tradeoff between the ecosystem function and the anthropogenic impact that makes it very sensitive and delicate. Human impacts include altering the catchment (changes in land cover), encroachment, solid waste disposal in lake beds, sustained inflow of untreated sewage from urban localities, etc. (Ramachandra, 2002, 2009a, 2010; Ramachandra et al., 2003)

Increased and unprecedented population growth has resulted in enormous stress on potable water from a daily consumption point of view and also in regards to increased wastewater generated by the city. Bangalore had flourished during 19th and early 20th century owing to a salubrious microclimate and abundance of water in the city of lakes. Globalisation, liberalization, privatization are the agents fuelling urbanization in most parts of India during early 1990's. Unplanned growth has led to radical land use conversion of forests, surface water bodies, etc. with the irretrievable loss of land prospects (Ramachandra et al., 2013a). Land use analyses show 584% growth in built-up area during the last four decades with the decline of vegetation by 66% and water bodies by 74%. Analyses of the temporal data reveals an increase in urban built up area of 342.83% (during 1973 to 1992), 129.56% (during 1992 to 1999), 106.7% (1999 to 2002), 114.51% (2002 to 2006) and 126.19% from 2006 to 2010 (Ramachandra et al., 2012a).

Rapid urbanisation in recent times has led to the large scale generation of wastewater. Untreated or partially treated wastewaters are fed to surface water that finds its way into ground water sources. The sustained inflow of untreated or partially treated sewage to wetlands leads to the enrichment of nutrients such as nitrogen (N) and phosphorus (P), evident from the algae bloom and profuse growth of macrophytes. This has lead to the contamination of existing water resources with pathogens and nutrients resulting in algal bloom due to eutrophic status of surface water. This has also contaminated nearby groundwater sources affecting the human health. Nitrogen as nitrate-N pollution leads to physiological disorders including blue baby syndrome (methemoglobinemia) and the persistent assimilation of nitrate rich water leads to carcinogenic symptoms (as nitrates get reduced in the body forming nitrosamines, which are carcinogens). Macrophytes grow profusely in these nutrient rich environment and progressively cover the entire surface of the water body hindering the passage of sunlight and diffusion of gases to the underlying water layers. Absence of sunlight affects trophic levels with the reduced algae and photosynthetic O_2 generation depleting the dissolved oxygen concentration and thence affects the local biota.

Wetlands are the regional ecological barometers reflecting the health of a region due to the ecosystem services such as regulating the regional micro-climate (Benjamin et al. 1996; Ramachandra and Kumar 2010), recharging groundwater aquifers, thereby influencing the life of the people adjacent to it. There were 203 wetlands spread over an area of 2003 ha in 1973, that number declined to 93 (both small and medium size) with an area of 918 ha in the Greater Bangalore region in 2007 (Ramachandra and Kumar, 2008; 2010). Urban water bodies are prone to increased anthropogenic stress in recent times due to dumping of solid waste, encroachment of wetlands, sustained inflow of domestic sewage and industrial effluents leading to poor water quality. Untreated or partially treated wastewater has resulted in the enrichment of nutrients, leading to eutrophication with a very frequent algal blooms and rapid macrophyte growth with periodic successions (Mahapatra et.al, 2011). Influx of partially treated and untreated sewage has resulted in overgrowth, ageing, and subsequent decay of macrophytes creating anoxic conditions and devouring the system from life giving oxygen. This has impacted the food chain and hence the ecological integrity of the system.

Bangalore city is located on two ridges (North-Northeast and South-Southwest) with three watersheds (Hebbal-Nagavara, Koramangala-Bellandur, Vrishabhavathi). Northern and eastern parts of the city are with gentle slopes, while southern and western parts are very rugged Undulating terrain of the region has helped in the creation of interconnected water-bodies to meet the domestic and irrigation requirements during the pre-colonial period. These interconnected drainage system is supposed to transfer the storm water from one water-body to another, started receiving sewage with rapid population growth and lack of appropriate sewage treatment systems. Population in Bangalore has increased from 5.6 millions (2001) to 9.5 millions (2011). Population increase has led to large quantum of sewage influx into wetlands leading to contamination of wetlands and associated groundwater systems.

Collapse of land regulation is evident during the past two decades due to large scale unauthorized occupation of open spaces (wetlands, grasslands, parks) by the influential section of the society in collusion with the bureaucracy. Large scale land conversion of common lands to built-up in recent times further substantiates the nexus (Ramachandra et al., 2007, Ramachandra and Sudhira, 2007). Changes in the land cover have altered the regional hydrology evident from frequent floods, conversion of perennial wetlands to seasonal wetlands and decline of groundwater table. However authorities have kept some wetlands alive by diversion of sewage, which flows consistently and maintains the water levels in the system of interconnected lakes.

1.1 Water supply in Bangalore: Water is being pumped from Cauvery River ~100 km from the city with an electricity requirement of 75-100 MW. Bangalore is located at higher elevation (900 m above mean sea level) and Cauvery river courses are at 500 m above mean sea level. This exercise suffices the need for approximately 55 % of Bangalore city dwellers, while the rest are dependent on ground water and unauthorized drinking water supplies. Arkavathy River, with two reservoirs at Hesaraghatta (built in 1894, now dry) and Tippagondanahalli (built in 1933) insignificantly and irregularly contribute to a small fraction of the demand (30 MLD). The Chamrajasagar reservoir at Thippagondanahalli (or TG Halli reservoir), located at the confluence of the Arkavathy and Kumudavathy rivers, receives inflow mostly from the Kumudavathy but with a low flow rate (Sharachchandra Lele et. al, 2013, Ramachandra and Solanki, 2007). Water demand in Bangalore is roughly about 150 liters per day (lpd) per person and the total water requirement for domestic purposes is about 1,400 million liters per day (MLD). Water available from Cauvery (Stages I to IV, Phase I) and Arkavathy (Hesarghatta and Tippagondanahalli reservoirs) rivers is about 975 MLD. The loss of water during transportation and distribution is assumed to be ~30%. Significant portion is met from groundwater sources as indicated in Table 1 and Figure 1.

Table 1: Zone-wise piped water and ground water supply

Zone	Surface water	Groundwater	Total
Central	67.1	38.91	106.01
North	210.46	87.08	297.54
West	184.89	149.45	334.34
East	169.19	50.46	219.65
South	133.106	176.00	309.11
Southeast	104.79	67.80	172.59
Total	869.536	569.7	1439.24

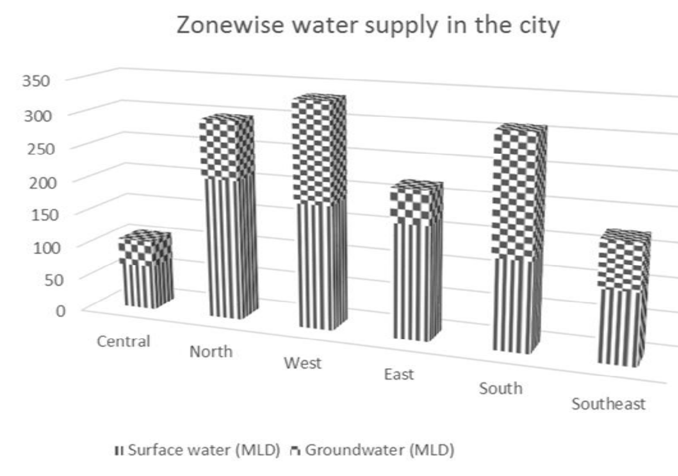

Figure 1: Water usage in Bangalore (piped water supply and from groundwater sources)

Due to insufficient water from Cuavery River, most of the new city municipal councils and town municipal council (merged with Bangalore city, in the formation of BBMP) are dependent on groundwater sources. A rapid increase in the number of borewells in Bangalore, was observed over the last three decades from 5,000 to around 4.08 lakh. It is estimated that 40% of population of Bengaluru are dependent on 750 MLD of ground water, which is extracted every day. According to the CGWB (Central Ground Water Board), between 2001 and 2007, the water level in Bengaluru has declined by 7 meters (m) at the rate of about 1m per year. Over exploitation of groundwater coupled with minimal recharge due to changes in land over (increase in paved surface with the loss of vegetation and water-bodies) has led to decline in groundwater table (as high as 500 to 600 m), evident from the prevalence of gray, dark and over-exploited groundwater blocks in the major part of Bangalore.

Communities have been dependent on wetlands for food, domestic, agricultural and industrial requirements. The economic benefits from wetlands to the society are in the form of water supply, commercial fisheries, agriculture, energy resource, wildlife resource, recreation, tourism, cultural heritage, biodiversity, etc. (Ramachandra et al., 2011). The myriad ways, in which wetlands are used, along with the numerous anthropocentric activities, have stressed wetlands in diverse ways. This has altered the wetlands quality disrupting its natural functions. Anthropogenic activities include direct physical destruction (drained for agricultural and developmental activities), siltation (soil erosion and removal of vegetative cover) and pollution from both point sources (municipal sewage and industrial effluents) and non-point sources (urban and agricultural runoffs) within the watershed (Kiran and Ramachandra, 1999, Ramachandra and Rajinikanth, 2003).

Treatment and disposal of wastewater generated in the neighbourhood constitute key environmental challenges faced in urban localities due to burgeoning population in the recent decade. Nutrient laden wastewater generated in municipalities is either untreated or partially treated and is directly fed into the nearby water bodies regularly, resulting in nutrient enrichment resulting in algal blooms. Conventional wastewater treatment options are energy and capital intensive apart from their inability to remove nutrient completely. In this backdrop, algal processes are beneficial and remove nutrients with carbon sequestration and resultant biomass production. Algae grows rapidly and uptakes nutrients (C, N and P) available in the wastewater (Ramachandra et al., 2013a; Mahapatra et al., 2013) and hence are useful in nutrient remediation. Treatment of sewage and letting into wetlands would help in further treatment (removal of N, P and heavy metals). This also prevents contamination of groundwater resources. Thus wetlands provide a cost effective option to handle sewage generated in the community and also helps in addressing the water crisis in the region.

Microalgae and native macrophytes of the wetlands help in the treatment due to abilities to uptake nutrients and heavy metals. Techniques have been developed for exploiting the algae's fast growth and nutrient removal capacity (Karin Larsdotter, 2006). The nutrient removal is basically an effect of assimilation of nutrients as the algae grow. Also, nutrient stripping happens the due to high pH induced by the algae as in ammonia volatilization, phosphorus precipitation, etc.

2.0 Constructed Wetlands: Reed bed (typha, etc.) with Algal pond as wastewater treatment systems

Wetlands aid in water purification (nutrient, heavy metal and xenobiotics removal) and flood control through physical, chemical, and biological processes. When sewage is released into an environment containing macrophytes and algae a series of actions takes place. Through contact with biofilms, plant roots and rhizomes processes like nitrification, ammonification and plant uptake will decrease the nutrient level (nitrate and phosphates) in wastewater (Garcia et.al, 2010). Algae based lagoons treat wastewater by natural oxidative processes. Various zones in lagoons function equivalent to cascaded anaerobic lagoon, facultative aerated lagoons followed by maturation ponds (Mahapatra et al., 2011b). Microbes aid in the removal of nutrients and are influenced by wind, sunlight and other factors (Mahapatra et.al, 2011, 2013a,b).

2.1 Nutrients as source of contamination: The conventional wastewater treatment systems (sewage treatment plants - STP) are expensive and require input of external energy sources (e.g.; electricity, organic carbon) and chemical additives. These treatment systems generate concentrated waste streams necessitating environmentally sound disposal.

There is an urgent need to develop an innovative, environmental friendly and cost effective sustainable technologies for treating sewage generated in the community every day. Untreated sewage leads to the neighborhood contamination of land and water resources (groundwater). An easy way to check the sewage contamination is to test the level of nutrients (nitrates and phosphates). Nitrate is a substance that develops from organic waste. Algae convert nitrate into organic compounds (proteins, lipids) through photosynthesis in the presence of sunlight. Algae can exhibit growth rates that are higher than other plants due to their extraordinarily efficient light and nutrient utilization. By taking advantage of rapid availability of nutrient enriched water, high solar intensity and favorable microclimate for algal growth, higher densities of algae can be grown continuously that provides ample biomass and at the same time treat wastewater within a short period of time.

Algal bacterial symbiosis is very effective in these tropical conditions. Algae the primary producers generate O_2 (during photosynthesis) which aid in the efficient oxidation of organic matter with the help of the chemo-organotrophic bacteria. The type and diversity of the algae grown are potential indicators of treatment process (Amengual-Morro et al. 2012; Mahapatra et al., 2013a,b; Mahapatra et al., 2014)) and bacterial system disintegrates and degrades the organic matter providing the algae with an enriched supply of CO_2, minerals and nutrients.

Focus of the current investigation is to assess the efficacy of wetlands in Jakkur lake system. This has been done through water quality assessment (physicochemical analysis) at various stages of the integrated wetland system consisting of sewage treatment plant (10 MLD), wetlands (with macrophytes), algal pond and Jakkur Lake. Nitrate and phosphate levels were monitored at various stages of wetlands ecosystem.

3.0 Study Area

Jakkur Lake (Figure 2) situated at 13º 04'N and 77° 36'E, North East of Bangalore. Ten MLD sewage treatment plant is functional in this locality. Partially treated water is let into Jakkur Lake through wetlands (consisting of emergent macrophytes and algae). Water samples were collected (figure 2) from Inlet (S6), outlets (S1, S2, S3), middle (S4, S5 and S9) and at treatment plant outlet (S6 and S7) totaling nine locations. The treated water from the treatment plant passes through the wetlands to Jakkur Lake.

4.0 Integrated Wetlands Ecosystem

Integrated wetlands system at Jakkur consists of i) treatment plant (treats sewage partially before letting to wetlands, ii) constructed wetlands consisting of macrophytes, iii) algal pond and v) lake (figure 2). Jakkur lake with wetlands is manmade and constructed about 200 years ago to meet the domestic and irrigation water requirement of Jakkur village located about hundred meters south west in the downstream of the lake (figure 3). The lake used to be perennial containing water all 12 months due to vegetation cover in its catchment. The lake was a source of livelihood to poor farmers and washer men. Even today during potential fish growth seasons, fish cash is estimated to be as high as 500 kgs per day. Twelve to fifteen dhobi (washer men) families are also dependent on the lake for washing cloth daily. In the command area of the lake agriculture and horticulture (coconut, banana and mango plantations) was practiced and remnants of these plantations could be seen even today in the region. Rapid urbanisation in recent times has led to large scale land use changes leading to an increase in paved surfaces. This has resulted in the decline of infiltration ability of the capacity resulting in lake retaining water for 8-9 months. Lake receives partially treated sewage daily with the implementation of sewage treatment plant in the upstream of the lake, near the inlet of constructed wetlands. Water flows from the treatment plant (in the north) towards the outlets in the south of the lake. Catchment and command area of the lake was mainly agrarian during pre-ninety's, are now dominated by urban land uses. Around the lake are different kinds of human activities, such as banana plantations, slums, a golf course, and newly built residential buildings.

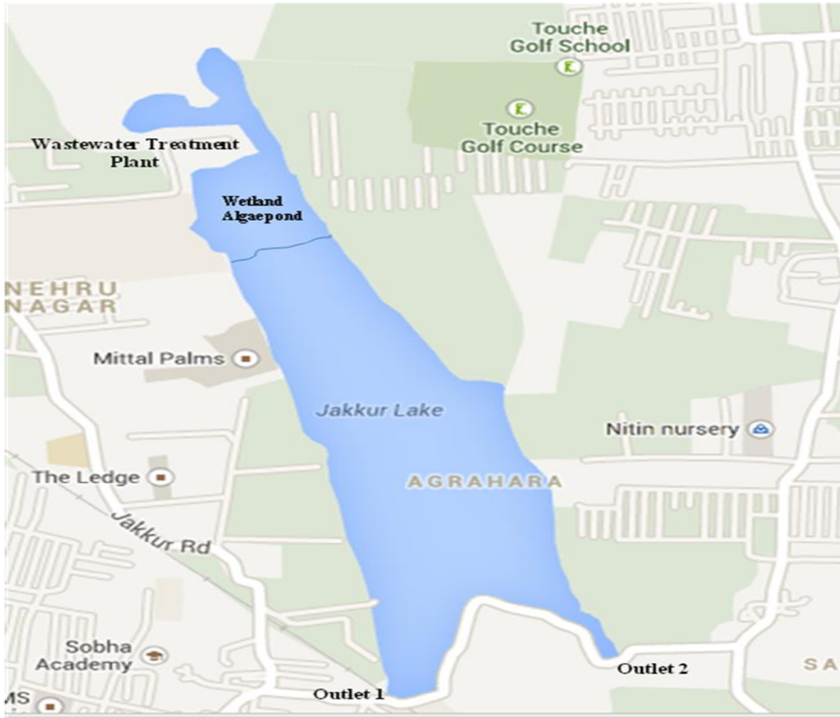

Figure 2: integrated wetlands ecosystem: Sewage treatment plant, wetlands (macrophytes and algae pond), Jakkur lake (source: Google map)

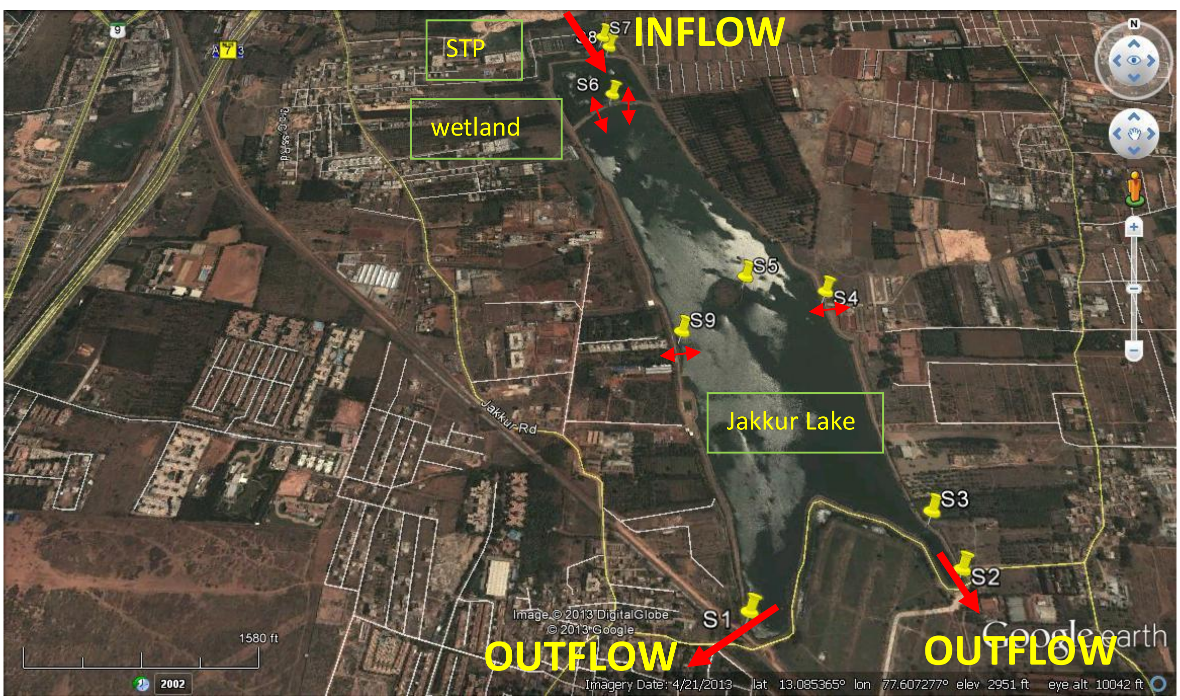

Figure 3: water sampling locations in wetlands system (source: earth.google.com)

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5.0 Results and Discussion

Water quality analysis was carried out to assess physico-chemical and biological properties of water at various stages of the treatment and its suitability for domestic and irrigation purposes. Water samples were collected from nine locations (marked in Figure 2) twice at 45 days interval. The water samples were collected in clean acid washed one liter polythene bottles. Temperature, TDS, Conductivity and pH were measured on the site. Water quality parameters were analyzed as per the standard protocol (APHA, 1998). Algal samples collected from sampling locations were identified using standard keys (Prescott 1973;1982) based on their external appearance, colour, morphological characteristics, size, habitat, structure and orientation of chloroplast, cellular structure and pigments etc. Water samples collected were concentrated by centrifuging 15 ml volume.

5.1 Dissolved Oxygen: Dissolved oxygen (DO) is the most essential feature in aquatic system that helps in aquatic respiration as well as detoxification of complex organic and inorganic mater through oxidation. The presence of organic wastes demands high oxygen in the water leading to oxygen depletion with severe impacts on the water ecosystem. The DO of the analyzed water samples varied between 0 to 17.74mg/l. The higher variations of DO especially lower DO values are indicative of high organic matter in the immediate vicinity. The DO was very low at the inlets of wetlands and increased immediately after the algal pond. Lower DO values were observed near the macrophytes (invasive exotic weeds as water hyacinth, *Eichhornia crassipes*) infested regions at the outfalls outlets.

5.2 Total Dissolved Solids (TDS): Total dissolved solids present as as mineral matter in the form of dissolved cations and anions and to a smaller extent by organics, sourced from decomposing matter. Other sources include runoff from urban areas, road salts used on street, fertilizers and pesticides used on lawns and farms (APHA, 1998). TDS affect the water quality in many ways impacting the domestic water usage for cleaning, bathing etc as well as drinking purposes (Ramachandra et al., 2012). Surface as well as groundwater with high dissolved solids are of inferior flavor and induce an unfavorable physiological reaction to the dependent population. The TDS values in the samples analyzed, ranged from 612 to 710 mg/lacross all locations. It was higher in the inlets and reduced in the middle region of the lake. The TDS was little higher in the outlets than middle due to human activities (like washing, etc.), macrophyte and plankton cover etc.

Table 1: Onsite parameters

Site	GPS	DO(mg/l)		Water Temp (°C)		TDS (mg/l)		pH		EC (µS)		Comments
Period		1	2	1	2	1	2	1	2	1	2	
S1	13.07931N, 77.61032E	5.08	7.26	24.3	25	637	636	7.8	8.4	1179	1160	Outlet, People washing clothes
S2	13.08019N, 77.61463E	--	3.71	--	24.4	--	631	--	8.2	--	1204	Outlet, after the cover of macrophytes
S3	13.08143N, 77.61428E	16.94	8.06	24	24.2	630	630	8	8.2	1213	1215	Outlet
S4	13.08670N, 77.61265E	16.53	8.06	24	--	629	643	8.1	--	1221	--	Middle
S5	13.08725N, 77.61060E	16.13	9.35	--	25	617	612	7.9	7.8	1134	1256	Middle
S6	13.09266N, 77.60769E	17.74	8.06	--	24.1	648	709	7.4	7.2	1213	1389	Inlet to the lake after algae pond
S7	13.09433N, 77.60767E	2.02	0.00	24.7	22.3	652	692	7.2	7.7	1293	1368	Untreated sewage water entering lake
S8	13.09423N, 77.60767E	5.40	4.60	23	24.9	683	630	7.8	8.2	1327	1244	Treated water from treatment plant
S9	13.08582N, 77.60922E	9.68	7.26	24.3	24.3	631	640	8	7.2	1228	1216	Middle

Table 2: Chemical parameters of Water analysis

Sites	Chloride (mg/l)		Total Hardness (mg/l)		Ca (mg/l)		Mg (mg/l)		Na (mg/l)		K (mg/l)		Total Alkalinity (mg/l)	
Period	1	2	1	2	1	2	1	2	1	2	1	2	1	2
S1	259.86	254.18	212	206	40.88	39.28	26.82	26.33	300.8	331.6	47.6	51.6	260	252
S2	--	249.92	--	204	--	40.08	--	25.36	--	367.6	--	56.4	--	252
S3	249.92	249.92	212	204	42.48	39.28	25.84	25.84	360	359.6	58	57.6	250	248
S4	166.14	190.28	208	200	43.29	40.08	24.38	24.38	343.6	334	52.8	54.4	260	256
S5	180.34	168.98	210	224	44.09	38.48	24.38	21.93	284.8	282.4	54.4	53.2	240	254
S6	251.34	249.92	240	256	59.32	59.93	22.42	22.90	293.6	260.4	53.2	56	290	310
S7	254.18	257.02	252	244	65.73	61.72	21.44	21.93	256.4	266	52.4	55.6	420	444
S8	252.76	254.18	256	254	71.34	67.71	19.00	24.87	268.8	320.8	56	54.8	440	448
S9	230.04	210.16	206	198	44.89	46.49	22.91	19.99	330.4	342.4	55.2	57.6	260	252

Table 3: Nutrient analysis of water

Sites	COD (mg/l)		BOD (mg/l)		Phosphate (mg/l)		Nitrate (mg/l)	
Period	1	2	1	2	1	2	1	2
S1	28	20	17.14	5.04	0.09	0.15	0.28	0.32
S2	--	20	--	9.58	--	0.20	--	0.34
S3	34	10	19.15	1.01	0.09	0.20	0.26	0.34
S4	30	14	22.18	5.04	0.10	0.25	0.26	0.36
S5	18	20	27.22	1.01	0.10	0.67	0.21	0.33
S6	16	48	25.20	16.13	0.21	1.00	0.24	0.27
S7	161.3	28	128	6.05	0.72	1.29	0.22	0.22
S8	88	16	46.37	4.54	0.35	0.27	0.36	0.38
S9	18	16	20.16	5.04	0.09	0.18	0.20	0.26

5.3 pH: pH is a numerical expression that indicates the degree to which water is acidic or alkaline, with the lower pH value tends to make water corrosive and higher pH has negative impact on skin and eyes. The pH value ranged from 7.2 to 8.4.

5.4 Chlorides: Chlorides are essentially anionic radical that imparts chlorosity to the water. An excess of chlorides leads to the formation of potentially carcinogenic and chloro-organic compounds like chloroform, etc. Chloride values in samples collected from Jakkur lake system ranged from 166-260mg/l. Chloride values were high at inlets (treated and untreated water) and relatively lower at the outlet of algal pond and the middle portion of Jakkur lake. At outlets, it is higher due to washing activities with the use of bleaching powder i.e. $CaO(Cl)_2$.

5.5 Sodium: Sodium (Na) is one of the essential cations that stimulate various physiological processes and functioning of nervous system, excretory system and membrane transport in animals and humans. Increase of sodium ions has a negative impact on blood circulation, nervous coordination, hence affecting the hygiene and health of the nearby localities. In this study the concentration of sodium ranged from 256 to 367 mg/land higher values were observed in samples collected at outlets.

5.6 Potassium: Potassium (K) is an essential element for both plant and animal nutrition, and occurs in ground waters as a result of mineral dissolution, decomposing of plant materials and also from agricultural runoff. Potassium ions in the plant root systems helps in the cation exchange capacity to transfer essential cations like Ca and Mg from the soil systems into the vascular systems in the plants in replacement with the potassium ions (APHA, 1998). Incidence of higher potassium levels in soil system affects the solute transfer (active and passive) through the vascular conducting elements to the different parts of the plants. The potassium content in the water samples ranges between 47-58mg/l. The potassium values were high at outlets due to decomposition of plant materials.

5.7 Alkalinity: Alkalinity is a measure of the buffering capacity of water contributed by the dynamic equilibrium between carbonic acid, bicarbonates and carbonates in water. Sometimes excess of hydroxyl ions, phosphate, and organic acids in water causes alkalinity. High alkalinity imparts bitter taste. The acceptable limit of alkalinity is 200mg/l. Alkalinity of the samples was in range 240-444 mg/l. High alkalinity of 448 and 444 mg/l was observed at the

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inlet of wetlands (or outlet of the treatment plant). These values declined after the water passed through wetlands (in particular the algal pond) and also in the middle of Jakkur lake.

5.8 Total hardness: Hardness is a measure of dissolved minerals that decides the utility of water for domestic purposes. Hardness is mainly due to the presence of carbonates and bicarbonates i.e temporary hardness and due to sulphates and chlorides i.e. permanent hardness. It is caused by variety of dissolved polyvalent metallic ions predominantly calcium and magnesium cation or other cations like barium, iron, manganese, strontium and zinc. In the present study, the total hardness ranged between 198 to 256mg/l. It was higher in the inlets. High values of hardness are probably due to the regular addition of sewage and detergents.

5.9 Calcium: Calcium (Ca) is one amongst the major macro nutrients which are needed for the growth, development and reproduction in case of both plants and animals. The presence of Ca in water is mainly due to its passage through deposits of limestone, dolomite, gypsum and other gypsiferous materials (APHA, 1998) along with the Ca (from sewage). It contributes to the total hardness of the water. Ca concentration in all samples analyzed periodically ranged between 39 to 71mg/l. Ca concentration was high in the sewage water (treated and untreated) entering into the lake.

5.10 Magnesium: Magnesium (Mg) in one of the most essential macro nutrients that helps as a co-factor in the enzyme systems and in the central metal ions that constitutes the chlorophyll molecule essential for plant photosynthesis. According to WHO guidelines the maximum admissible limit is 50mg/l. In this study the concentration of Magnesium ranged from 19–26.82 mg/l.

5.11 Nutrients (nitrates and phosphates): Nutrients essentially comprise of various forms of N and P that readily mineralizes (inorganic mineral ions) to enable uptake by microbes and plants. Accumulation of nitrates and inorganic P induces changes in water quality that affects its integrity leading to higher net productivity. Nitrates in excess amounts together with phosphates accelerate aquatic plant growth in surface water causing rapid oxygen depletion or eutrophication in the water. Nitrates at high concentrations (10 mg/l or higher) in surface and groundwater used for human consumption are particularly toxic to young children affecting the oxygen carrying capacity of blood cells (RBC) causing cyanosis (methemoglobinemia). In the present study, nitrate values ranged from 0.2 to 0.38 mg/land phosphate values ranged between 0.09 to 1.29mg/l. The nitrate and phosphate values are higher at the wetlands inlets and significantly reduce after the passage through wetlands and algal pond as elucidated in Figure 4.

5.12 BOD and COD: BOD and COD are important parameters that indicate the presence of organic content. Biochemical oxygen demand (BOD) is the amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions. It is required to assess the pollution of surface and ground water where contamination occurred due to disposal of domestic and industrial effluents. Chemical oxygen demand (COD) determines the oxygen required for chemical oxidation of most organic matter and oxidizable inorganic substances with the help of strong chemical oxidant. In conjunction with the BOD, the COD test is helpful in indicating toxic conditions and the presence of biologically resistant organic substances (Sawyer and McCarty 1978). In this study the BOD values ranged from 17-128 mg/l. There was reduction of 66% in BOD after the algal pond and 23% removal in the water which flows out of the lake. The COD values ranged from 16 to 161 mg/l. The COD reduced by 45% in the algae pond and 32 % in the lake as shown in Figure 4.

6.0 Integrated Wastewater Management System

The treatment of domestic sewage in natural systems such as constructed wetlands and lagoons is being practiced in developing nations. Significant advantages are its construction and operation are simple and economically viable. Lagoon systems are associated with a high growth rate of phytoplankton that are beneficial and are caused by the influence of light and the continuous nutrient inflow. Algal growth contributes towards the treatment of wastewater by transforming dissolved nutrients into particle aggregates (biomass). Algal retention in the lagoon helps in the treatment, which has to be harvested at regular interval to ensure effective treatment. Wetlands consisting of reed-bed and algal pond help in the removal of nutrients (Mahapatra et al., 2011; 2013).

Emergent macrophytes (such as Typha) act as a filter in removing suspended matter and avoiding anaerobic conditions by the root zone oxidation and the dissolved nutrients would be taken up by the lagoon algae. This type of treatment helps in augmenting the existing treatment system in complete removal of nutrients and bacteria. The combination of wetlands (with macrophytes assemblages), algal lagoon and a sustained harvesting of algae and macrophytes would provide complete solution to wastewater treatment systems with minimal maintenance. Integrated wetland system at Jakkur provides an opportunity to assess the efficacy of treatment apart from providing insights for replicating similar systems to address the impending water scarcity in the rapidly urbanising Bangalore.

6.1 Insights to the efficacy of treatment: The treatment plant (1.6 Ha) with an installed capacity of 10 MLD, comprises of an Upflow Anaerobic Sludge Balnket Reactor (UASB) with an extended aeration system for sewage treatment. The treatment effluent then gets into wetlands (settling basin) of spatial extent ~4.63 hecatres consisting of diverse macrophytes such as *Typha* sp., *Cyperus* sp., *Ludwigia* sp., *Alternanthera* sp., Water hyacinth sp., etc. in the shallow region (with an area of ~1.8 hectares) followed by deeper algal basin (covering an area of about 2.8 hecatre). This being the significant functional component with macrophytes and algae jointly helps in the nutrient removal and wastewater remediation. The water from the settling basin flow pases through three sluices of which only the middle one is functional (with moderate flow). This water flows into Jakkur lake that spans over 45 hectares. There were notably less occurance of floating macrophytes, except near the outfalls (~0.5 Ha) due to blockage of the ouflow channels by solid wastes and debris. These macrophytes are being managed by local fishermen. Water in the Jakkur lake is clear with abundant phytoplankton diversity and acceptable densities, which indicates of a healthy trophic status.

The nutrient analysis shows (illustrated in Figure 4), that treatment happens due to immergent macrophytes of the wetlands and algae, which removes ~45% COD, ~66 % BOD, ~33 % NO_3-N and ~40 % PO_4^{3-}—P. Jakkur lake treats the water and acts as the final level of treatment which shown as stage two that removes ~ 32 % COD, ~23% BOD, ~ 0.3 % NO_3-N and ~34 % PO_4^{3-}—P.. The synergestic mechanism of sewage treatment plants followed by wetlands helps in the complete removal of nutrients to acceptable levels according to CPCB norms.

Jakkur STP (of 10 MLD capacity) treats only6 MLD of sewage that is drawn from Yelhanka town. Yet, It is observed that sewer channel carrying voluminous wastewater with the treatment plant effluents into wetlands. The major nutrient removal and polishing is done by the manmade wetland and the lake. This wetland comprise of emergent macrophytes as *Typha augustata*, etc and plays a key role in oxygenation of soil subsystems through root zone oxidation and entrapment of necessary nutrients that otherwise would cause an algal bloom in the lake. The algal species in this manmade wetland region (Figure 5) primarily comprised of memebers of chlorophyceae followed by cyanophyceae, eugelnophyceae and

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bacillariophyceae (Figure 6). The relative abundances are provided in the pie-diagrams below. The detailed list of algal species, their presence and absence have been listed and provided in Table 4.

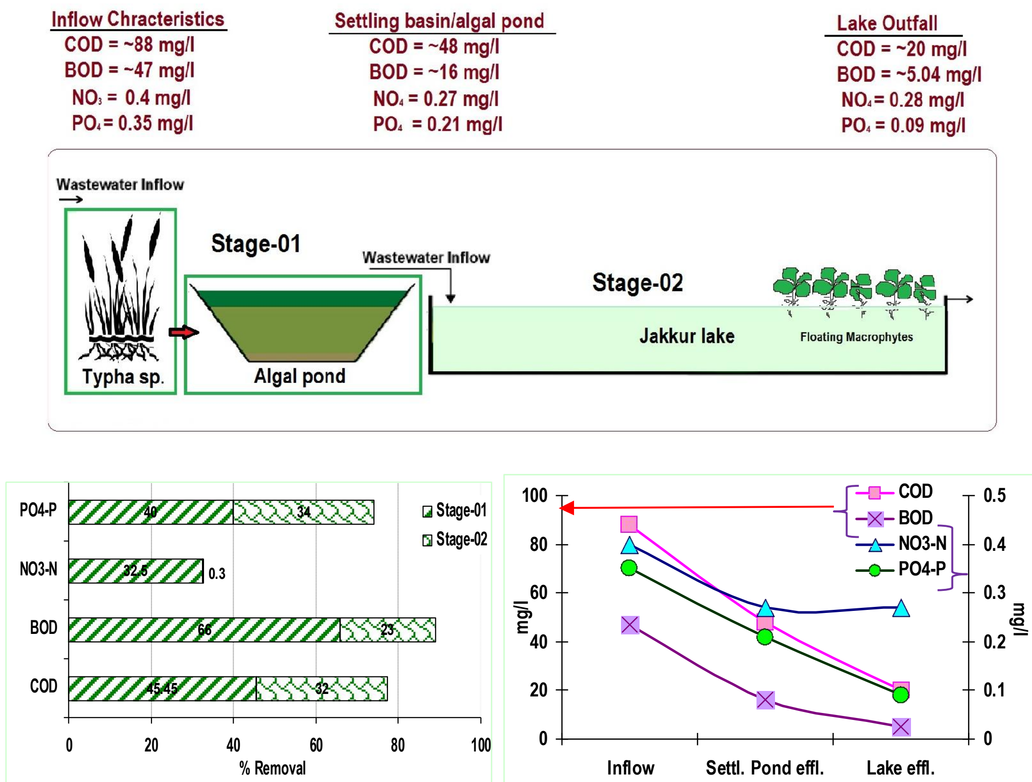

Figure 4: Integrated wastewater management system

Table 4: Algal species in Jakkur lake system

S.No	Algae	Site1	Site2	Site3	Site4	Site5	Site6	Site7	Site8	Site9
1	*Actinastrum* sp.	+	+	+	+	+	+	+	+	+
2	*Anabaena* sp.	+	+	+	+					
3	*Ankistrodesmus* sp.				+	+			+	+
4	*Aphanocapsa* sp.	+	+	+	+	+			+	+
5	Arthrodesmus sp.		+	+	+	+				+
6	*Asterococcus* sp.	+	+	+	+	+	+	+		+
7	*Chlorella* sp.	+	+	+	+	+	+	+	+	+
8	*Chroococcus* sp.	+		+	+	+		+	+	+
9	Cladophora sp.						+			
10	*Closterium* sp.	+	+	+	+	+	+	+	+	+
11	*Coelastrum* sp.		+	+	+	+	+	+	+	
12	*Coelosphaerium* sp.								+	
13	*Coenocystis* sp.								+	
14	*Cosmarium sp.*	+	+	+	+	+		+	+	+
15	*Crucigenia sp.*	+	+	+	+	+	+	+	+	+
16	*Cyclotella sp.*	+	+	+	+	+	+		+	+
17	Cymbella sp.			+	+					

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18	*Desmodesmus sp.*	+							+	+
19	Dictyococcus sp.		+	+	+	+	+	+		+
20	*Dictyosphaerium* sp.		+	+	+	+	+	+	+	+
21	Eudorina sp.			+						
22	*Euglena spp.*	+	+	+	+	+	+	+	+	+
23	*Glaucocystis sp.*	+	+		+	+				
24	*Gloeocystis* sp.								+	
25	*Golenkinia* spp.		+			+	+		+	
26	*Gomphonema sp.*							+		
27	*Gonium spp.*	+	+	+	+	+	+	+	+	+
28	Gyrosigma sp.					+				
29	*Krichenerilla sp.*	+	+	+	+	+	+	+	+	+
30	*Limnothrix sp.*		+		+	+	+			+
31	*Melosira sp.*	+	+	+	+	+			+	+
32	*Merismopedia* sp.		+	+	+	+	+	+	+	
33	Micracitinium sp.		+	+	+	+	+	+	+	+
34	*Microcystis sp.*	+	+	+	+	+			+	
35	*Monoraphidium sp.*	+	+	+	+	+	+	+	+	
36	*Navicula sp.*	+	+		+	+	+	+	+	
37	*Nephrocystis* sp.								+	
38	*Nitzschia sp.*	+	+		+	+		+	+	+
39	*Oocystis sp.*	+		+	+	+	+	+		+
40	*Ophiocytium* sp.								+	
41	*Oscillatoria sp.*	+				+	+	+		
42	Pandorina sp.					+	+	+		+
43	*Pediastrum sp.*	+	+	+	+	+	+		+	+
44	*Phacus spp.*	+	+	+	+	+	+	+	+	+
45	*Phormidium sp.*	+	+	+	+	+			+	+
46	Pinnularia sp.						+			+
47	*Plantothrix*	+			+			+		
48	*Pseudanabaena sp.*						+			
49	*Quadrigula sp.*	+	+	+	+	+				+
50	*Radiocystis sp.*	+	+	+	+	+		+		+
51	*Scenedesmus spp.*	+	+	+	+	+	+	+	+	+
52	Schroederia sp.		+	+	+	+		+		+
53	*Spirulina* sp.		+	+	+	+	+	+	+	
54	*Staurastrum* sp.								+	
55	*Stichococcus sp.*	+	+	+	+	+	+			+
56	Surirella sp.					+	+	+		
57	*Synechococcus* sp.								+	
58	Synedra sp.		+		+	+	+			
59	Synura sp.									+
60	*Tetraedron spp.*	+	+	+	+	+	+	+	+	+
61	*Tetraedron* spp.							+		
62	Tetrastrum sp.			+				+		
63	*Trachelomonas sp.*	+	+	+						
64	*Xanthidium sp.*	+								

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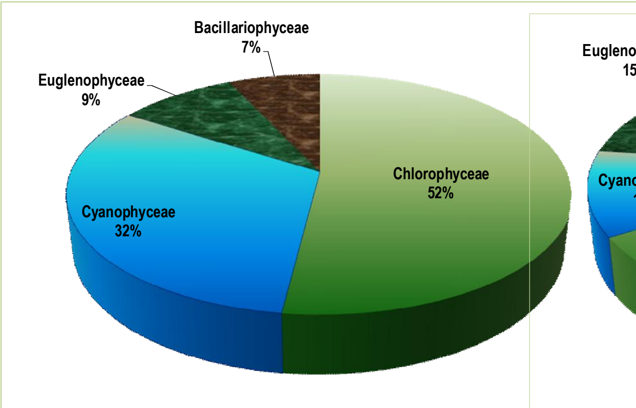

Figure 5: Composition of algae in Man Made Wetland System

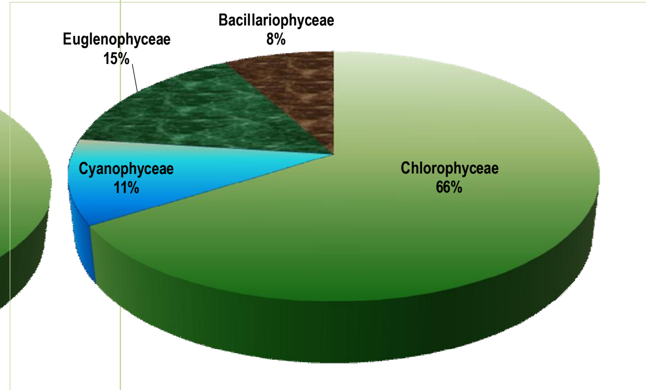

Figure 6: Composition of algae in Jakkur Lake

Similarly macrophytes play an important role in the effluent stabilisation. Table 5 lists the prominent macrophytes of wetlands ecosystem at Jakkur. The distribution of the macrophytes in the wetland area as well as at the outfalls of the lake is provided in Figure 7. *Typha augustata* species were dominating (54%) in the wetland area followed by *Alternanthera philoxeroides* (28%). However even though the macrophyte population was scarce in the lake, but still amongst them *Eicchornia crassipes* (84%) were dominating (Figure 8), which were only restricted to the outlet reaches due to fish nets, deployed for fishing in core area.

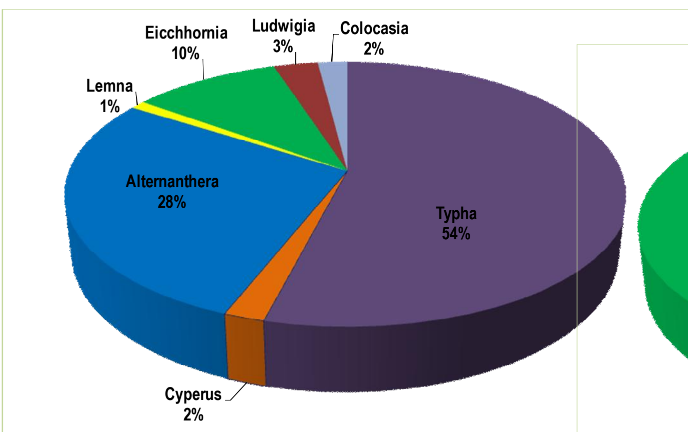

Figure 7: Composition of Macrophytes in Man Made Wetland System

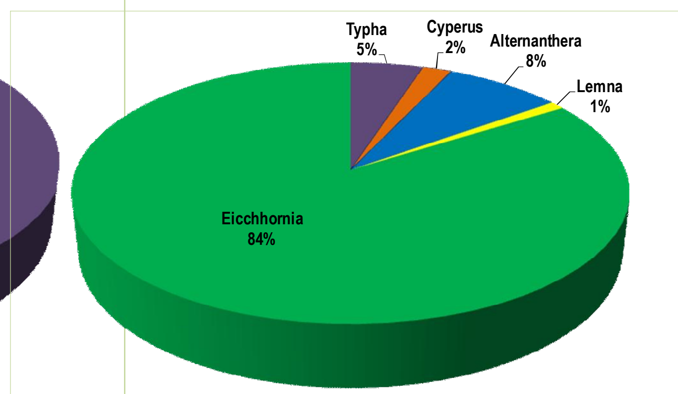

Figure 8: Composition of Macrophytes in Jakkur Lake

Table 5: Macrophytes of Wetlands at Jakkur

<table>
<tr><td>
Name: Alternanthera philoxeroides
Common name: Alligator weed
Habitat: grow in a variety of habitats, including dry land but usually found in water(Shallow water or wet soils, ditches, marshes, edges of ponds and slow-moving watercourses) These grow best under high-nutrient (eutrophic) conditions
Stems are pinkish, long, branched, and hollow. Fleshy, succulent stems can grow horizontally and float on the surface of the water, forming rafts, or form matted clumps which grow onto banks
Leaves are simple, elliptic, and have smooth margins. They are opposite in pairs or whorls, with a distinctive midrib, and range in size from 5-10 cm.
Flowers: Whitish, papery ball-shaped flowers that grows on stalks.
Fibrous roots arising at the stem nodes may hang free in water or penetrate into the sediment/soil.
Flowering: December-April
Harvesting period: May
Impact: Alligator weed disrupts the aquatic environment by blanketing the surface and impeding the penetration of light. Such blanketing can also prevent gaseous exchange (sometimes leading to anaerobic conditions) which adversely affects aquatic flora and fauna. It also competes with and displaces native flora along river and in wetlands
</td><td>


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<tr><td>
Name: Typha
Common name: Cattail
Description: It is a common perennial marsh, Aquatic or wetland plant in temperate, tropical, and subtropical climates. Plants are rhizomatous monoecious herb, grow upto 1.5-3m high, Leaves radical, sheath white. Flowering stem length is typically equal to or somewhat longer than leaf length. Numerous tiny, dense, flowers occur in a terminal spike that is 0.7 to 2 inches, Male flowers make up the upper, narrower half of the spike and female flowers the lower, slightly wider half
Flowering: June- August
Harvesting period: September
Habitat: It grows in shallow water of lakes, rivers, ponds, marshes, and ditches. These species grow vigorously under eutrophic conditions and in low nutrient wetlands, they grow sparsely.
Significance: Phytoremediation, wastewater treatment, Used as medicine, fodder
</td><td>

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</table>

Name: *Lemna* **Common name***:* Common duckweed ***Lemna minor***: free-floating aquatic plants, with one, two or three leaves each with a single root hanging in the water; as more leaves grow, the plants divide and become separate individuals. The root is 1-2 cm long. The leaves are oval, 1-8 mm long and 0.6-5 mm broad, light green, with three (rarely five) veins, and small air spaces to assist flotation. It propagates mainly by division, and flowers rarely produced. **Habitat:** Grows in water with high nutrient levels and a pH of between 5 and 9, optimally between 6.5 and 7.5, and temperatures between 6 and 33 °C. **Significance:** Important food resource for fish and birds(ducks)	 *Lemna minor*  *Lemna gibba*
Name: *Cyperus* It is a perennial plant, which may reach a height of up to 40 cm. **Common name:** nut grass, nut sedge **Habitat:** *Cyperus* is found in cultivated fields, farmlands, neglected areas, wastelands, grasslands, at the edges of forests, and on roadsides, sandy or gravelly shores, riverbanks and irrigation canal banks. Grow profusely in nutrient rich environment. **Leaves:** Leaves sprout in ranks of three from the base of the plant. The flower stems have a triangular cross-section. The flower is bisexual and has 3 stamina and a three-stigma carpel. The fruit is a three-angled achene. **Rhizome:** The root system of a young plant initially forms white, fleshy rhizomes. Some rhizomes grow upward in the soil, then form a bulb-like structure from which new shoots and roots grow, and from the new roots, new rhizomes grow. Other rhizomes grow horizontally or downward, and form dark reddish-brown tubers or chains of tubers. **Harvesting period:** November/December **Impacts/significance:** It is a weed and the world's worst invasive weed based on its distribution and effect on crops. It contains several chemical compounds and used in medicines.	 

Name: *Ludwigia*
Common name: Water Primrose, Water Dragon, marshy jasmine
Habitat: Still or slow flowing freshwater habitats, occurring in marshes, swamps, ditches, ponds, and around lake margins, where they form dense floating mat. Shallow, nutrient-rich ponds, lakes, and drainage ditches provide ideal conditions for abundant growth of this weed.
Aquatic floating herb, floats crowded at nodes, white
Leaves alternate simple, ovate, obtuse entire
Flowers: Axillary, solitary, peduncle 2.5 cm long, corolla 5, yellow, inserted on the rim of the disc, base narrow.
Flowering: February-July
Harvesting period: August
Impacts: Once established, however, it forms dense, monotypic stands along shorelines and banks and then begins to sprawl out into the water and can form floating islands of vegetation. At this point, Ludwigia can clog waterways, damage structures and dominate native vegetation. Large accumulations of this species can lead to a depletion of oxygen levels in the water while also competing with native species for space and resources.

Name: *Colocasia*
Common name: Green Taro, cocoyam
Habitat: This species usually grows in wet fields and near the banks of ponds and streams.
Description: plant is a perennial herb with clusters of long heart- or arrowhead-shaped leaves
It produces heart shaped leaves 2-3 ft long and 1-2 ft across on 3 ft long stalks that all emerge from an upright tuberous rootstock, corm.
The stems are usually several feet high. Plant bears a short underground stem called a corm, where the plant stores starch produced by the leaves. The inflorescence is a pale green spathe and spadix
Flowers tiny, densely crowded on upper part of fleshy stalk, with female flowers below and male flowers above. Fruit a small berry, in clusters on the fleshy stalk.
Significance: the plant is used for several purposes across the worlds such as fodder, medicine or as an ornamental plant

Name: *Eichhornia crassipes* **Common Name:** Water hyacinth **Description:** Water hyacinth is a free-floating perennial aquatic plant, with broad, thick, glossy, ovate leaves; leaves are 30-40 cm long with spongy petiole. Roots are fibrous and featherlike. **Flowering:** March-July **Harvesting period:** August **Habitat:** Water hyacinth grows in still or slow-flowing fresh water in tropical and temperate climates. Optimum growth occurs at temperatures of between 28°C and 30°C, and requires abundant nitrogen, phosphorus and potassium. **Impact:** Its wide spread occurrence in the fresh water lakes and riverbeds is harmful to fishing (depleting DO), rowing, and depleting water content from the water bodies and interfering in water utilization and other activities. Water hyacinth by its abundance of leaves, dense vegetation and innumerable rootlets in tertiary manner obstruct water flow in irrigation channels and displaces many aquatic grasses, which were useful as fodder for cattle, and suppresses the phytoplankton growth. Water hyacinth provides suitable breeding places for mosquitoes and other disease-carrying insects by stagnating the water in ditches and shallow areas. **Uses**: Phytoremediation, wastewater treatment	 

7.0 Land use (LU) Dynamics in Wetlands Catchment

Land use changes in the wetland catchments are the direct and indirect consequence of human actions to secure essential resources. These changes encompass the greatest environmental concerns of human populations today, including loss of biodiversity, pollution of water and soil, and changes in the climate. Monitoring and mitigating the negative consequences of LU changes, while sustaining the production of essential wetlands resources has therefore become a major priority today.

Land use change analyses is done using Landsat MSS (1973), IRS P6 data (2013) and Google Earth (http://earth.google.com). The Landsat data is cost effective, with high spatial resolution and freely downloadable from public domains like GLCF (http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp) and USGS (http://glovis.usgs.gov/). IRS P6 LISS-IV (Indian Remote Sensing Satellite, part of the Indian Space Programme) data was procured from the National Remote Sensing Centre, Hyderabad (http://www.nrsc.gov.in).

Remote sensing data obtained were geo-referenced, rectified and cropped corresponding to the study area. Geo-registration of remote sensing data (Landsat data) has been done using ground control points collected from the field using pre calibrated GPS (Global Positioning System) and also from known points (such as road intersections, etc.) collected from geo-referenced topographic maps published by the Survey of India. In the correction process numerous GCP's are located in terms of their two image coordinates; on the distorted image and in terms of their ground coordinates typically measured from a map or located in the field, in terms of UTM coordinates as well as latitude and longitude. The Landsat data of 1973 are with a spatial resolution of 57.5 m x 57.5 m (nominal resolution), while IRS P6 are of 5.8 m.

Land use analyses involved (i) generation of False Color Composite (FCC) of remote sensing data (bands–green, red and NIR). This composite image helps in locating heterogeneous patches in the landscape, (ii) selection of training polygons by covering 15% of the study area (polygons are uniformly distributed over the entire study area) (iii) loading these training polygons co-ordinates into pre-calibrated GPS, (vi) collection of the corresponding attribute data (land use types) for these polygons from the field. GPS helped in locating respective training polygons in the field, (iv) supplementing this information with Google Earth and (v) 60% of the training data has been used for classification, while the balance is used for validation or accuracy assessment. The land use analysis was done using supervised classification technique based on Gaussian maximum likelihood algorithm with training data (collected from field using GPS).

Classifier based on Gaussian Maximum Likelihood algorithm has been widely applied as an appropriate and efficient classifier to extract information from remote sensing data. This approach quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel of remote sensing data, assuming the distribution of data points to be Gaussian. After evaluating the probability in each category, the pixel is assigned to the most likely class (highest probability value). **GRASS GIS *(Geographical Resources Analysis Support System***, http://ces.iisc.ernet.in/grass***)*** a free and open source software with the robust support for processing both vector and raster data has been used for analyzing RS data. Temporal remote sensing data have been classified through supervised classification techniques by using available multi-temporal "ground truth" information. Earlier time data were classified using the training polygon along with attribute details compiled from the historical published topographic maps, vegetation maps, revenue maps, land records available from local administrative authorities.

Figure 9: Land use dynamics in Jakkur lake catchment

1973 (57M) 2013 (2.7M)

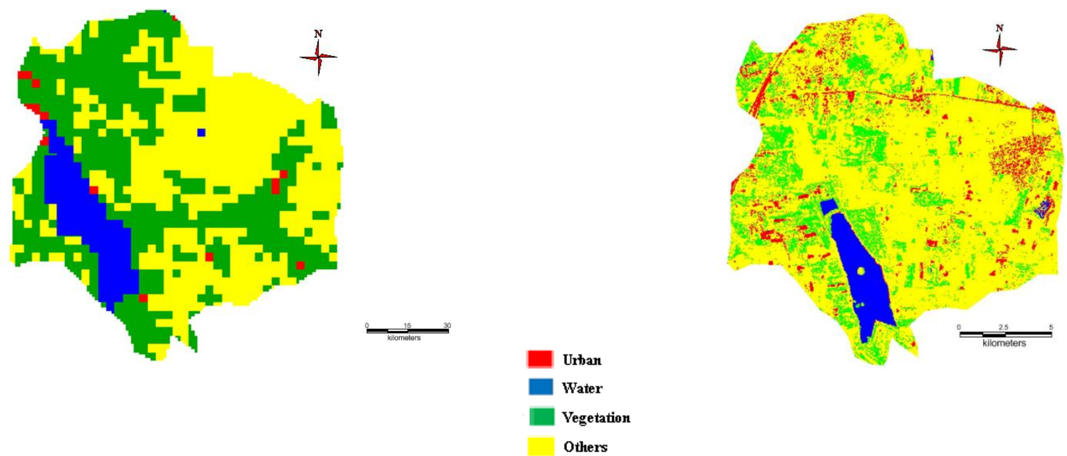

Table 6: Land use changes in Jakkur lake catchment (1973 -2013)				
Land Use categories (%)				
Years	**Urban**	**Vegetation**	**Water**	**Others**
1973	1.19	44.06	5.63	49.1
2013	6.56	22.38	4.79	65.81
% Change	5.37	-21.68	-0.84	18.71

Temporal remote sensing data of Landsat (1973) and IRS data (2013) were classified into four land use categories (**Figure 9**): tree vegetation, built-up, water-bodies and others (agriculture, open area, etc.). The analyses show decline of tree vegetation by 50% from 44.06% (1973) to 22.38% (2013), with an increase in built-up from 1.19 (1973) to 6.56% (2013). Details of land use analyses are listed in Table 6.

8.0 Integrated Wetlands Ecosystem: Sustainable Model to Mitigate Water Shortage in Bangalore

Performance assessment of an integrated wetland ecosystem at Jakkur provides vital insights towards mitigating water crisis in Bangalore. An integrated system as outlined in Figure 10. The integration of sewage treatment plant with wetlands (consisting of reed bed and algal pond) has helped in sustained treatment of water for reuse.

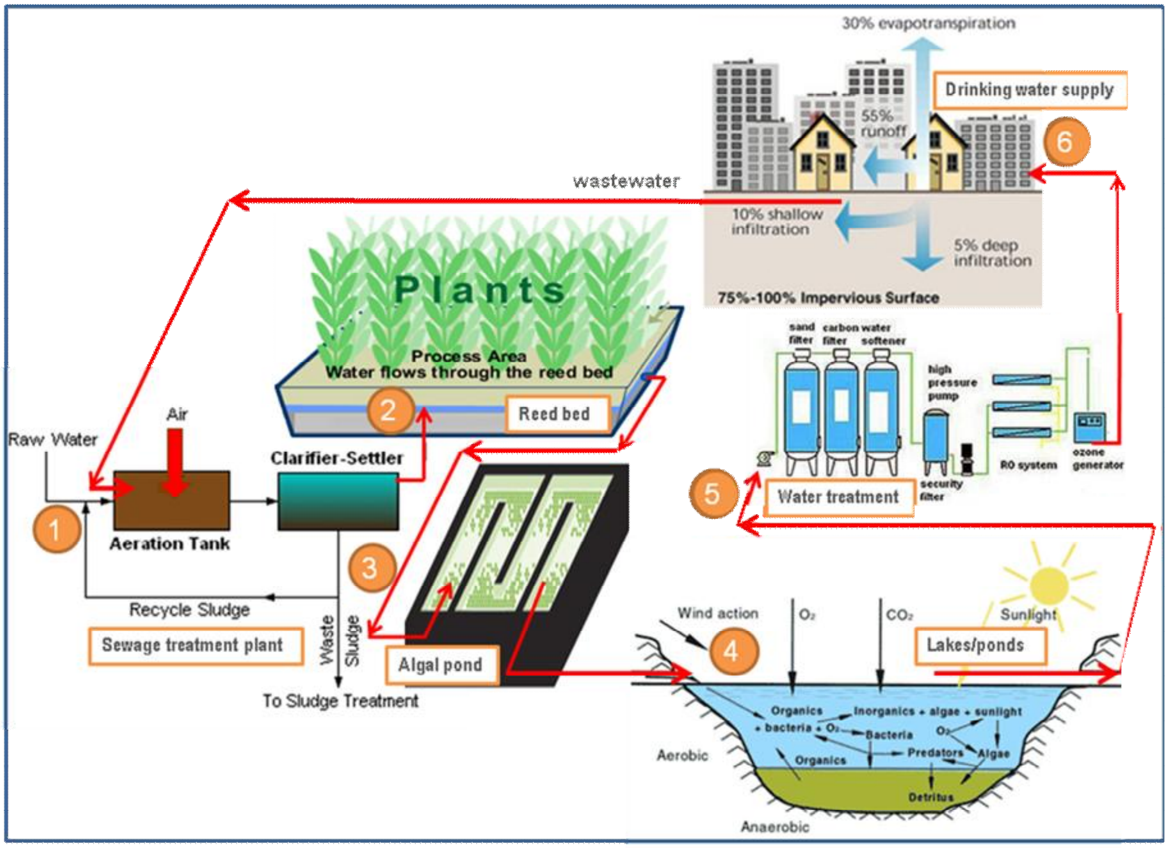

Figure 10: Integrated wetlands system for managing water and wastewater

8.1 Functional aspects of the integrated wetlands systems are:

- Sewage Treatment Plant (STP): The purpose of sewage treatment is to remove contaminants (Carbon and solids) from sewage to produce an environmentally safe water. The treatment based on physical, chemical, and biological processes include three stages – primary, secondary and tertiary. Primary treatment entails holding the sewage temporarily in a settling basin to separate solids and floatables. The settled and floating materials are filtered before discharging the remaining liquid for secondary

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treatment to remove dissolved and suspended biological matter. STP's effluents were still nutrient rich requiring further treatment (for nutrient removal) and stabilization for further water utilities in the vicinity.

- Integration with wetlands [consisting of reed (typha etc.) beds and algal pond] would help in the complete removal of nutrients in the cost effective way. A nominal residence time (~5 days) would help in the removal of pathogen apart from nutrients. However, this requires regular maintenance of harvesting macrophytes and algae (from algal ponds). Harvested algae would have energy value, which could be used for biofuel production. The wetland systems helps in the removal of ~77 % COD, ~90% BOD, ~33% NO_3-N and ~75% PO_4^{3}-P (Figure 11).

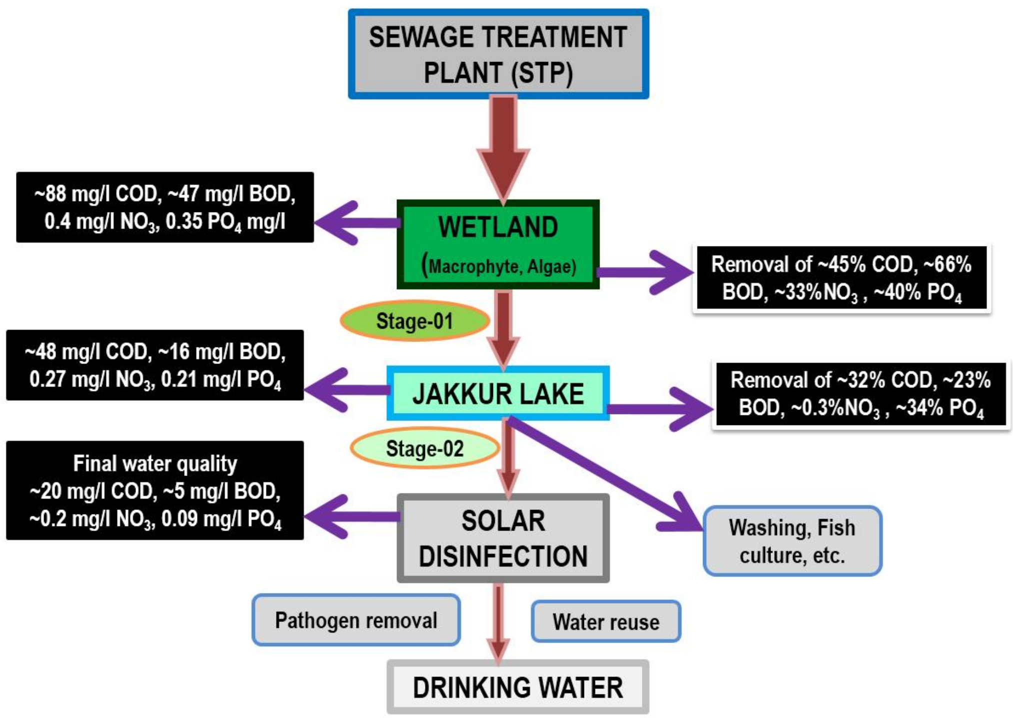

Figure 11: Level of treatment at various stages of integrated wetlands system

Pilot scale experiment in the laboratory has revealed nutrient removal of algae are 86%, 90%, 89%, 70% and 76% for TOC, TN, Amm.-N, TP and OP respectively (Figure 11) and lipid content varied from 18-28.5 % of dry algal biomass. Biomass productivity is of ~122 mg/l/d and lipid productivity of ~32 mg/l/d. Gas chromatography and mass spectrometry (GC-MS) analysis of the fatty acid methyl esters (FAME) showed a higher content of desirable fatty acids (biofuel properties) with major contributions from saturates such as palmitic acid

[C16:0; ~40%], stearic acid [C18:0; ~34%] followed by unsaturates as oleic acid [C18:1(9); ~10%] and linoleic acid [C18:2(9,12); ~5%]. The decomposition of algal biomass and reactor residues with calorific exothermic heat content of 123.4 J/g provides the scope for further energy derivation (Mahapatra et al., 2014). Water that comes out of the wetlands is portable with minimal efforts for pathogen removal via solar disinfection.

Our earlier experiments have shown the vital role of wetlands in recharging the groundwater resources, evident from the decline of groundwater table to 200-300 m from 30 to 50 m with the removal of wetlands. This means, Jakkur lake system is helping in recharging the groundwater sources. There need to be regulation on the exploitation of groundwater in Bangalore. Over exploitation of groundwater through borewells by commercial private agencies would harm the sustainability, depriving the local residents in the vicinity who are dependent on borewells in the absence of piped water supply from the government agency.

Measures required to mitigate water crisis in burgeoning Bangalore are:

1. Rainwater harvesting at decentralized levels through wetlands (lakes) is the most efficient and cost effective mechanism to address the water crisis in the region than technically infeasible, ecologically unsound and economically unviable river diversion or inter linking of river schemes being proposed by vested interests in various parts of the country.
2. Rejuvenation, restoration of existing lakes. This is necessary to decontaminate water bodies due to the unabated inflow of effluents and sewage.
3. Removal of deposited silt would enhance the storage capacity as well as bioremediation capability of lakes.
4. Integrated wetlands ecosystem (consisting of reed bed (typha, etc.), algal pond) with lake helps in the treatment of water entering the lake through bioremediation. Replicating Jakkur wetland ecosystem would help in the treatment of water and reuse. This also has an added advantage of maintaining groundwater quality in the vicinity. Studies have shown that groundwater sources in the vicinity of sewage fed lakes are contaminated, evident from the nutrient enrichment, presence of coliform, etc.
5. Sustainable management of integrated wetlands ecosystem includes
   i). Letting only treated sewage to wetlands.

ii). Maintaining at-least 33% vegetation cover in the lake catchment. This is necessary to ensure sufficient infiltration of rainwater to ensure water in the lake throughout the year.

iii). Ban on number of borewells (or extraction of groundwater) in the lake catchment and command area

iv). Restriction on overexploitation of groundwater in the lake catchment to ensure sustained water availability to the local residents

v). Regular harvesting of macrophytes

vi). Mechanism to harvest algae at regular interval and manufacture of biofuel and other beneficial biochemical products. These would enhance the employment opportunity in the region.

vii). Provision of appropriate infrastructure for washer men who depend on the lake for livelihood through washing clothes.

viii). Restriction on the introduction of exotic species of fish by commercial vendors

ix). Permission to scientific fish culturing through strict regulations (on fish species introduction, type of nets, frequency of harvesting, restrictions during breeding season and locations)

9.0 Conclusion

Surface water-bodies (lakes, ponds, tanks, etc.) in Bangalore are subjected to high nutrient loads due to the sustained inflow of untreated or partially treated sewage, altering physico-chemical and biological integrity of water bodies. The treated water from sewage treatment plant in Jakkur still contains nutrients as primary and secondary treatment does not completely remove nutrients. However, passage of STP effluents through wetlands (consisting of emergent macrophytes and algal pond) ensures removal of nutrients to an extent ensuring portability of water. This study investigates the water quality at different stages in the integrated wetland system. Physico-chemical and biological parameters were monitored as water enters the algal pond (wetland) from the STP (sewage treatment plant), outlet of wetlands and at the inlet, middle and outlets of Jakkur Lake. The nutrient analysis highlights of nutrient removal by wetlands due to macrophytes and algae, which removes 77 % COD, ~90 % BOD, ~33 % NO_3-N and ~75 % PO_4^{3-}P. The first stage comprising of emmergent vegetataion and algal pond removes ~45% COD, ~66 % BOD, ~33 % NO_3-N and ~40 %

PO_4^{3-}P. Jakkur lake as a seconf stage treats the water and acts as the final level of treatment and removes ~ 32 % COD, ~23% BOD, ~ 0.3 % NO_3-N and ~34 % PO_4^{3-}P.The combination of all the stages leads to a complete removal of nutrients to acceptable levels according to CPCB norms. This study provided vital insights towards environmentally sound option of managing wastewater, while addressing water crisis due to unscientific and chaotic urbanisation in Bangalore.

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Macrophytes of Wetlands at Jakkur	
	
	
	
	

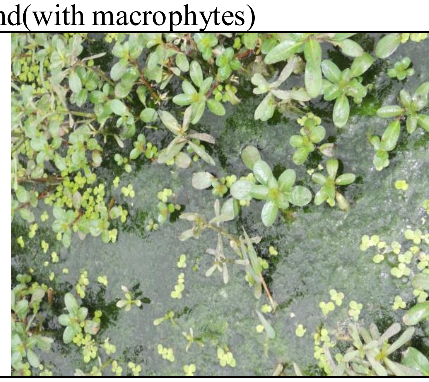
Outlet of the lake - people washing clothes (S1)

Second Outlet (S2)

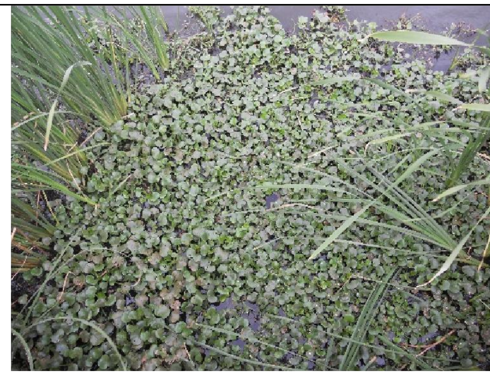

Macrophyte cover before outlet


Inlet from treatment plant(treated water in channel and untreated beside)


Inlet to the lake after algae pond(with macrophytes)

Algae and macrophyte in the algae pond(wetland)



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