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Diatom-Based Pollution Monitoring in Urban Wetlands

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Diatoms comprise a ubiquitous, photosynthetic and distinctive group of unicellular algae. They are more specific in their preference and tolerance of environmental conditions than most aquatic biota and have long been recognized as excellent indicators of ecological status of water bodies. This study documents the diatom flora of six urban wetlands of Coimbatore city, examines benthic diatom assemblages across different habitats and investigates pollution status based on diatom composition. 96 species belonging to 34 genera were recorded and out of them 27 species were dominant. The dominant species that are cosmopolitan include *Cyclotella meneghiniana*, *Nitzschia* sp., *Sellaphora pupula*, *Gomphonema parvulum* and *Navicula* sp. Singanallur wetland and Noyyal river stretches are characterized by pollution-tolerant species with low diatom diversity. Diatom assemblages indicate wetlands, Vedapatti, Perur and Sundakamuthur are moderately polluted, while Pallapalayam, Noyyal River and Singanallur wetlands are heavily polluted.

Keywords: Urban wetlands, Pollution indicators, Diatom-indices, Diatom assemblages, Coimbatore

Introduction

Wetlands are essential part of human civilization, meeting many crucial needs for life on earth such as drinking water, energy, fodder, biodiversity, flood storage, transport, recreation and climate stabilizers. In recent times, humans have distorted the natural flow regime of wetlands in urban area either by altering natural drains, changing land cover drastically or letting sewage into wetland. The removal of wetland systems or letting sewage has caused the deterioration of water quality and ecological degradation in catchment (Prasad *et al.*, 2002). In India, wetlands are distributed in all the biogeographic regions occupying 58.2 million ha, including areas under wet paddy cultivation

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(Directory of Indian Wetlands, 1990). They exhibit significant ecological diversity, primarily because of variability in climate, habitat and topography. Today, wetlands are one of the most threatened habitats in India, which has been converted for agriculture, industry or settlements and some are affected by industrial effluents, sewage, household wastes and sedimentation. Due to urbanization and lack of holistic approaches in land management, land and water bodies in and closer to urban area have been targeted. The water crisis, frequent flooding in urban areas necessitates understanding the role of wetlands, and the need for integrated approaches to maintain the ecological balance, while meeting the demands of the growing population. Effective assessment tools are needed for consistent evaluation of the condition with stressors of wetland resources for solving problems. Many environmental factors vary on different spatial and temporal scales in wetlands, which include climate, land use and geomorphology of a watershed to the physical, chemical and biological characteristics (Richards *et al.*, 1996). In this context, monitoring involving biological communities of an ecosystem would help in assessing, since they integrate and reflect the effects of chemical and physical disturbances that occur in short duration as well as over an extended period of time.

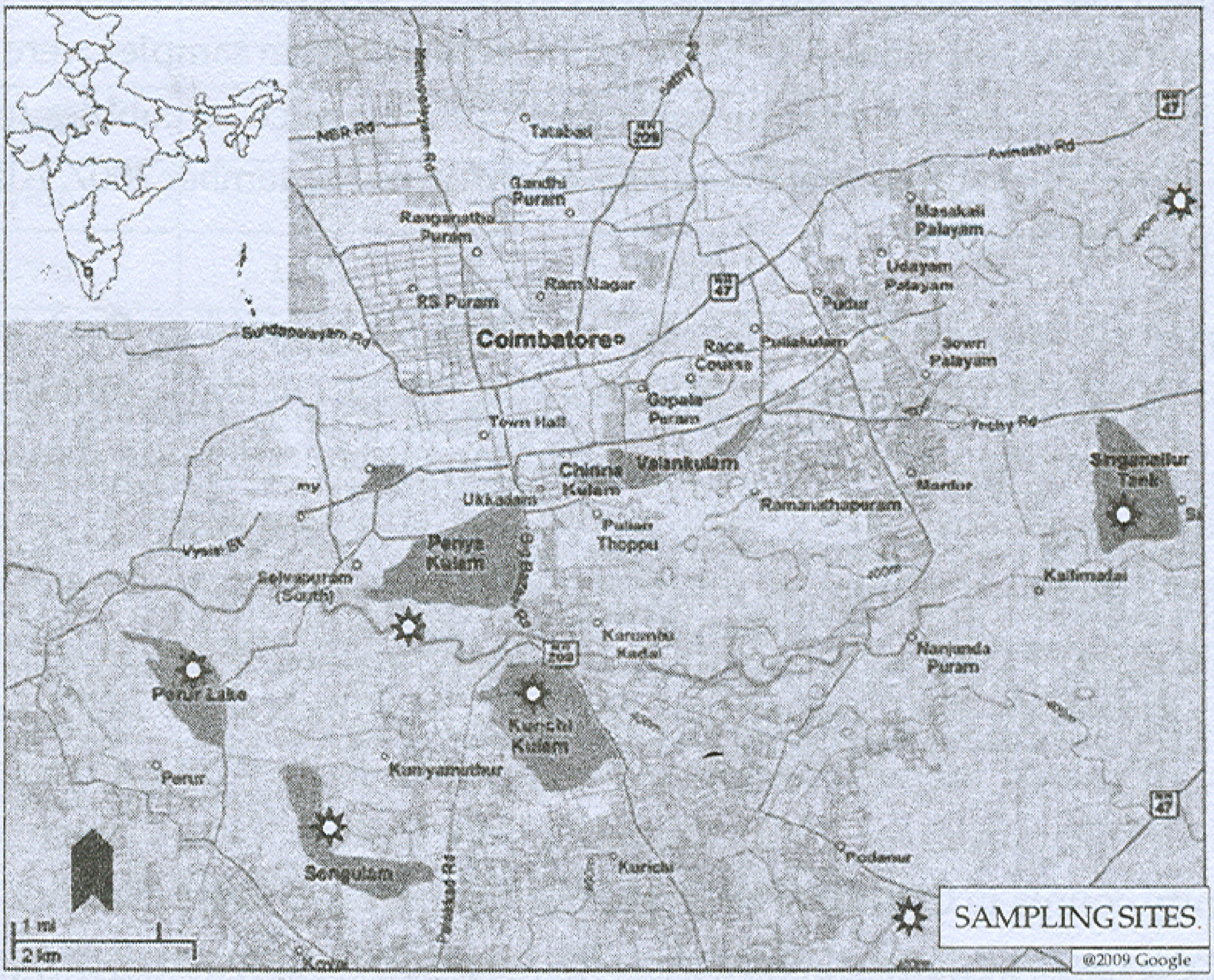
Diatoms are more specific in their preference and tolerance of environmental conditions than most other aquatic biota. Diatoms were the first group of biota used for detecting organic pollution (e.g., the saprobian system by Kolkwitz and Marsson, 1909, cited in Stoermer and Smol, 2001). They respond directly and are sensitive to many physical, chemical and biological changes such as temperature, nutrient concentration and herbivory. They are sensitive to many habitat conditions and show variability in biomass and species composition. At higher spatial and temporal levels, effects of resources and stressors on diatom assemblages can be constrained by climate, geology and land use. Diatoms are readily distinguished to species and subspecies level based on unique morphological features. Diatoms have one of the shortest generation times of all biological indicators. They reproduce and respond rapidly to environmental change and provide early warning of both pollution increases and habitat restoration success. Diatom frustules are preserved in sediments and record habitat history. Diatoms collection and methods are easy and cost effective. A golden-brown mucilage film on the surface of substrata indicates the presence of benthic diatoms whereas free living in the water column is the planktonic diatoms. Data on diatoms as indicators of water quality reflecting pH, salinity and organic pollution in Europe, America, South Africa and Japan have been available for a long time (e.g., Patrick, 1986; Schoeman, 1973; Round *et al.*, 1990; and Cox, 1991). However, there is no information available on diatoms as indicator species of wetlands in India. The present study assesses the pollution status of six major wetlands in an urban ecosystem using diatoms as bioindicators.

Materials and Methods

Study Area

Coimbatore, known popularly as 'Manchester of India', is an important industrial city, located in Tamil Nadu (10°55′-11°10′ N, and 77°10′- 76°50′ E) at an average altitude of 470 m, ranking 11th in terms of population (Figure 1). There are more than 30,000 small, medium and large industries including textile mills and foundries in the city employing about 40% of the population. The growing industrial sector and ensuing immigration of people pose heavy burden on the city infrastructure that did not grow in proportion. The city does not have facilities for treatment of industrial, municipal and domestic wastes. Wetlands and Noyyal river have been used for disposal of wastes of the city. Natural drainage networks have been converted to storm water drains for letting the sewerage into wetlands without any treatment. In Coimbatore city there are 28 wetlands, mostly fed by the river Noyyal. The river, flowing through the city on its south, originates in the Vellingiri hills in Western Ghats, located on the southwestern side of the city. Wetlands in Coimbatore are seasonal and also have been used as dumping yard for garbage and industrial wastes during dry period (Mohanraj *et al.*, 2000). During the monsoon, with the inflow of water, this activity leads to contamination of groundwater sources. Six wetlands selected for biomonitoring (Figure 1) are: Vedapatti (VP), Pallapalayam (PP), Sundakamuthur (SM), Perur (PR), Noyyal (NL) and Singanallur (SN).

Figure 1: Coimbatore City Map with the Sampling Points Marked



Note: Inset Study Area Marked in India (Maps Courtesy: Google).

Table 1: Diatom Indices Used in this Study		
Abbreviation	Full Name	Reference
IPS	Specific Pollution Sensitivity Metric	Coste (1987)
SLAD	Sládeček's Pollution Metric	Sládeček (1986)
DESCY	Descy's Pollution Metric	Descy (1979)
L&M	Leclercq and Maquet's Pollution Metric	Leclerq and Maquet (1987)
SHE	Steinberg and Schiefele Trophic Metric	Steinberg and Schiefele (1988)
WAT	Watanabe *et al.* Pollution Metric	Lecointe *et al.* (1993)
TDI	Trophic Diatom Metric	Kelly and Whitton (1995)
EPI-D	Pollution Metric Based on Diatoms	Dell'Uomo (1996)
ROTT	Trophic Metric	Rott *et al.* (1999)
IDG	Generic Diatom Metric	Lecointe *et al.* (2003)
CEE	Commission for Economical Community Metric	Descy and Coste (1991)
IBD	Biological Diatom Metric	Prygiel and Coste (1999)
IDAP	Indice Diatomique Artois Picardie	Lecointe *et al.* (2003)
IDP	Pampean Diatom Index (IDP)	Gómez and Licursi (2001)

Water and Diatom Sampling

Water samples were collected from all sampling sites in the sterilized polythene bottles. Physical variables like pH, temperature, electric conductivity, salinity and total dissolved solids were measured on-site using EXTECH combo probe. Diatom samples were collected simultaneously during water sampling from three habitats such as cobbles (epilithic), aquatic plants (epiphytic) and sediment (episammic) during September 2007. All samples were reserved in 70% ethanol.

In the laboratory, samples were processed by $KMnO_4$ + hot HCl method, and slides were prepared using standard methods of Taylor *et al.* (2005). Diatom communities were then analyzed by counting 400 to 450 valves. During enumeration the dimensions of diatom valve characteristics, like length, width and striae densities in 10 μm were measured. Identification of diatoms to the least possible taxonomic level was carried out using taxonomic guides (Gandhi, 1957, 1959a, 1959b, 1961, 1962, 1964, 1967, 1998; Lange-Bertalot, 2001; Krammer, 2002; Taylor *et al.*, 2007; and Karthick *et al.*, 2008). Ecological diversity was calculated for each sample using diversity indices (Magurran, 2004) on PAST version 1.89 (Hammer *et al.*, 2001). Diatom specific indices (Table 1) were calculated from community counts in OMNIDIA version 5.3. Canonical Correspondence Analysis (CCA) using PAST was performed to examine the taxa distribution across sampling sites with reference to environmental variables. CCA mainly focuses on those taxa that vary with measured environmental variables. Only those taxa which are present at least in one sampling site with % relative abundance of 10% are included in the CCA analysis.

Results and Discussion

Water Quality and Diatom Community

Physical variables of water such as pH, temperature, Electric Conductivity (EC), salinity and Total Dissolved Solids (TDS) are listed in Table 2. pH ranged from 7.4 to 9 indicating neutral to alkaline conditions. Electric conductivity ranged from 280 (Vedapatti)-2,250 μScm^{-1} (Singanallur). Diatom analysis revealed that 96 species belonging to 34 genera were recorded from these wetlands, which are listed in Appendix 1. Among all species, 27 species were dominant (i.e., occurring >5% of any given community). Table 3 lists the diversity indices, which shows a significant difference in community structures across the wetlands. Higher values of Shannon, Simpson and Evenness values are recorded for Pallapalayam wetland (PP) compared to Singanallur wetland (SN), where Dominance Index was relatively higher.

Table 2: Water Quality Variables of Coimbatore Wetlands

Sampling Site	Conductivity (mS/cm)	Water Temperature (°C)	pH	Total Dissolved Solids (mg/L)
Vedapatti	280	29.6	7.47	195
Sundakamuthur	283	32.4	9.06	198
Sundakamuthur	283	32.4	9.06	198
Perur	347	29.0	7.92	242
Pallapalayam	733	27.9	9.05	511
Pallapalayam	770	29.3	8.83	543
Noyyal River	1,121	29.7	7.70	781
Singanallur	2,250	29.3	8.53	1,590

Common diatoms genera, such as *Cyclotella* Kiitzing ex Brebisson, *Gomphonema* Ehrenberg, *Nitzschia* Hassall and *Fragilaria* Lyngbye accounted for large proportion of the community in all sites. Figure 2, a plot of genera across pH and Electrical conductivity ranges revealed the following observations: (a) *Cyclotella* sp. occurred in neutral to high alkaline and high electrolytic; (b) *Gomphonema* sp. and *Nitzschia* sp. occurred in entire pH and conductivity ranges; and (c) *Fragilaria* sp. preferred neutral to alkaline pH and moderate electrolytic water.

Diatom Assemblages and Trophic Condition

Distribution of diatom reflects the average ecological conditions of water (Cholnoky, 1968; and Lowe, 1974). In Vedapatti wetland, cosmopolitan extreme pollution-resistant species with measured environmental variables. Only those taxa which are present at least in one sampling site with % relative abundance of 10% are included in the CCA analysis.

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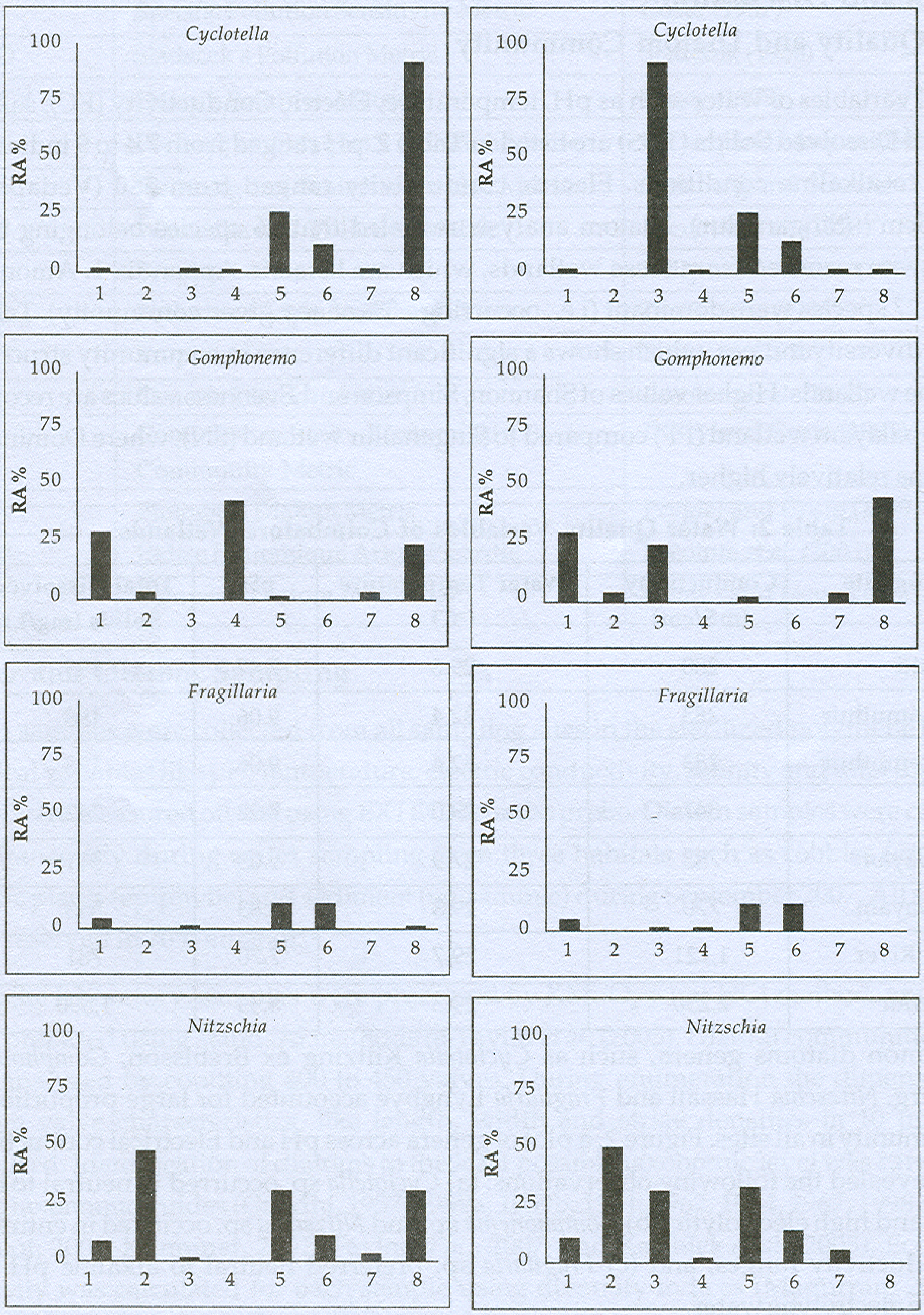
Figure 2: Relative Abundance of Four Most Dominant Genera Plotted with Sites Arranged in Order of Increase in Electrical Conductivity (Left) and pH (Right)



Diadesmis confervaceae Kützing, *Gomphonema gracile* Ehrenberg and *G. turris* Ehrenberg were dominant among 23 species highlighting eutrophic status of water with higher electrolyte. *Aulocosira granulata* (Ehrenberg) Simonsen and *Cyclotella meneghiniana* Kützing

Table 3: List of Diversity Indices for Coimbatore Wetlands								
	VP	**PP**	**SM**	**PP**	**SN**	**PR**	**SM**	**NL**
Number of Species	23	22	29	26	10	28	30	14
Shannon Index	2.3710	2.4980	2.0660	2.6210	0.4135	2.3660	2.5380	1.4720
Simpson	0.8526	0.8877	0.7276	0.8764	0.1402	0.8545	0.8740	0.6768
Evenness	0.4654	0.5529	0.2723	0.5289	0.1512	0.3805	0.4217	0.3114
Margalef	3.6490	3.4530	4.6600	4.1610	1.4960	4.5600	4.9730	2.0160
Equitability	0.7560	0.8083	0.6137	0.8045	0.1796	0.7100	0.7461	0.5579
Fisher Alpha	5.2470	4.88 00	7.1430	6.1890	1.8500	7.0130	7.9270	2.5360
Berger-Parker	0.3060	0.1986	0.4963	0.2604	0.9268	0.2547	0.2317	0.4596

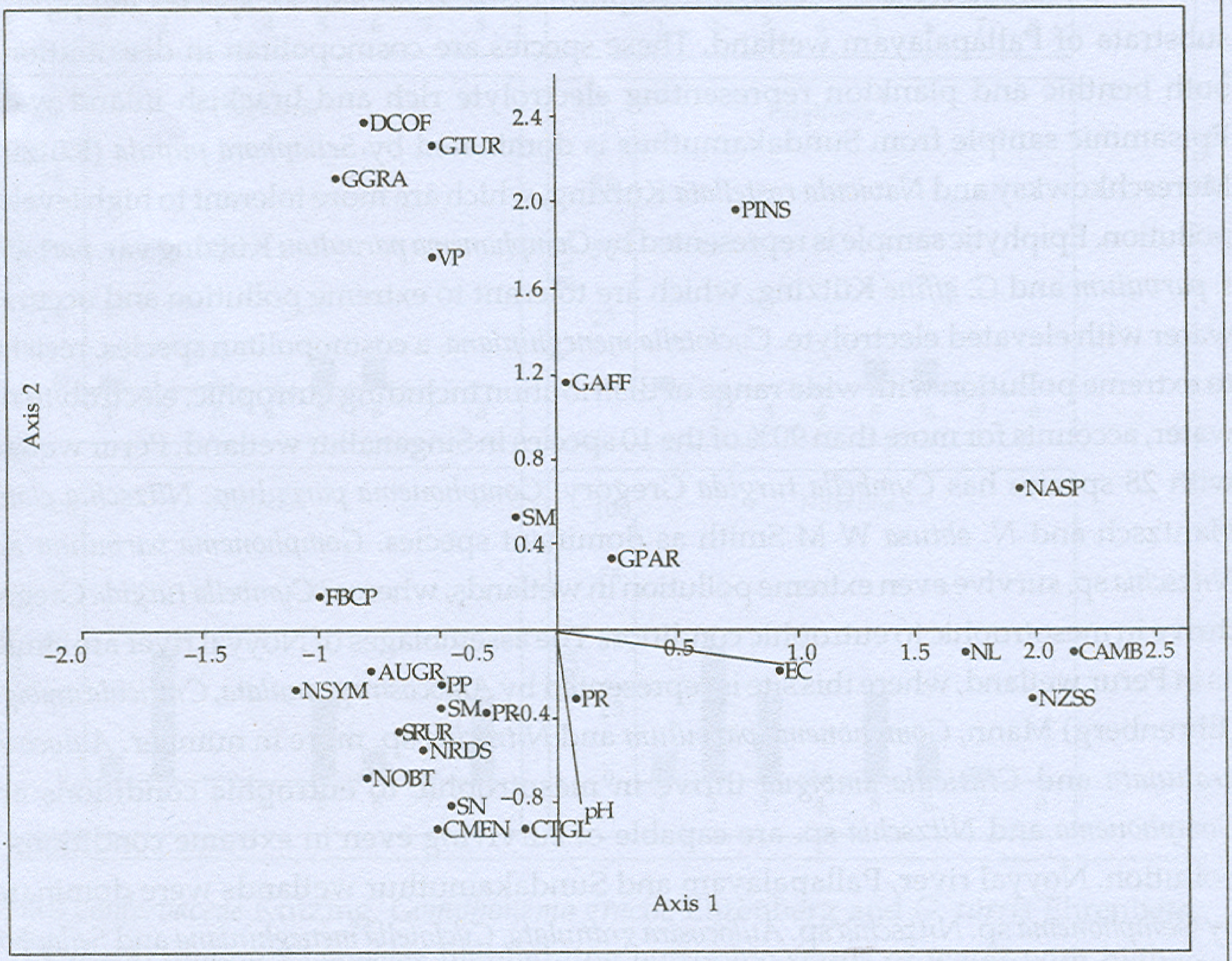
Note: VP-Vedapatti (Epiphytic); PP-Pallapalayam (Epilithic); SM-Sundakamuthur (Episammic); PP-Pallapalayam (Epiphytic); SN-Singanallur (Epiphytic); PR-Perur (Epiphytic); SM-Sundakamuthur (Epiphytic); and NL-Noyyal (Epiphytic).

are dominant among 22 species in the epilithic substrata and 26 species in epiphytic substrata of Pallapalayam wetland. These species are cosmopolitan in distribution in both benthic and plankton representing electrolyte rich and brackish inland water. Episammic sample from Sundakamuthur is dominated by *Sellaphora pupula* (Kützing) Mereschkowksy and *Navicula rostellata* Kützing, which are more tolerant to high levels of pollution. Epiphytic sample is represented by *Gomphonema parvulum* Kützing var. *parvulum* f. *parvulum* and *G. affine* Kützing, which are tolerant to extreme pollution and occurs in water with elevated electrolyte. *Cyclotella meneghiniana*, a cosmopolitan species, resistant to extreme pollution with wide range of distribution including eutrophic, electrolyte rich water, accounts for more than 90% of the 10 species in Singanallur wetland. Perur wetland with 28 species has *Cymbella turgida* Gregory, *Gomphonema parvulum*, *Nitzschia clausii* Hantzsch and *N. obtusa* W M Smith as dominant species. *Gomphonema parvulum* and *Nitzschia* sp. survive even extreme pollution in wetlands, whereas *Cymbella turgida* Gregory thrive in mesotrophic to eutrophic condition. The assemblages of Noyyal river are similar as in Perur wetland, where this site is represented by *Aulocosira granulata*, *Craticula ambigua* (Ehrenberg) Mann, *Gomphonema parvulum* and *Nitzschia* sp. more in number. *Aulocosira granulata* and *Craticula ambigua* thrive in mesotrophic to eutrophic conditions and *Gomphonema* and *Nitzschia* sp. are capable of surviving even in extreme conditions of pollution. Noyyal river, Pallapalayam and Sundakamuthur wetlands were dominated by *Gomphonema* sp. *Nitzschia* sp. *Aulocosira granulata*, *Cyclotella meneghiniana* and *Sellaphora pupula*. These wetlands receive untreated sewage and are eutrophic to mesotrophic evident from diatom assemblages.

Canonical Correspondence Analysis

CCA triplot explains the distribution of species across sampling sites (Figure 3). The species abbreviations used in the CCA diagram are given in Appendix 1. Among water quality variables, physical variables such as pH and electric conductivity were included in the CCA analysis because of the variation across sampling sites. Ordination axis 1 explains gradient in site distribution with *Gomphonema parvulum*, *Nitzschia* species, *Navicula* species and *Craticula ambigua* as more abundant, showing tolerance for conductivity (EC) at Singanallur lake and Sundakamuthur lake. Axis 2 describes impact of alkaline pH on species such as *Cyclotella meneghiniana* at Singanallur lake and pallapalayam with *Aulocoseira granulata,* while *Nitzschia obtuse* W M Smith; *Sellaphora pupula* at Sundakamathur and *Cymbella turgidula* Grunow at Perur. Vedapatti is less influenced by pH and conductivity, while the dominant *Diadesmis confervaecae* Kützing reveals organically polluted water condition.

Figure 3: CCA Triplot Showing Relationship Between Environmental Variables and Diatom Species in the Coimbatore Wetlands



Note: Acronyms of Species are Listed in Appendix 1.

Diatom Indices

The diatom indices calculated to evaluate water quality is listed in Table 4. IPS, GDI and TDI indices attributing to trophic status are listed in Table 5 (adopted from Eloranta and Soininen, 2002; and Taylor, 2004). The TDI scores (Table 5) ranged from 76 to 99.9

Table 4: Diatom Indices Values for the Wetlands

SITES	IPS	SLAD	DESCY	L&M	SHE	WAT	EPI-D	ROTT	IDG	CEE	IBD	IDAP	TDI
VP	7.7	13.2	17.3	11.1	14	8.5	10.9	16.3	12.8	11.6	1.0	11.6	84.3
PP	7.3	10.3	11.3	9.6	13.4	10.6	7.6	8.3	10.1	4.6	6.1	7.2	92.5
SM	9.3	10.6	9.8	9.3	13	6.2	8.1	11.3	10.0	8.4	8.1	7.2	76.0
PP	7.6	10.1	11.1	9.3	13.4	10.2	7.9	12.7	11.9	3.7	6.6	7.2	90.3
SN	5.9	7.8	10.4	8.2	8.9	1.7	8.1	NA	13.5	3.3	6.5	5.8	99.9
PR	13.5	10.1	11.7	9.1	6.1	13.6	8.3	10.7	12.3	6.3	15. 8	6.7	77.9
SM	9.8	10.5	9.9	8.5	8.6	10.7	8.3	11	12.2	8.2	7.7	4.9	86.3
NL	8	9.2	9.8	7.8	9.6	10.9	8.9	3.8	6	5.2	3.9	7.2	81.3

Note: VP- Vedapatti wetland (epiphytic); PP- Pallapalayam wetland (epilithic); SM Sundakamuthur wetland (episammic); PP-Pallapalayam wetland (epiphytic); SN-Singanallur wetland (epiphytic); PR-Perur wetland (epiphytic); SM- Sundakamuthur wetland (epiphytic); NL-Noyyal River (epiphytic). Refer Table 1 for details about the diatom indices.

Table 5: Class Limit Values for Diatom Indices (Eloranta and Soininen, 2002)

Class No.	Index Score	Class	Trophy
1	>17	High quality	Oligotrophy
2	15 to 17	Good quality	Oligo-mesotrophy
3	12 to 15	Moderate quality	Mesotrophy
4	9 to 12	Poor quality	Meso-eutrophy
5	<9	Bad quality	Eutrophy

indicating bad water quality with an increasing level of pollution or eutrophication in all wetlands. Dominant diatom assemblage specific to substrata along with water quality class and trophic conditions of the wetlands are listed in Table 6.

Habitat Preference

Diatom community structure varied very distinctly across the habitats. Epiphytic, Epilithic and Episammic habitats contained 50%, 10.4%, and 7.2% of taxa, respectively, unique to that habitat. In all these habitats, *Gomphonema affine*, *G. parvulum*, *Aulocosira granulata* and *Navicula rostellata* Kützing were common, while *G. parvulum* and *A. granulata* were

Table 6: Trophic Condition of the Wetlands with Dominant Species					
Site Name	**Dominant Species**	**Substrata**	**Class**	**Water Quality**	**Trophic Conditions**
Vedapatti Wetland (VP)	*Diadesmis confervaceae*, *Gomphonema turris*, *G. gracile*	Aquatic plant	3-4	Moderate to poor quality	Meso-eutrophic to mesotrophic
Pallapalayam Wetland (PP)	*Aulocosiera granulata*, *Nitzschia* sp., *Cyclotella meneghiniana*	Stone	3-5	Moderate to bad quality	Mesotrophic to eutrophic
Sundakamuthur Wetland (SM)	*Sellaphora pupula*, *Navicula rostellata*	Sediment	4-5	Bad quality	Eutrophic
Pallapalayam Wetland (PP)	*Cyclotella meneghiniana*, *Aulocosira granulata*	Aquatic plant	3-5	Moderate to bad quality	Mesotrophic to Eutrophic
Singanallur Wetland (SM)	*Cyclotella meneghiniana*	Aquatic plant	5	Bad quality	Eutrophic
Sundakamuthur Wetland (SN)	*Sellaphora pupula*, *Gomphonema parvulum*, *Gomphonema* sp.	Aquatic plant	4-5	Bad to poor quality	Eutrophic
Perur Wetland (PR)	*Gomphonema parvulum*, *Cymbella turgida*, *Nitzschia obtusa*, *Nitzschia clausii*	Aquatic plant	4	Moderate to Poor quality	Meso-eutrophic
Noyyal River (NL)	*Nitzschia* sp., *Navicula* sp.	Aquatic plant	4-5	Bad to poor quality	Meso-eutrophic

abundant. Appendix 2 list species with their habitats indicating majority of the diatom species as epiphytic. Diatoms specific to epilithic habitats are *Fragilaria ungeriana* Grunow, *Thalassiosira duostra* Peinaar, *Navicula anthracis* Cleve et Brun, *Eolimna subminuscula* (Manguin) Moser Lange-Bertalot and Metzeltin, *Amphora veneta* Kützing, *Navicula veneta* Kützing and *Nitzschia sigma* (Kiitzing) W M Smith. Epilithic habitat supports both centric and pennate diatoms. Episammic habitat supported 10 species which includes *Navicula viridula* (Kützing) Ehrenberg, *Aulacoseira muzzanensis* (Meister) Krammer, *Gomphonema pseudoaugar* Lange-Bertalot, *Hantzschia* Grunow, *Anomoeoneis sphaerophora* (Ehr.) Pfitzer, *Pinnularia microstauron* (Ehr.) Cleve, *P. Graciloides* Hustedt, *P. Interrupta* W M Smith, *Colonels bacillum* (Grunow) Krammer and *Rhopalodia* Miiller, *Cyclotella meneghiniana* and *Nitzschia obtusa* were most abundant and specific to epiphytic and epilithic substrata. Similarly, species with average dominance were restricted to only epiphytic and episammic habitats. However, diatom community specific to both epilithic and episammic were absent.

Conclusion

The investigation of six wetlands of Coimbatore records 27 dominant species such as *Cyclotella meneghiniana, Nitzschia* sp., *Sellaphora pupula, Gomphonema parvulum* and *Navicula* sp. which are cosmopolitan in its distribution. Singanallur wetland and Noyyal river stretches are characterized by pollution-tolerant species with low diatom diversity. Diatom assemblages indicate that Vedapatti, Perur and Sundakamuthur wetlands are moderately polluted, while Pallapalayam, Noyyal river and Singanallur wetlands are heavily polluted. In these wetlands, distribution of *Cyclotella* sp. was determined by high electrolyte conductivity and *Gomphonema* sp. and *Nitzschia* sp. were distributed in all pH and conductivity ranges, where *Fragilaria* sp. is restricted to neutral alkaline pH and moderate electrolytic waters. CCA plot also marks that Pallapalayam, Singanallur and Noyal river sites are associated with largest amount of variation in the dataset. High pH and electric conductivity values accounted for most of the variability in the diatom assemblages. With respect to habitat preference epiphytic, epilithic and episammic habitats contained 50%, 10.4% and 7.2% of taxa unique to that habitat. Diatoms indices revealed that water quality of the sampled wetlands are moderate (mesotrophic) to heavily polluted (eutrophic). The current study conveys that diatom indices can be used in gaining support and recognition for diatom-based approaches to water quality monitoring. This study can further be adopted in the formulation of diatom metrics for dissemination of simplified monitoring method as useful information to resource managers and government authorities for wetland management.

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Appendix 1

List of Species	
Achnanthidium exiguum (Grunow) Czarnnecki	AEHE
Actinocyclus normanii (Greg, ex Grev.) Hustedt morphotype *normanii*	ANMN
Amphora copulata (Kutz) Schoeman & Archibald	ACOP
Amphora montana Krasske	AMMO
Amphora veneta Kützing	AVEN
Anomoeoneis sphaerophora (Ehr.) Pfitzer	ASPH
Aulacoseira ambigua (Grun.) Simonsen	AAMB
Aulacoseira distans (Ehr.) Simonsen	AUDI
Aulacoseira granulata (Ehr.) Simonsen	AUGR
Aulacoseira muzzanensis (Meister) Krammer	AMUZ
Bacillaria paradoxa Gmelin	BPAR
Colonels bacillum (Grunow) Cleve	CBAC
Colonels molaris (Grunow) Krammer	CMOL
Craticula Grunow	CRAT
Cocconeis placentula Ehrenberg var. placentula	CPLA
Cocconeis Ehrenberg	COCS
Craticula accomoda (Hustedt) Mann	CRAC
Craticula ambigua (Ehrenberg) Mann	CAMB
Cyclotella meneghiniana Kützing	CMEN
Cyclotella woltereckii Hustedt	CWOL
Cymbella tumida (Brebisson) Van Heurck	CTUM
Cymbella turgida Gregory	CTUR
Cymbella turgidula Grunow	CTGL
Diadesmis confervaceae Kützing	DCOF
Diploneis ovalis (Hilse) Cleve	DOVA
Diploneis puella (Schumann) Cleve	DPUE
Encyonema mesianum (Cholnoky) D G Mann	ENME
Encyonema minutum (Hilse in Rabh.) D G Mann	ENMI
Eolimna Lange-Bertalot & Schiller	EOLI
Eolimna subminuscula (Manguin) Moser Lange-Bertalot & Metzeltin	ESBM
Eunotia mesiana Cholnoky	EMES
Eunotia minor (Kützing) Grunow	EMIN

Appendix 1 (Cont.)

Eunotia Ehrenberg	EUNO
Fallacia pygmaea (Kützing) Stickle & Mann	FPYG
Fragilaria biceps (Kützing) Lange-Bertalot	FBCP
Fragilaria ulna (Nitzsch.) Lange-Bertalot var. *ulna*	FULN
Fragilaria ulna var.acus (Kutz.)Lange-Bertalot f. *teratogene*	FUAT
Fragilaria ungeriana Grunow	FUNG
Geissleria decussis(Ostrup) Lange-Bertalot & Metzeltin	GDEC
Gomphonema affine Kützing	GAFF
Gomphonema gracile Ehrenberg	GGRA
Gomphonema parvulum Kützing var. *parvulum f. parvulum*	GPAR
Gomphonema pseudoaugur Lange-Bertalot	GPS A
Gomphonema Ehrenberg sp. 1	GOMS
Gomphonema Ehrenberg sp. 2	GOMS
Gomphonema turris Ehr.	GTUR
Hantzschia Grunow	HANI
Lemnicola hungarica (Grunow) Round & Basson	LHUN
Luticola acidoclinata Lange-Bertalot	LACD
Navicula anthracis Cleve et Brun	NANT
Navicula erifuga Lange-Bertalot	NERI
Navicula germainii Wallace	NGER
Navicula gregaria Donkin	NGRE
Navicula rostellata Kützing	NROS
Navicula Bory sp. 1	NASP
Navicula Bory sp.2	NAVI
Navicula symmetrica Patrick	NSYM
Navicula trivialis Lange-Bertalot var. *trivialis*	NTRV
Navicula veneta Kützing	NVEN
Navicula viridula (Kützing) Ehrenberg	NVIR
Navicula zanoni Hustedt	NZAN
Nitzschia amphibia Grunow f.amphibia	NAMP
Nitzschia capitellata Hustedt	NCPL
Nitzschia clausii Hantzsch	NCLA
Nitzschiafrustulum (Kützing) Grunow var.frustulum	NIFR

Appendix 1 (Cont.)

Nitzschia liebetruthii Rabenhorst *var.liebetruthii*	NLBT
Nitzschia obtusa W M Smith	NOBT
Nitzschia palea (Kützing) W Smith	NPAL
Nitzschia pumila Hustedt	NPML
Nitzschia sigma (Kützing) W M Smith	NSIG
Nitzschia Hassall	NZSS
Nitzschia supralitorea Lange-Bertalot	NZSU
Nitzschia tt/w&o7zata(Ehrenberg) Lange-Bertalot	NUMB
Nupela Vyverman et. Compere	NUPE
Pinnularia acrospheria Rabenhorst	PACR
Pinnularia graciloides Hustedt	PGRO
Pinnularia interrupta W M Smith	PINT
Pinnularia microstauron (Ehr.) Cleve	PMIC
Pinnularia Ehrenberg	PINS
Pinnularia Ehrenberg sp. 1	PIN1
Pinnularia viridiformis Krammer	PVIF
Placoneis Mereschk. sp. 1	PLAS
Placoneis Mereschk. sp. 2	PLAS
Planothidium robustum (Hustedt) Lange-Bertalot	PLRO
Planothidium rostratum (Oestrup) Lange-Bertalot	PRST
Pleurosigma salinarum (Grunow) Cleve & Grunow	PSAL
Rhopalodia gibba (Ehr.) O Muller *var.gibba*	RGIB
Rhopalodia Müller	RHOS
Sellaphora laevissima (Kützing) D G Mann	SELA
Sellaphora pupula (Kützing) Mereschkowksy	SPUP
Seminavis D G Mann	SMNA
Surirella angusta Kützing	SANG
Surirella Turpin	SURS
Surirella tenera Gregory	SUTE
Thalassiosira duostra Pienaar	TDUO
Tryblionella calida (grunow in Cl. & Grun.) D G Mann	TCAL

Appendix 2

Species List With Their Occurrence in Three Habitats			
Species	**Epiphytic**	**Epilithic**	**Episammic**
Gomphonema affine Kützing	+	+	+
Gomphonema parvulum Kützing var. *parvulum*	+	+	+
Aulacoseira granulata (Ehr.) Simonsen	+	+	+
Navicula rostellata Kützing	+	+	+
Cyclotella meneghiniana Kützing	+	+	–
Craticula accomoda (Hustedt) Mann	+	+	–
Nitzschia obtusa W M Smith	+	+	–
Nitzschia frustulum(Kützing) Grunow var. *frustulum*	+	+	–
Eunotia mesiana Cholnoky	+	+	–
Fragilaria biceps (Kützing) Lange-Bertalot	+	+	–
Navicula erifuga Lange-Bertalot	+	+	–
Fragilaria ulna var. *acus* (Kütz.)LangeBertalot	+	+	–
Nitzschia Hassall	+	+	–
Seminavis D G Mann	+	+	–
Navicula symmetrica Patrick	+	+	–
Tryblionella calida Grunow in Cl. & Grun.	+	–	+
Gomphonema Ehrenberg	+	–	+
Sellaphora laevissima (Kützing) D G Mann	+	–	+
Fallacia pygmaea (Kützing) Stickle & Mann	+	–	+
Surirella tenera Gregory	+	–	+
Sellaphora pupula (Kützing) Mereschkowksy	+	–	+
Luticola acidoclinata Lange-Bertalot	+	–	+
Pinnularia acrospheria Rabenhorst	+	–	+
Nupela Vyverman et Compere	+	–	+
Nitzschia palea (Kützing) W Smith	+	–	+
Placoneis Mereschk.	+	–	+
Navicula gregaria Donkin	+	–	+
Pinnularia Ehrenberg	+	–	+
Craticula ambigua (Ehrenberg) Mann	+	–	+
Amphora copulata (Kütz) Schoeman & Archibald	+	–	+
Caloneis molaris (Grunow) Krammer	+	–	–
Nitzschia umbonata (Ehrenberg) Lange-Bertalot	+	–	–
Navicula trivialis Lange-Bertalot var. *trivialis*	+	–	–
Aulacoseira ambigua (Grun.) Simonsen	+	–	–
Bacillaria paradoxa Gmelin	+	–	–

Appendix 2 (Cont.)

Species	Epiphytic	Epilithic	Episammic
Navicula zanoni Hustedt	+	–	–
Nitzschia pumila Hustedt	+	–	–
Craticula Grunow	+	–	–
Cymbella turgidula Grunow	+	–	–
Navicula germainii Wallace	+	–	–
Cocconeis Ehrenberg	+	–	–
Cocconeis placentula Ehrenberg var. *placentula*	+	–	–
Nitzschia liebetruthii Rabenhorst var.*liebetruthii*	+	–	–
Surirella angusta Kützing	+	–	–
Rhopalodia gibba (Ehr.) O Muller var. *gibba*	+	–	–
Pinnularia viridiformis Krammer	+	–	–
Surirella turpin	+	–	–
Amphora montana Krasske	+	–	–
Actinocyclus normanii (Greg. ex Grev.) Hustedt	+	–	–
Pleurosigma salinarum (Grunow) Cleve & Grunow	+	–	–
Aulacoseira distans (Ehr.) Simonsen	+	–	–
Pinnularia Ehrenberg	+	–	–
Nitzschia supralitorea Lange-Bertalot	+	–	–
Planothidium rostratum (Oestrup) Lange-Bertalot	+	–	–
Planothidium robustum (Hustedt) Lange-Bertalot	+	–	–
Gomphonema turris Ehr.	+	–	–
Gomphonema gracile Ehrenberg	+	–	–
Geissleria decussis(Ostrup) Lange-Bertalot	+	–	–
Diploneis ovalis (Hilse) Cleve	+	–	–
Cyclotella woltereckii Hustedt	+	–	–
Diadesmis confervacea Kützing	+	–	–
Gomphonema Ehrenberg	+	–	–
Encyonema mesianum (Cholnoky) D G Mann	+	–	–
Eunotia Ehrenberg	+	–	–
Eolimna Lange-Bertalot & Schiller in Schiller & Lange-Bertalot 1997	+	–	–
Fragilaria ulna (Nitzsch.) Lange-Bertalot	+	–	–
Diploneis puella (Schumann) Cleve	+	–	–
Encyonema minutum (Hilse in Rabh.) D G Mann	+	–	–
Eunotia minor (Kützing) Grunow in Van Heurck	+	–	–

Appendix 2 (Cont.)

Species	Epiphytic	Epilithic	Episammic
Lemnicola hungarica (Grunow) Round & Basson	+	–	–
Cymbella turgida Gregory	+	–	–
Nitzschia clausii Hantzsch	+	–	–
Nitzschia amphibia Grunow f.amphibia	+	–	–
Navicula Bory	+	–	–
Cymbella tumida (Brebisson) Van Heurck	+	–	–
Placoneis Mereschk.	+	–	–
Navicula Bory	+	–	–
Nitzschia capitellata Hustedt	+	–	–
Fragilaria ungeriana Grunow	–	+	–
Thalassiosira duostra Pienaar	–	+	–
Navicula anthracis Cleve et Brun	–	+	–
Eolimna subminuscula (Manguin)			
Moser Lange Bertalot & Metzeltin	–	+	–
Amphora veneta Kützing	–	+	–
Navicula veneta Kützing	–	+	–
Nitzschia sigma (Kützing) W M Smith	–	+	–
Navicula viridula (Kützing) Ehrenberg	–	–	+
Aulacoseira muzzanensis (Meister) Krammer	–	–	+
Gomphonema pseudoaugur Lange-Bertalot	–	–	+
Hantzschia Grunow	–	–	+
Anomoeoneis sphaerophora (Ehr.) Pfitzer	–	–	+
Caloneis bacillum (Grunow) Cleve	–	–	+
Pinnularia microstauron (Ehr.) Cleve	–	–	+
Pinnularia graciloides Hustedt	–	–	+
Pinnularia interrupta W M Smith	–	–	+
Rhopalodia O Mull.	–	–	+

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