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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).

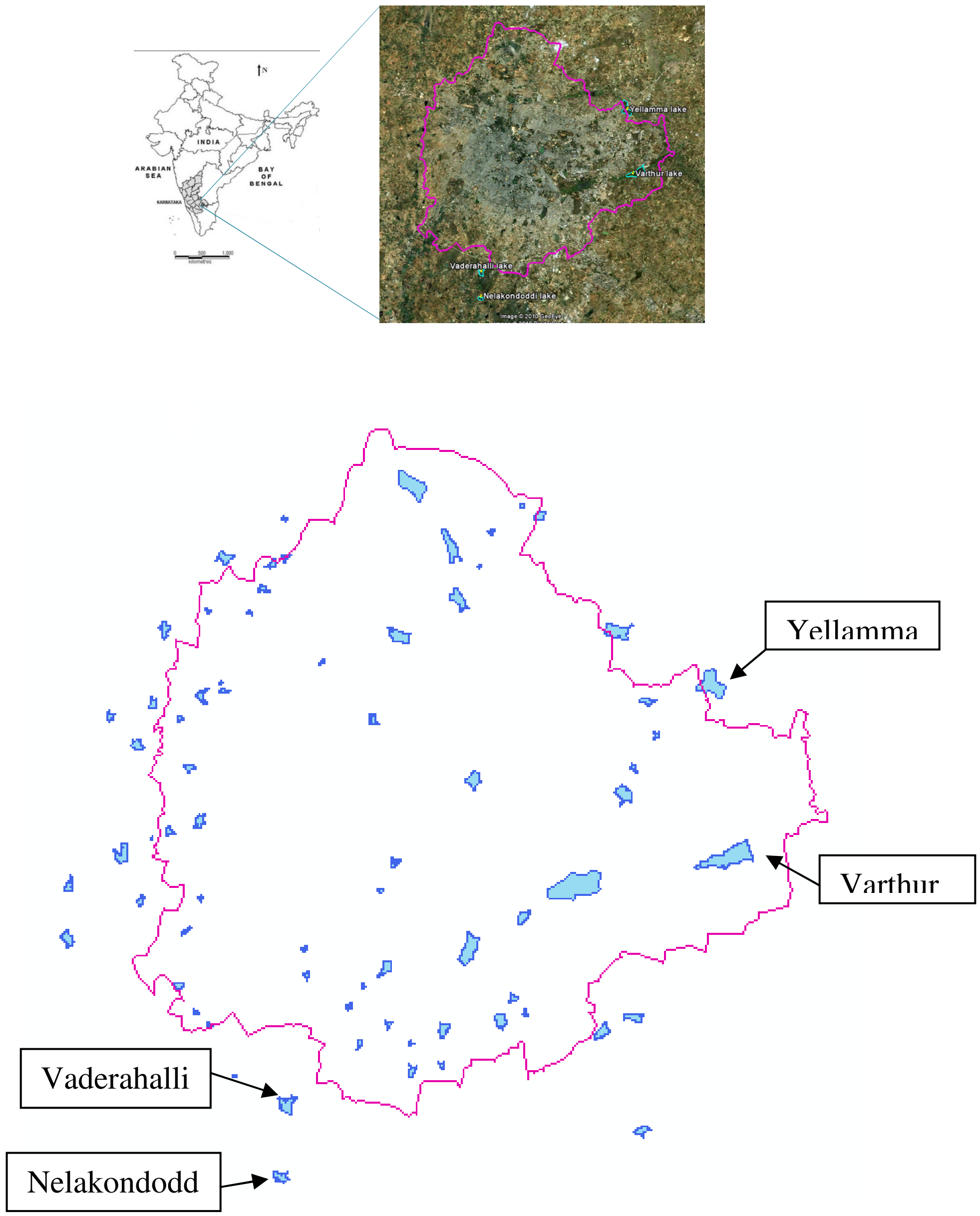

Figure 1: Study area with India Map and Bangalore map with 4 lakes marked on the digitized vector layer of Bangalore

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).

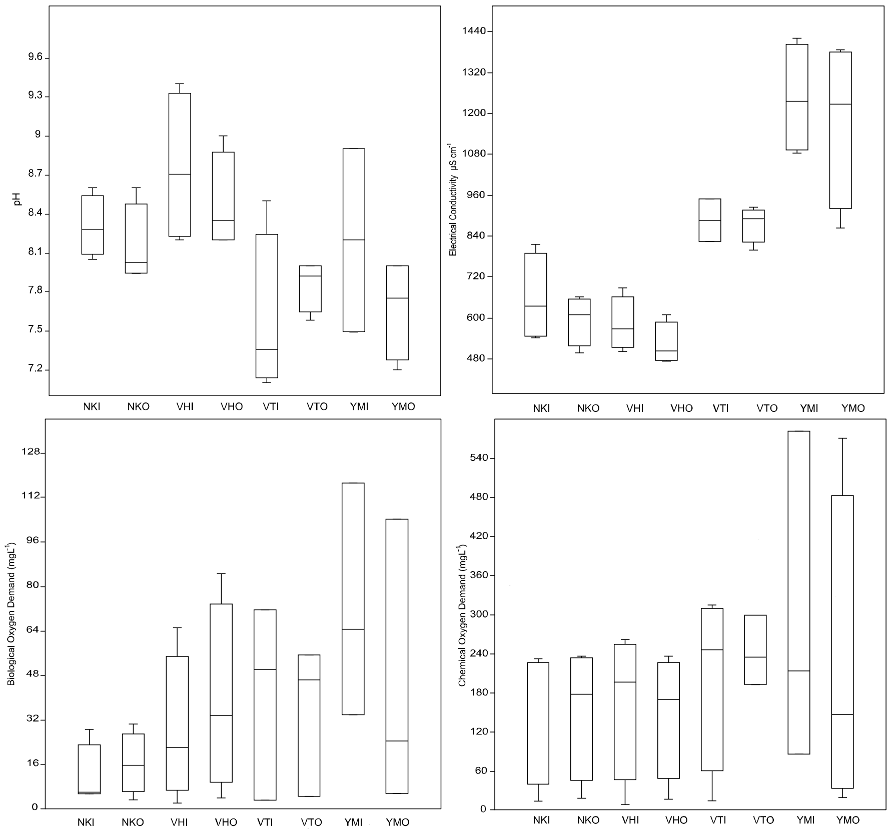

Figure 2: Variation in water quality across sampling sites [For sampling sites and its codes refer annexure I](a) pH (b) Electric conductivity (c) Biological oxygen demand (d) Chemical oxygen demand

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.

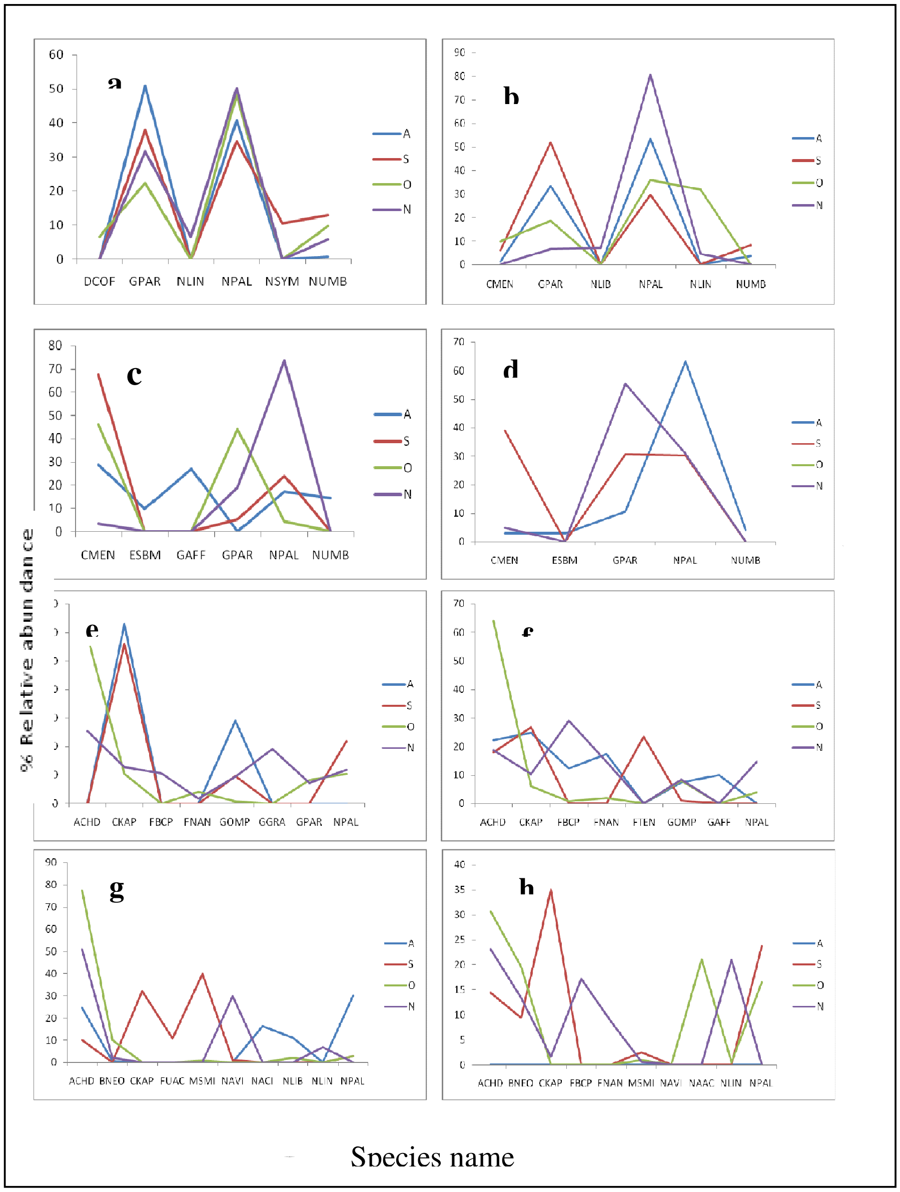

Figure 3: Percentage relative abundance of species across months [A-August, S-September, O-October, N-November] (a) Varthur Siddapura (b) Varthur Fishing (c) Yallamma Outlet (d) Yallamma Inlet (e) Vaderahalli Outlet (f) Vaderahalli Inlet (g) Nelakondoddi Outlet.

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).

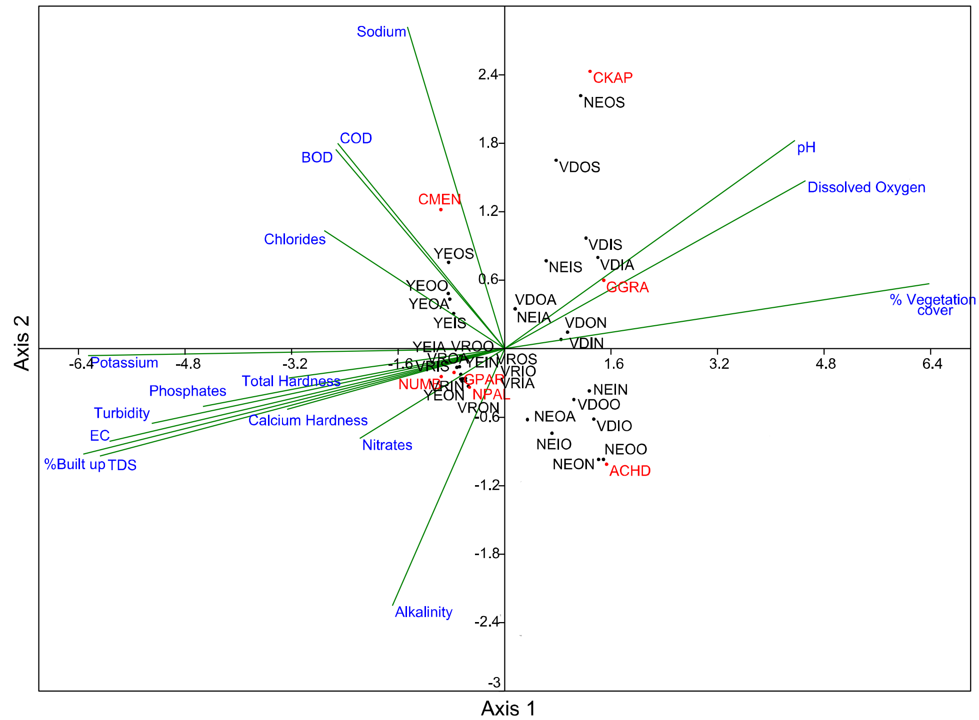

Figure 4 Canonical correspondence analysis (CCA) plot explaining impact of land use/ land cover on species distribution.

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.

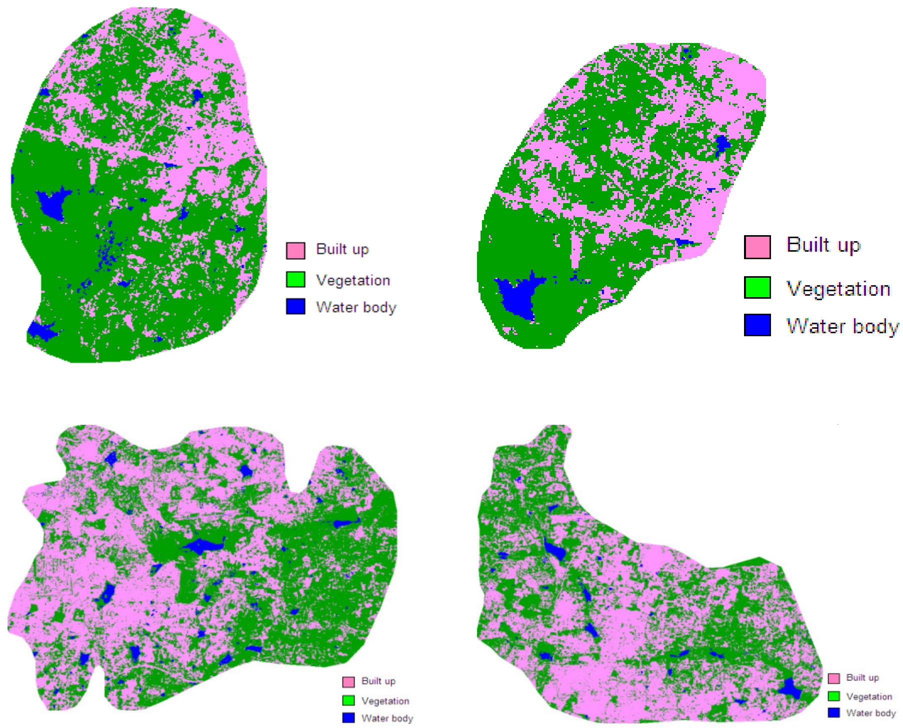

Figure 6: Land use in the catchments of . (a) Nelakondoddi, (b) Vaderahalli, (c) Varthur and (d) Yellamma wetlands.

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).

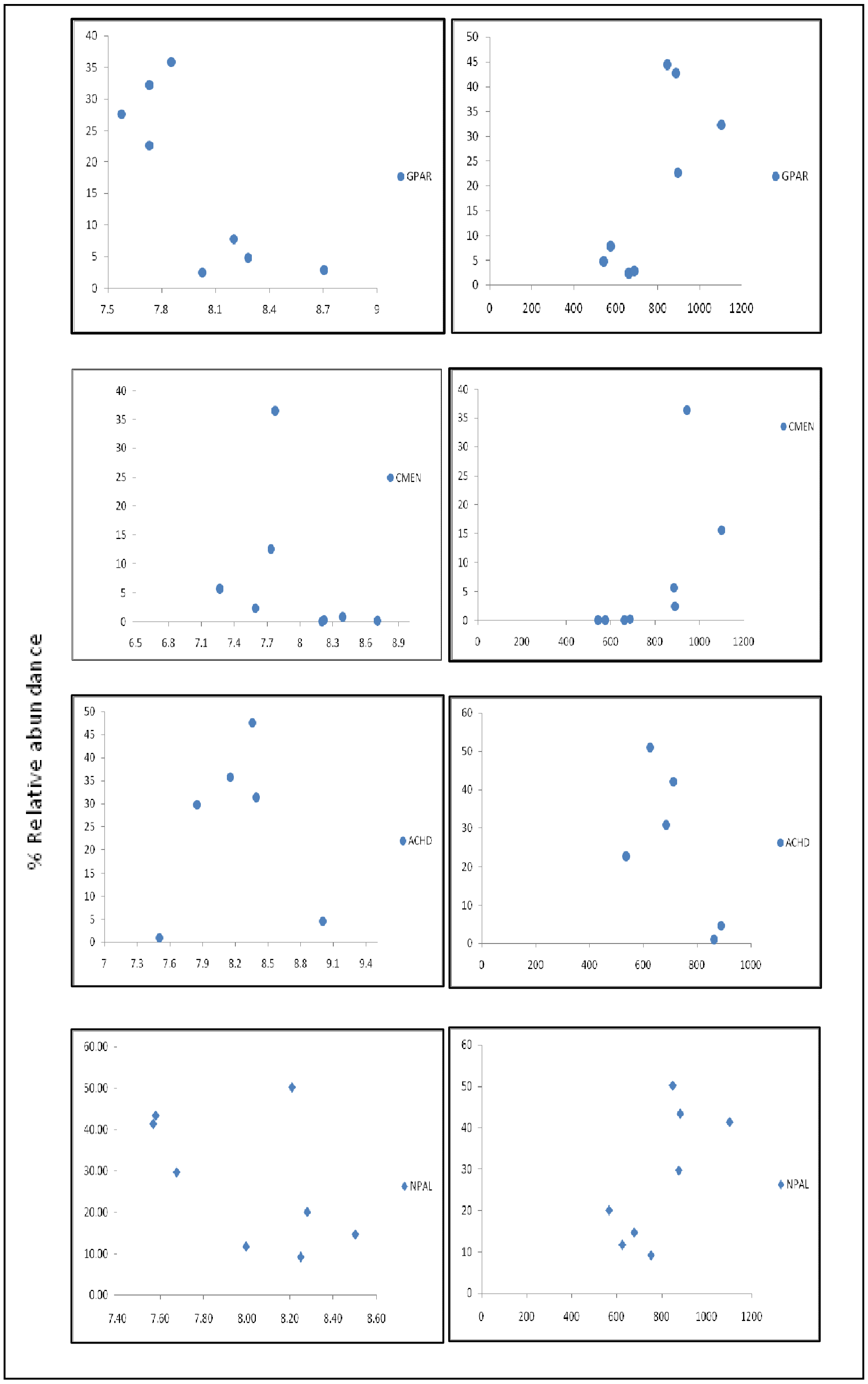

Figure 5 Distribution and autecology of dominant taxa across pH and Electric conductivity

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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