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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).

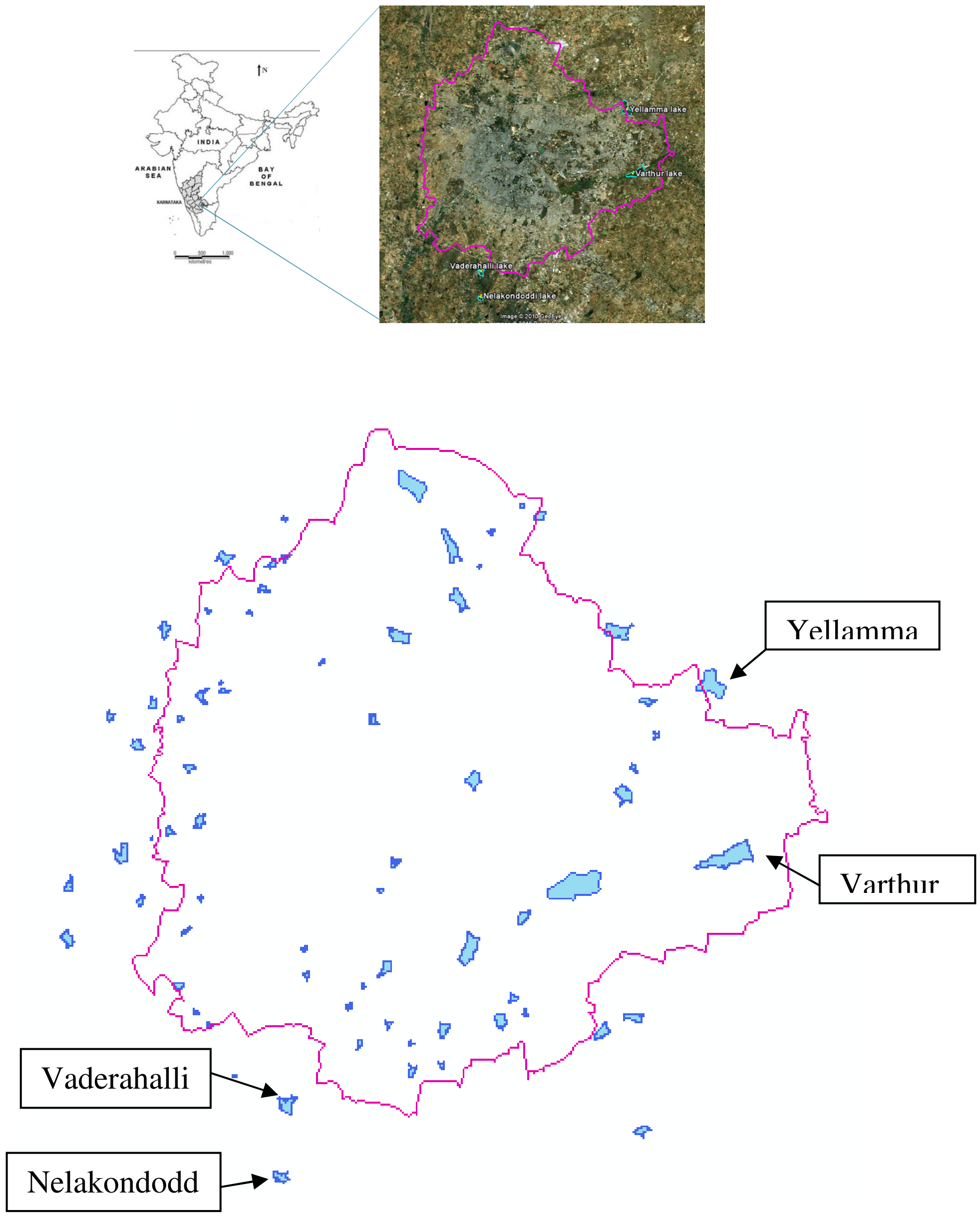

Figure 1: Study area with India Map and Bangalore map with 4 lakes marked on the digitized vector layer of Bangalore

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).

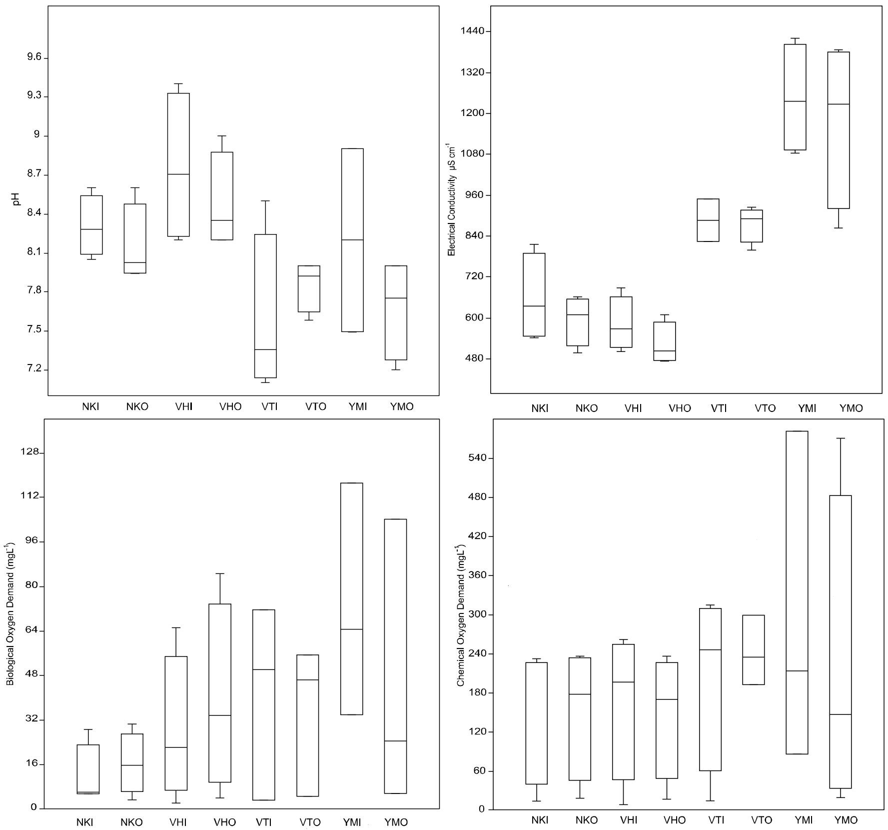

Figure 2: Variation in water quality across sampling sites [For sampling sites and its codes refer annexure I](a) pH (b) Electric conductivity (c) Biological oxygen demand (d) Chemical oxygen demand

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.

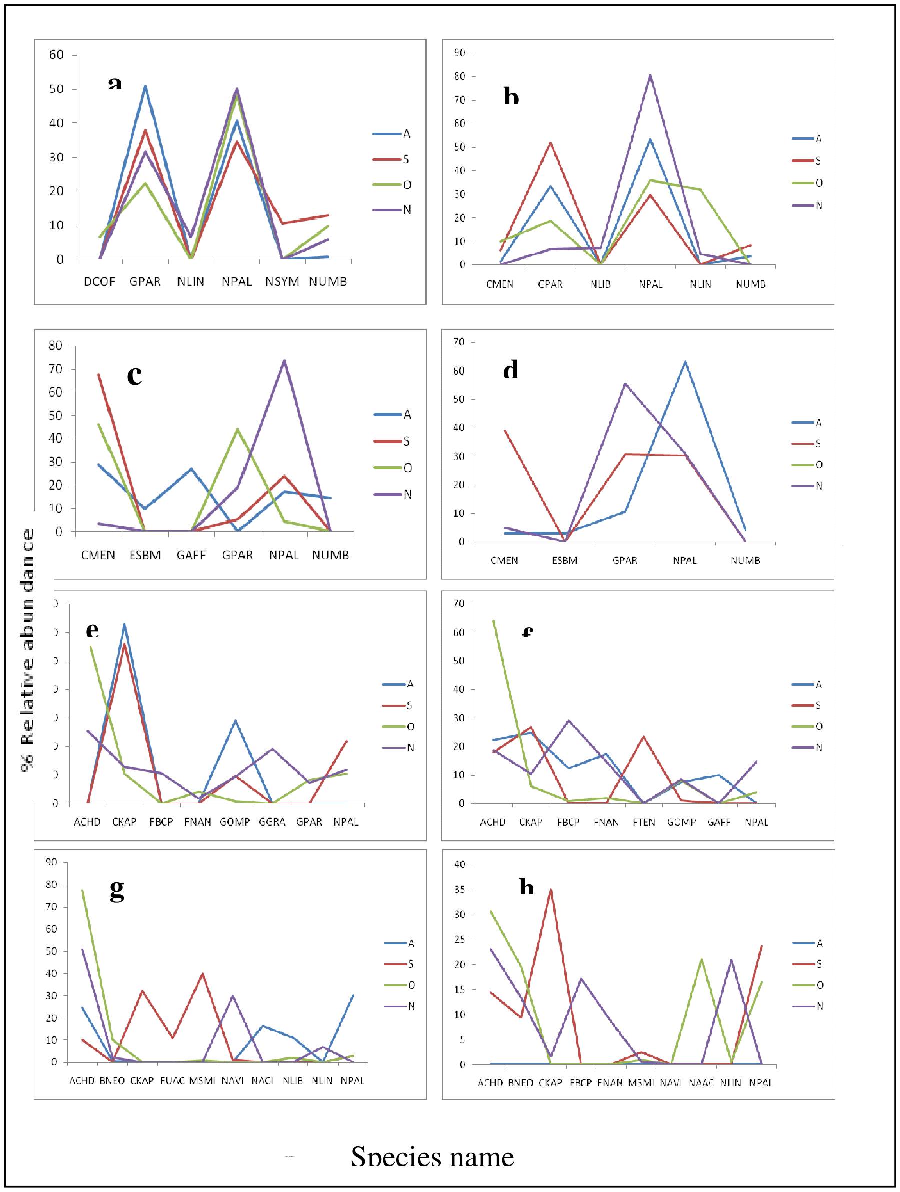

Figure 3: Percentage relative abundance of species across months [A-August, S-September, O-October, N-November] (a) Varthur Siddapura (b) Varthur Fishing (c) Yallamma Outlet (d) Yallamma Inlet (e) Vaderahalli Outlet (f) Vaderahalli Inlet (g) Nelakondoddi Outlet.

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).

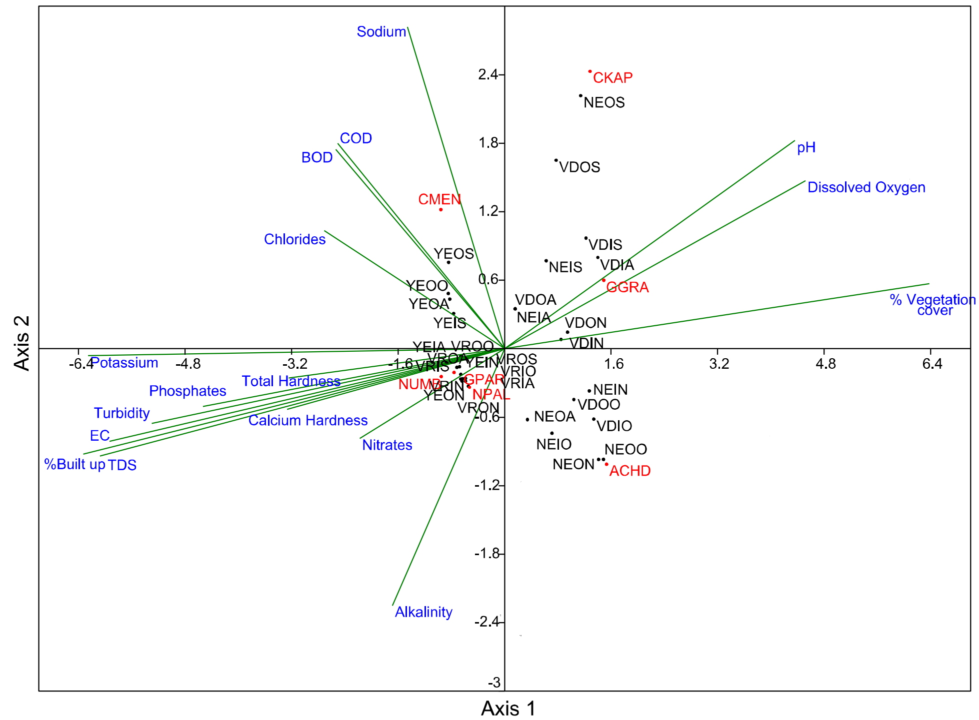

Figure 4 Canonical correspondence analysis (CCA) plot explaining impact of land use/ land cover on species distribution.

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.

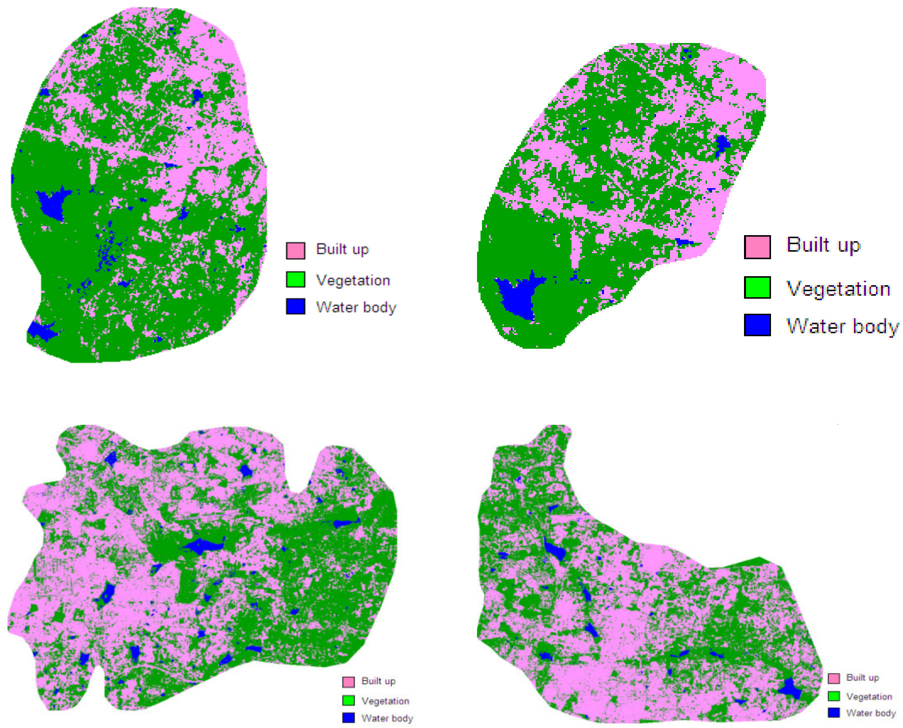

Figure 6: Land use in the catchments of . (a) Nelakondoddi, (b) Vaderahalli, (c) Varthur and (d) Yellamma wetlands.

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).

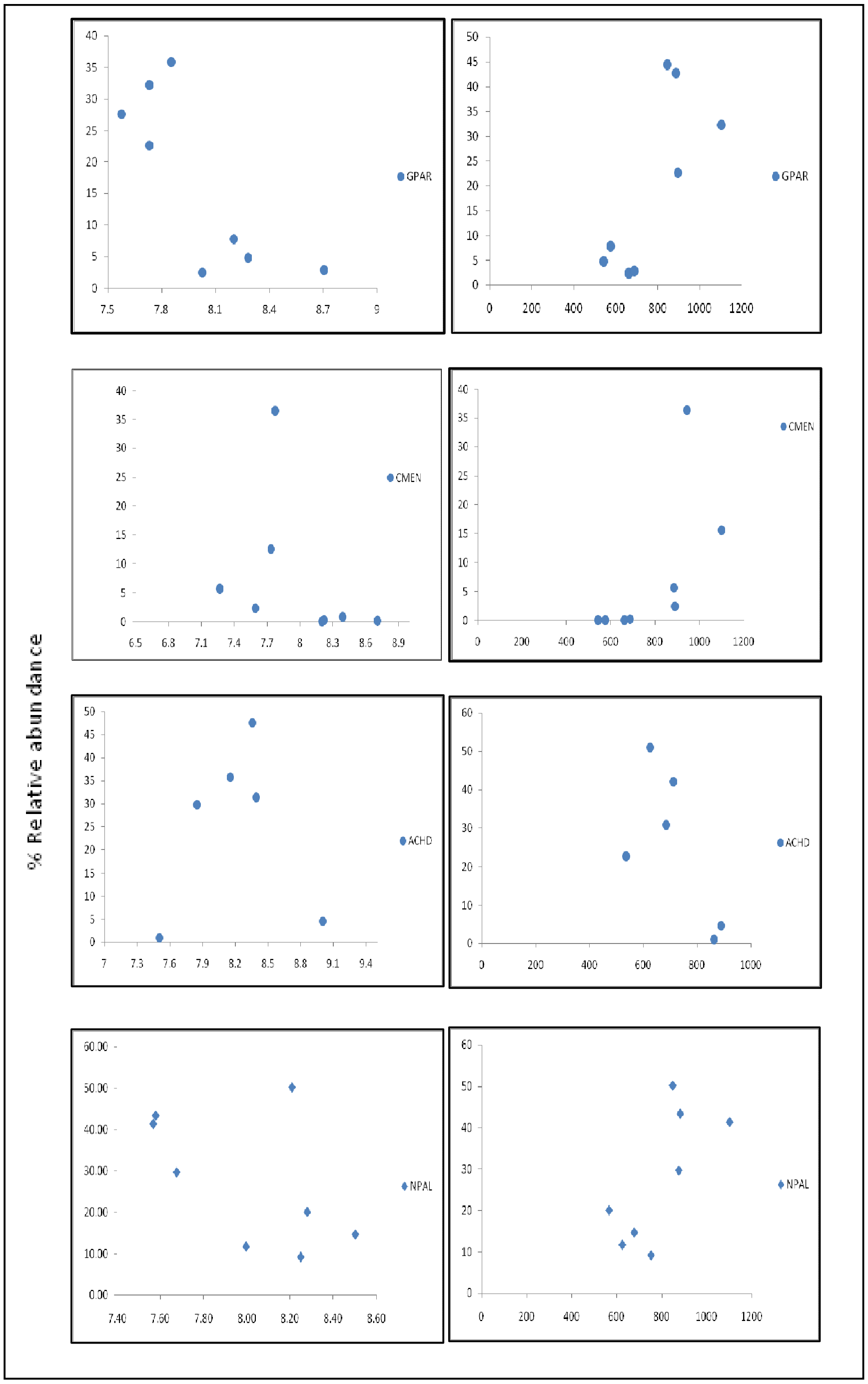

Figure 5 Distribution and autecology of dominant taxa across pH and Electric conductivity

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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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.

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

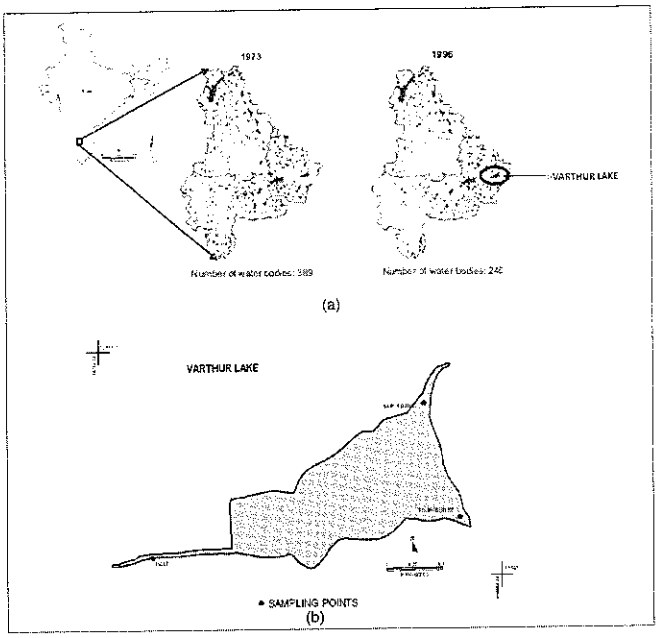

Fig. 1: (a) No. of water bodies in Bengaluru in 1973 and 1996 and (b) Varthur Lake with samplig points (inlet, north outlet and south outlet)

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 (°C)	29.00	30.00	26.00	—
Air Temperature (°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	761	755	768	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	29	1.06	0
Chlorides (ppm)	-	100	170	167.56	1917
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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