DIATOM BASED POLLUTION MONITORING IN URBAN WETLANDS OF COIMBATORE, TAMIL NADU

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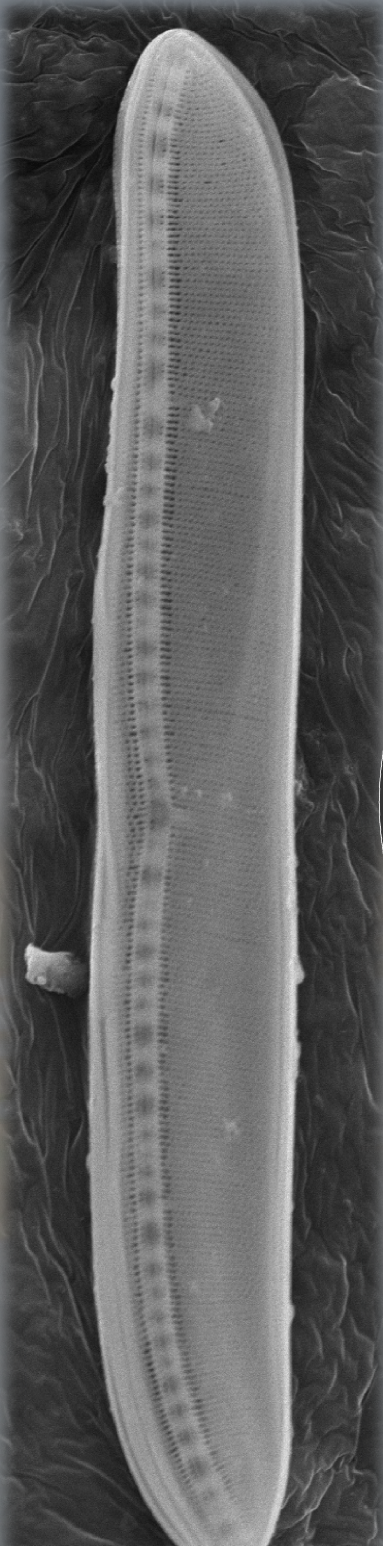

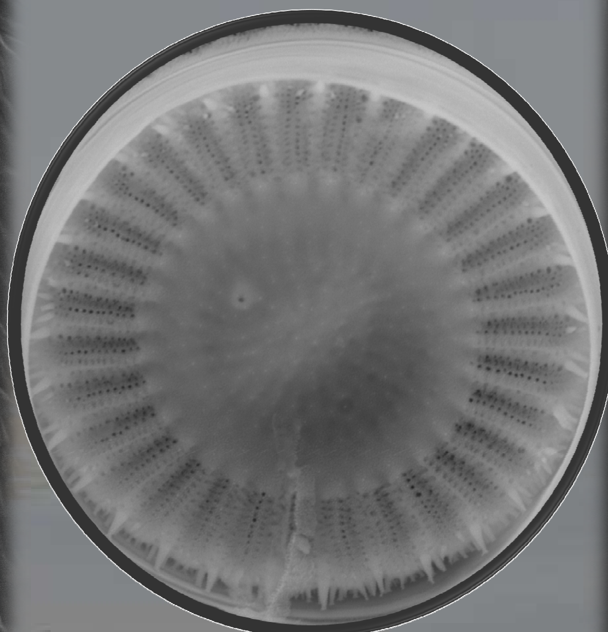

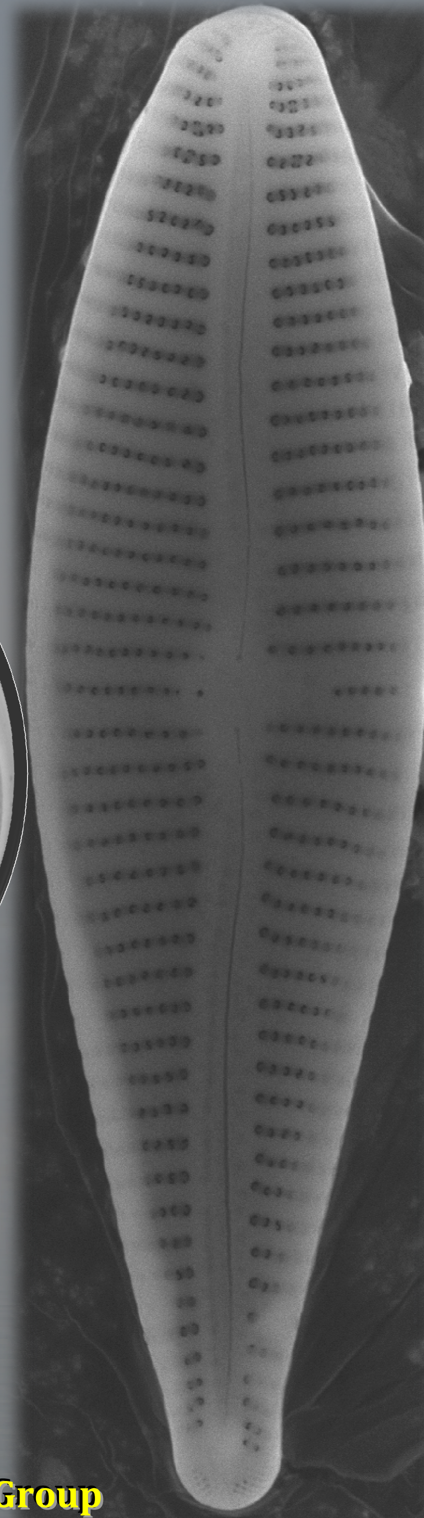

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Summary

Diatoms comprise a ubiquitous, photosynthetic and distinctive group of essentially unicellular algae. They are more specific in their preference and tolerance of environmental conditions than most other aquatic biota and have long been recognised 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 characterised 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, *Cyclotella*, Coimbatore

Diatom Based Pollution Monitoring in Urban Wetlands of Coimbatore, Tamil Nadu

Introduction

Wetlands are an 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. They also aid in improving water quality by filtering sediments and nutrients from surface water. Wetlands play a major role in removing dissolved nutrients such as nitrogen and to some extent heavy metals (Ramachandra *et al.,* 2002). Hence, they are often described as "Kidneys of the landscape". Wetlands encompass many different habitats including wetlands, marshes, swamps, flood plains, bogs, shallow ponds, littoral zones of larger water bodies and peatlands. All these share the fundamental feature of complex interactions among basic components such as soil, water, flora and fauna.

Wetlands are ecologically important in relation to stability and biodiversity in a region and also in terms of energy and material flow. Wetlands are "lands transitional between terrestrial and aquatic ecosystems where the water table is usually at or near the surface or the land is covered by shallow water" (Mitch and Gosselink, 1986). Hydrological conditions of a wetland modify or change chemical and physical properties such as nutrient availability, degree of substrate anoxia, soil salinity, sediment properties and pH, which in turn, influence the biotic integrity (Gosselink and Turner, 1978). Wetlands retain water during dry periods, thus keeping the water table high and stable. During floods they diminish floods intensity and biotic components trap suspended solids and attached nutrients. A healthy wetland retains a natural flow of water, minimising flooding in the catchment. Wetlands receive water deposited as groundwater, during dry seasons. Thus, a healthy wetland does the function of water recharge and discharge effectively, while meeting the human needs. However, humans have altered the natural flow regime of wetlands either by altering the natural drains, changing the land cover drastically or letting the untreated sewage in urban areas in recent times. The removal of such wetland systems or letting untreated sewage has caused the deterioration of water quality and ecological degradation in catchment (Prasad *et al.*, 2003).

In India, wetlands are distributed in all the biogeographic regions occupying 58.2 million hectares, including areas under wet paddy cultivation (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. They have 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 waterbodies in and closer to urban centres have been targeted. The water crisis, frequent flooding in urban areas has necessitated understanding the role of wetlands, and the need for integrated approaches to maintain the ecological balance, while meeting the demands of the growing population.

Need to study Wetlands

Rising water demand has exacerbated the impacts. Societies need to adopt improved strategies for integrated wetland management to ensure the quantity and quality of water is maintained for the ecosystem functions. In this regard, Ramsar Convention's Agenda 21 recommends the work towards better understanding of these threatened ecosystems through basic research, awareness and education, ecosystem and species conservation.

Wetland monitoring

Effective assessment tools are needed for consistent evaluation of the condition with stressors of wetland resources for solving problems. This entails inventorying and regular monitoring of wetlands. Physical and chemical monitoring of water quality has been practiced for a long time. Standard techniques are used for measuring light penetration, turbidity, conductivity, dissolved oxygen, biological oxygen demand and nutrients like phosphates, nitrates, nitrites, ammonia, and so on (Chapman, 1992). These measurements even though provide us simple values, but don't provide overall health and condition of the ecosystem enabling both preventive as well as restorative measures. Many environmental factors vary on different spatial and temporal scales in complex ecosystems such as wetlands. These variables range from climate, landuse, and geomorphology of a watershed (eg, Richards *et al.,* 1996) to the physical, chemical and biological characteristics. In this context, monitoring involving biological communities of an ecosystem would help in assessing, as they can integrate and reflect the effects of chemical and physical disturbances that occur in short duration as well as over extended period of time.

Biological monitoring

Monitoring using organisms, to assess the ecosystem's condition is referred as biological monitoring or biomonitoring. Biological indicators based on organisms living from one day to several years provide an integrated assessment of environmental conditions in streams, rivers and wetlands that are spatially and temporally variable. An ideal biomonitoring should be useful for both long and short term monitoring. Current conditions may be linked to the past conditions very effectively, if the same biomonitors are used for both short and long-term monitoring (Dixit *et al.,* 1992). Biomonitoring consists of groups of species, each group with well defined habitats, so that they may reflect changes in a variety of habitats. Biological indicators are important parts of environment assessment because protection and management of these organisms are the objectives of most programs. Aquatic communities (like algae, fish, riparian vegetation, macro-invertebrates), integrate and reflect the effects of chemical and physical disturbances. A biota that undergoes change from dominance to gradual disappearance of a species is of ecological significance. The primary aim here is to detect changes in abundance, structure and diversity of a target species assemblage as compared to the reference condition. Bio-indicators include organisms that are:

- close to the transfer of nutrient and energy in the food web;
- wider range of distribution;
- simple life-cycle stages, and identifiable to the species or even the morphotype level;
- sensitive to fine changes in the environment with a range of tolerance; and
- preference to environmental variables, so a change in the environment is reflected by a shift in species dominance.

Now, biological monitoring has begun to address the question of biological integrity of wetlands influenced by various anthropogenic land use activities.

Numerous methods have been developed in biomonitoring for an assessment of the integrity of aquatic systems. Most are based on the attributes of whole assemblages of organisms such as fish, algae or invertebrates. A variety of assemblages have been used in biological assessments ranging from macrophytes (Galatowitsch *et al.,* 1999, Gernes and Helgen, 1999) macroinvertebrates (Kerans and Karr, 1994 and Barbour *et al.*, 1996); amphibians (Micacchion, 2004); fish (Schulz *et al.,* 1999); birds (O'Connell *et al.,* 1998) and diatoms (Fore and Grafe, 2002).

Diatoms

Diatoms under Class *Bacillariophyceae* comprise a ubiquitous, photosynthetic and distinctive group of unicellular algae. Diatoms are made up of siliceous cell wall consisting of two valves; epivalve and hypovalve which fit together like a petri dish together known as frustules. In between two valves series of bands are present known as girdle bands. During cell division the new frustules are formed from the inside of the cell. The outer or older is the epivalve and inner or newly formed one is hypovalve forms one daughter cell where as outer or older hypovalve acts as epivalve and newly formed valve will become hypovalve. This forms another daughter cell. During this process cell size goes on decreasing. The original size is attained by undergoing sexual reproduction by auxospore formation.

Diatoms as bio-indicators

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 in 1909, cited in Stoermer and Smol, 2001). Diatoms respond directly and 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 climatic, 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 indicators of both pollution increases and habitat restoration success. Frustules are preserved in sediments and record habitat history. Diatoms collection and methods are ease and low cost. Samples can be archived easily for long periods of time for future analysis and long term records.

Diatoms occur in all types of environment where ever moisture is present. 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, 1986, 1990; Cox, 1991). However, there is no information available on diatoms as indicator species of wetlands in India. The present study assesses six major wetlands in an urban ecosystem using diatoms as bioindicators.

Objectives

Objectives of this research are to:

i. determine the pollution status of selected wetlands of Coimbatore by using diatoms
ii. prepare an illustrated guide to the common diatom flora of wetlands of Coimbatore.

Study Area

Coimbatore also referred 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 470m, 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 south-western side of the city. Some of these wetlands are seasonal and have also been used as dumping yard for garbage and industrial wastes during dry period (Mohan Raj *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 (VPP), Pallapalayam (PPL), Sundakamuthur (SMS), Perur (PRP), Noyyal (NLP) and Singanallur (SNP).

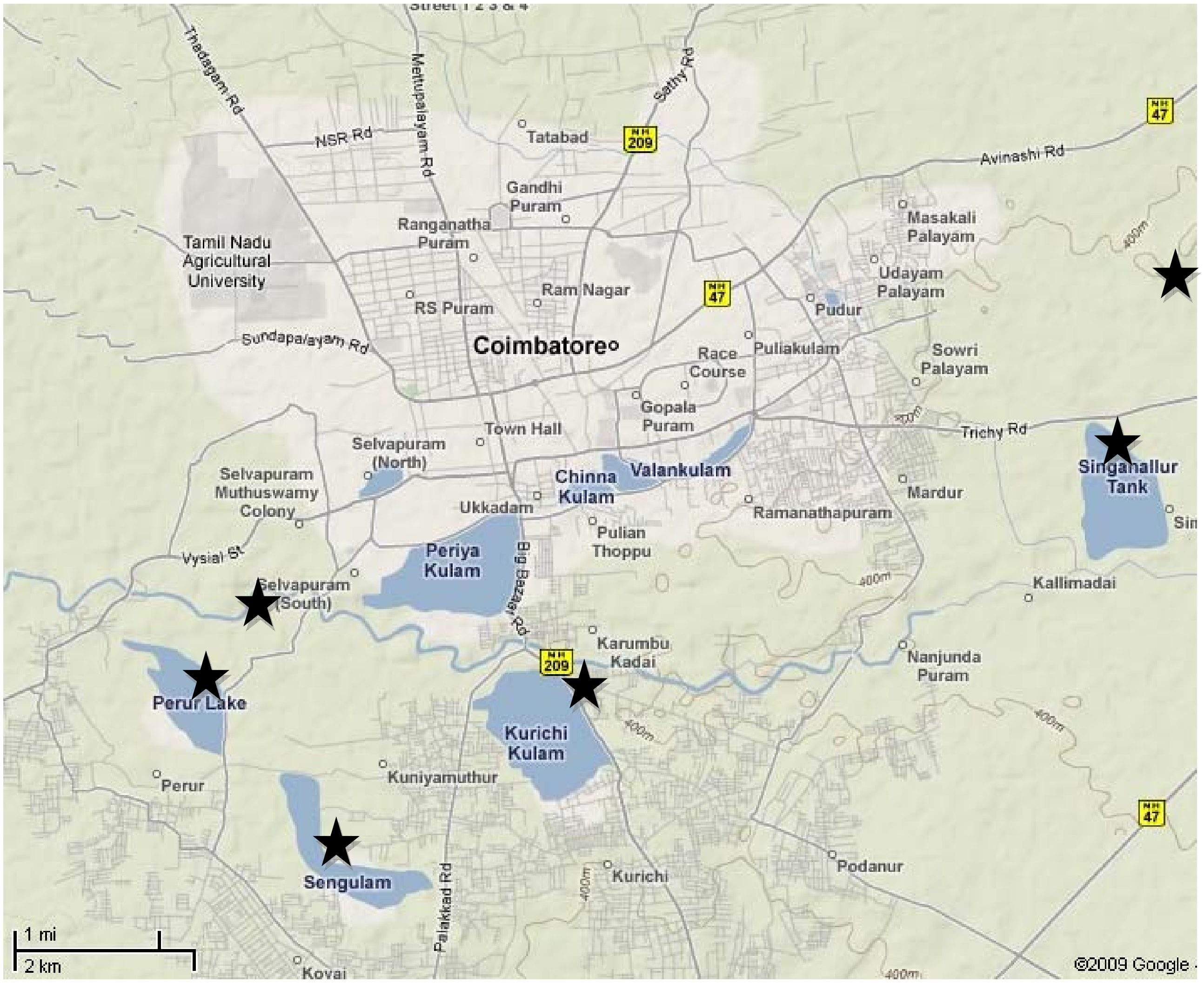

Figure 1 Coimbatore city with the sampling points. (Maps Courtesy: Google)

Methods and Materials

Diatom sampling

Diatom samples were collected (from cobbles, aquatic plants and sediment) and prepared using standard methods as per Taylor *et al.*, (2005) from selected wetlands. Diatom communities were then analysed by counting between 400 and 450 valves. During enumeration the dimensions of diatom valve characteristics, like its length, width and straie densities in 10 µm were measured. Identification of diatoms is carried out using taxonomic guides (Gandhi, 1957 1959a, 1959b, 1961, 1962, 1967, 1998; Lange-Bertalot, 2001; Krammer, 2002; Taylor, 2007; Karthick *et al.*, 2008).

Water sampling

Water samples were collected from all sites and physical variables like pH, temperature, Electric conductivity, Salinity and Total dissolved solids were measured using EXTECH combo probe.

Ecological Diversity and diatom indices

Ecological diversity was calculated for each sample using diversity indices given in Table 1.

Table 1 Diversity parameters and indices

Index	Equation	Remarks	References	Eq. No
Abundance	$\frac{\text{No. of Individuals of a species X 100}}{\text{No. of Sampling units}}$			1
Shannon Weiner's (H')	$H' = -\sum_{i=1}^{S} p_i \ln p_i$ Pi: proportion of individuals of i^{th} species	The value ranges between 1.5 and 3.5 and rarely surpasses 4.5	Ludwig and Renolds (1998); Legendre and Legendre 1998	2
Simpson's	$D = \frac{\sum_{i=1}^{S} n_i(n_i - 1)}{N(N-1)}$	The value varies from 0 to 1. A value of 0 indicates the presence of only one species, while 1 means that all species are equally represented.	Ludwig and Reynolds (1998)	3
Dominance	1-Simpson index D = sum $\left(\frac{ni}{n}\right)^2$ Where ni is number of individuals of taxon i.	The occupancy of a species over an area. Ranges from 0 (all taxa are equally present) to 1 (one taxon dominates the community completely)		4

Evenness	$H' = -\sum_{i=1}^{S} p_i \ln p_i$	The measure of biodiversity which quantifies how equal the community		5
Fisher's alpha	$S = a * \ln\left(\frac{1+n}{a}\right)$ Where S is number of taxa, n is number of individuals and *a* is the Fisher's alpha.	It is a mathematical model used to measure diversity		6
Berger-Parker	$d = \frac{Nmax}{N}$ Where Nmax is the number of individuals in the most abundant species and N is the total number of individuals in the sample.	The number of individuals in the dominant taxon relative to n, where n is the total number of species	Berger and Parker 1970;	7

Diatom specific indices like Generic Diatom Index or GDI (Coste and Ayphassorho, 1991), the Specific Pollution sensitivity Index or SPI (Coste in Cemagref, 1982), the Biological Diatom Index or BDI (Lenoir and Coste, 1996), the Artois-Picardie Diatom Index or APDI (Prygiel *et al.*,1996), Sládeček's index or SLA (Sládeček, 1986), the Eutrophication/Pollution Index or EPI (Dell'Uomo, 1996), Rott's Index or ROT (Rott, 1991), Leclercq and Maquet's Index or LMI (Leclercq and Maquet, 1987), the Commission of Economical Community Index or CEC (Descy and Coste, 1991), Schiefele and Schreiner's index or SHE (Schiefele and Schreiner, 1991), the Trophic Diatom Index or TDI (Kelly and Whitton, 1995), and the Watanabe index or WAT (Watanabe *et al.*, 1986) were also computed as listed in Table 2. All the diatom indices were calculated using Equation 8 (Zelinka and Marvan, 1961) except for the CEC, SHE, TDI and WAT index and all of the above indices, except TDI (maximum value of 100), the maximum value of 20 indicates pristine water.

$$index = \frac{\sum_{j=1}^{n} a_j s_j v_j}{\sum_{j=1}^{n} a_j v_j} \qquad \text{(Equation: 8)}$$

Where aj = abundance (proportion) of species j in sample, vj = indicator value and sj = pollution sensitivity of species j.

The performance of the indices depends on the values given to the constants s and v for each taxon and the values of the index ranges from 1 to an upper limit equal to the highest value of s. Each diatom species used in the calculation/equation is assigned two values; the first value reflects the tolerance or affinity of the diatom to a certain water quality (good or bad) while the second value indicates how strong (or weak) the relationship is. Abundance and weighted average were computed. This would indicate how many of the particular diatoms in the sample occur in relation to the total number counted.

Table 2 Diatom Indices

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	(Leclercq and Maquet, 1987)
SHE	Steinberg and Schiefele trophic metric	(Steinberg and Schiefele, 1988)
WAT	Watanabe *et al.*, pollution metric	(Lecointe *et al.*, 2003)
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)

Results and Discussion

Water samples were collected from all sites and physical variables like pH, Temperature, Electric conductivity, Salinity and Total dissolved solids were measured and are listed in Table 3. pH of sampled wetlands range from 7.4 to 9 indicating neutral to alkaline conditions. Electric conductivity ranges from 280 (Vedapatti) - 2250µS/cm (Singanallur).

Table 3 Water Quality Variables of Coimbatore Wetlands

Sampling site	Conductivity (µS/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	7.92	242
Pallapalayam	733	27.9	9.05	511
Pallapalayam	770	29.3	8.83	543
Noyyal River	1121	29.7	7.7	781
Singanallur	2250	29.3	8.53	1590

Diatom Diversity

Diatom samples were collected (from cobbles, aquatic plants and sediment) and prepared using standard methods from Vedapatti, Pallapalayam, Sundakamuthur, Perur, Noyyal and Singanallur wetlands in Coimbatore. Diatom communities were analysed as explained in methods section. 96 Species belonging to 34 Genera were recorded from these wetlands, which are provided in Appendix 1. Among these species, 27 species were dominant (i.e., occurring >5% of any given community). Appendix 2 gives the species-wise light microscopic illustrations. Table 3 lists the diversity indices, which show a significant difference in community structures across the sampled wetlands. Higher values of Shannon, Simpson and evenness values are for Pallapalayam wetland compared to Singanallur wetland, where dominance index was relatively higher.

Table 4 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	2.371	2.498	2.066	2.621	0.4135	2.366	2.538	1.472
Simpson	0.8526	0.8877	0.7276	0.8764	0.1402	0.8545	0.874	0.6768
Evenness	0.4654	0.5529	0.2723	0.5289	0.1512	0.3805	0.4217	0.3114
Margalef	3.649	3.453	4.66	4.161	1.496	4.56	4.973	2.016
Equitability	0.756	0.8083	0.6137	0.8045	0.1796	0.71	0.7461	0.5579
Fisher alpha	5.247	4.88	7.143	6.189	1.85	7.013	7.927	2.536
Berger-Parker	0.306	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); NL-Noyyal (Epiphytic)

Common diatoms genera namely *Cyclotella, Gomphonema, Nitzschia and Fragilaria* accounted for large proportion of the community in all sites. Figure 2, a plot of genera across pH and electrical conductivity ranges reveal that:

- *Cyclotella* – present in neutral to high alkaline, and high electrolytic;
- *Gomphonema*, *Nitzschia* – present in entire pH and conductivity ranges; and
- *Fragilaria* – prefer Neutral to alkaline, and moderate electrolytic water.

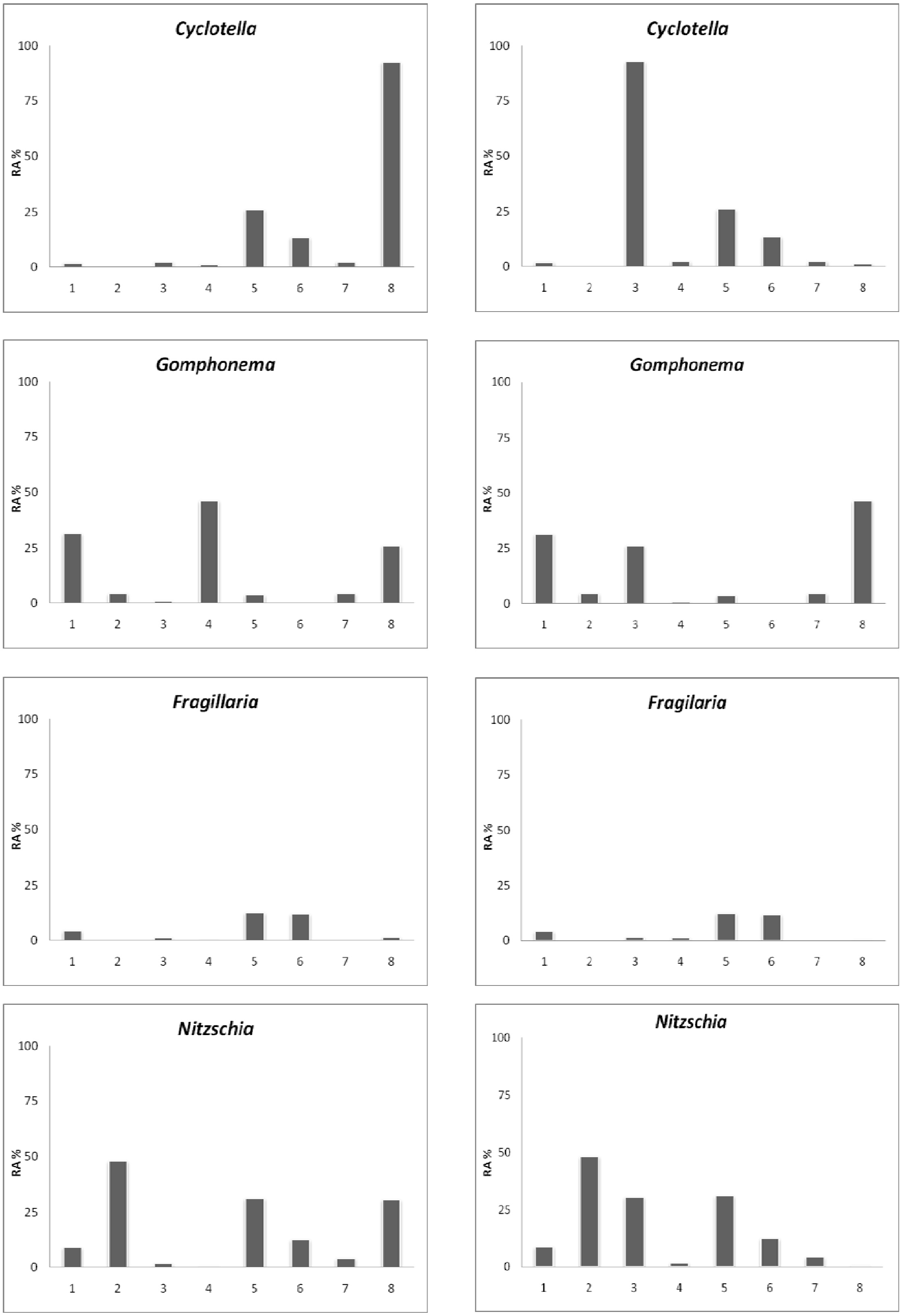

Figure 2 Relative abundance of four most dominant genera plotted with sites arranged in order of increase in electrical conductivity (left) and pH (right).

Dominance

Dominance is the degree to which different species in an ecological community predominate, ranging from 0 (all taxa are equally present) to 1 (a taxon dominates the community completely). Dominance is calculated (equation 4, Table 1) and is given in Figure 3. Singanallur wetland has 10 species with *Cyclotella meneghiniana* as dominant species (dominance: 0.85), while *Aulocosira granulata* (19.86 %,) dominated Pallapalayam (dominance: 0.11) and *Sellaphora pupula* (23.17%) and *Gomphonema parvulum* (18.48%) were prominent species in Sundakamuthur (dominance: 0.12) wetlands. Remaining sites showed dominance index value between 0.1- 0.4.

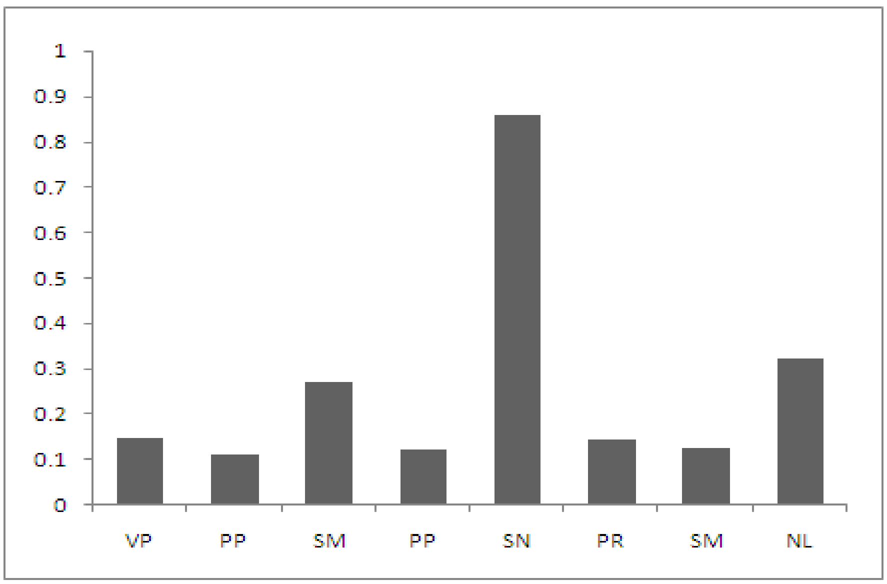

Figure 3 Dominance Index across sites

Note: VP- Vedapatti wetland; PP- Pallapalayam wetland; SM- Sundakamuthur wetland; PP-Pallapalayam wetland; SN-Singanallur wetland; PR-Perur wetland ; SM-Sundakamuthur wetland; NL-Noyyal River

Evenness

Evenness is a measure of biodiversity which quantifies how equal the community is numerically. Figure 4 depicts the evenness computed as per equation 5, Table 1.

Cyclotella meneghiniana constitute more than 90% of the total population accounted for low evenness in Singanallur wetland. In Pallapalayam wetland 22 species were recorded, among *Aulocosira granulata* and *Nitzschia obtuse* were represented by 19.86% and 14.61% abundance respectively.

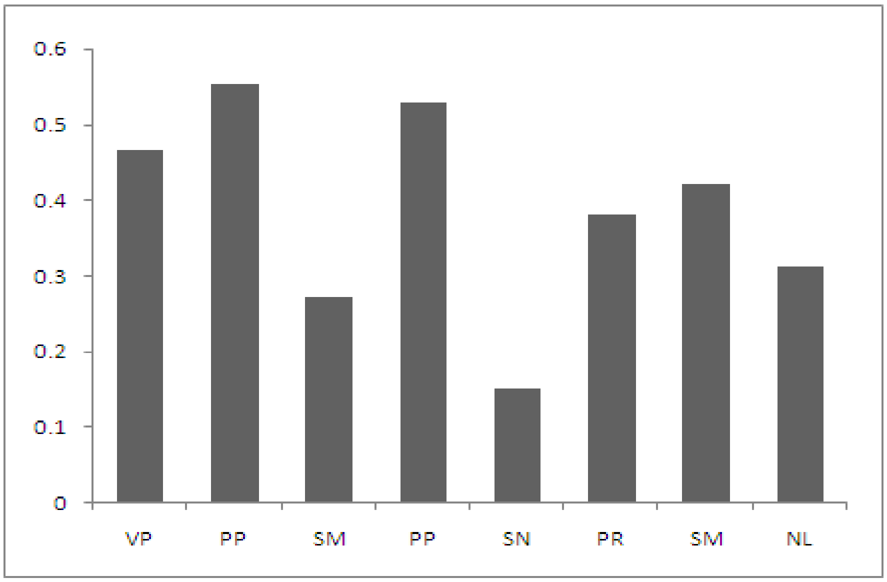

Figure 4 Evenness Index across sites

Shannon index

Shannon diversity index (H′) computed as per equation 2 (Table 1) takes into account the number of individuals as well as number of taxa. This varies from 0 for communities with only a single taxon to high values for communities with many taxa, each with few individuals. Low H′ was recorded in Singanallur wetland (0.4135, *C. meneghiniana* representing 92%) and Noyyal River (1.472, *Nitzschia sp* representing 45.95 %). Species abundance in other sites ranges from 20 to 26 species that represent 15-50% of the total population.

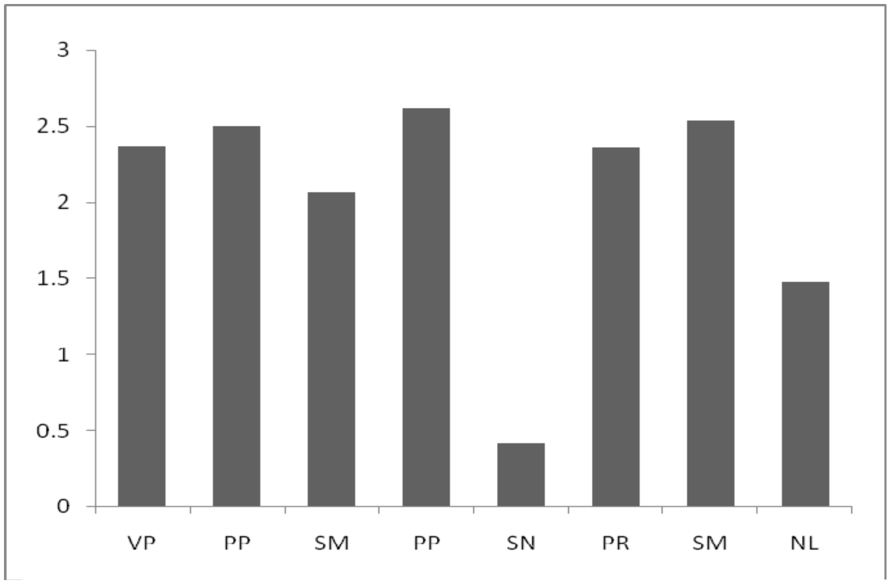

Figure 5 Shannon Index across sites

Fisher alpha diversity Index

High Fisher's alpha diversity index computed (equation 6, Table 1) was noticed in Sundakamuthur (7.8), Pallapalayam (6.2) and Perur (7) wetlands. Singanallur wetland and Noyyal River with less number of taxa shows low index value.

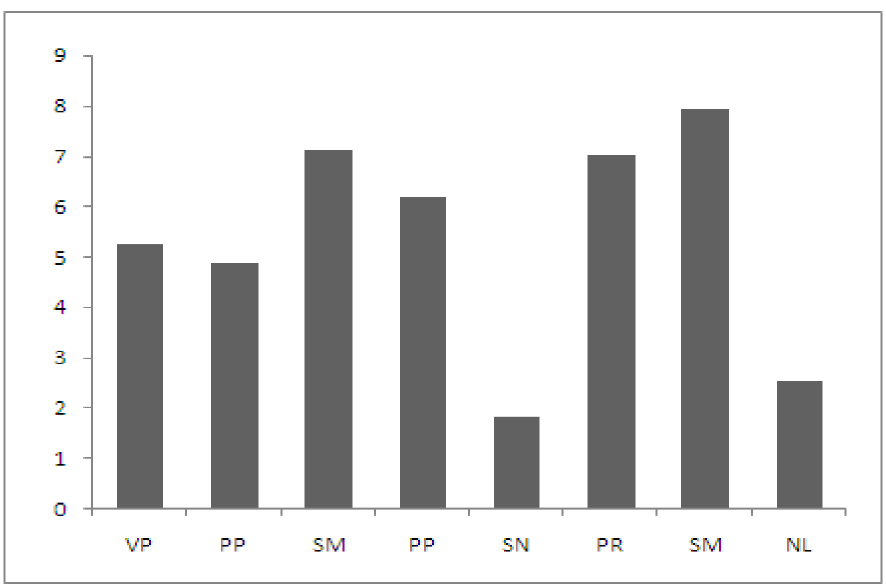

Figure 6 Fisher alpha Index across sites

Berger-Parker Index

Berger-Parker is calculated (equation 7, Table 1) from the number of individuals in the dominant taxon relative to the total number of species. *Cyclotella meneghiniana* is the dominant species (with 92.68% abundance) showing a high index value in Singanallur wetland. *Diadesmis confervaceae* and *Gomphonema turris* was observed as abundant species (15-30%) in Vedapatti wetland. In Pallapalayam wetland *Aulocosira granulata, Cyclotella meneghiniana* and *Nitzschia obtuse* represents to 13-20% of the population from an epilithic habitat and *Aulocosira granulata, Cyclotella meneghiniana* represents 19-26% of the population from an epiphytic habitat. *Gomphonema parvulum* and *Cymbella turgid* represents 25.47 and 22.25% respectively in Perur wetland. *Nitzschia sp.* (45%) and *Navicula sp.* (32%) characterize the Noyyal River. In Sundakamuthur wetland, *Sellaphora pupula* 49.63 % and *Navicula rostellata* 12.04% in episammic habitat whereas 23.17% *Sellaphora pupula* and 18.48% *G. parvulum* being present in epiphytic habitat (Figure 6).

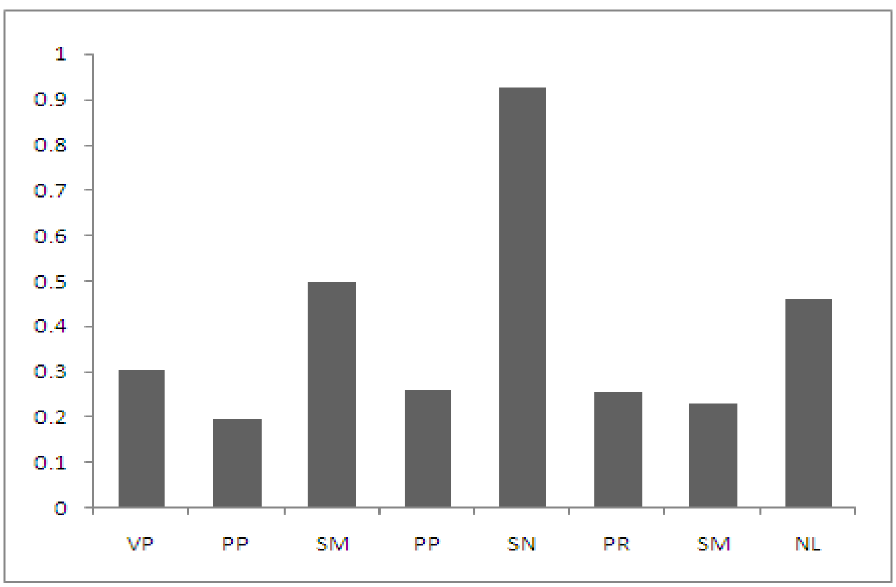

Figure 7 Berger- Parker Index across sites

Diatom assemblages and trophic condition

Distribution of diatoms reflects the average ecological conditions of water (Cholnoky 1968; Lowe 1974). In Vedapatti wetland, cosmopolitan extreme pollution resistant species *Diadesmis confervaceae, Gomphonema gracile* and *G.turris* were dominant among 23 species highlighting eutrophic status of water with higher electrolyte. *Aulocosira granulata* and *Cyclotella meneghiniana 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* and *Navicula rostellata,* which are more tolerant to high levels of pollution. Epiphytic substratum sample is represented by *Gomphonema parvulum* and *G. affine*, 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 10 species in Singanallur wetland. Perur wetland with 28 species has *Cymbella turgida*, *Gomphonema parvulum, Nitzschia clausii* and *N. obtuse* as dominant species. *Gomphonema parvulum* and *Nitzschia sp.* survive even extreme pollution in wetlands where as *Cymbella* turgida thrive in mesotrophic to eutrophic condition. The assemblages of Noyyal river is similar as of Perur wetland, where this site is represented by *Aulocosira granulata, Craticula ambigua, 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.

A wide range of diatoms distribution is observed in all sampled wetlands of Coimbatore, which include *Gomphonema sp.* and *Nitzschia sp. Aulocosira granulata, Cyclotella meneghiniana* and *Sellaphora pupula* were dominant in Noyyal River, Pallapalayam and

Sundakamuthur wetlands. These wetlands receives untreated sewage and are either eutrophic to mesotrophic evident from diatom assemblages.

Diatom Indices

Variants of diatom indices have been used across the globe. Table 2 lists most commonly used diatom indices for representing the degree of pollution suitable for tropical conditions. Diatom indices listed in Table 3 were computed for all sampled wetlands to evaluate water quality. This diatom index score is expressed as water quality optima (i.e. the tolerate limits of diatoms to water quality variables) of the sample, based on the diatom taxa 'i' weighted by the abundance of each taxon.

Table 5 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	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	8.4	8.1	7.2	76
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; PP- Pallapalayam wetland; SM- Sundakamuthur wetland; PP-Pallapalayam wetland; SN-Singanallur wetland; PP-Perur wetland ; SM-Sundakamuthur wetland; NL-Noyyal River. Refer Table 2 for details about the diatom indices

IPS and GDI Indices attributing to trophic status are listed in Table 6 (adopted from Eloranta & Soininen, 2002, Taylor, 2004). Based on this, scores listed in Table 5, indicate an increasing level of pollution or eutrophication.

Table 6 Class limit values for Diatom indices (Eloranta & Soininen, 2002)

Index score	Class	Trophy
>17	High quality	Oligotrophy
15 to 17	Good quality	oligo-mesotrophy
12 to 15	Moderate quality	Mesotrophy
9 to 12	Poor quality	meso-eutrophy
<9	Bad quality	Eutrophy

Diatom assemblages along with water quality class and trophic conditions of the wetlands are listed in Table 7.

Table 7 Trophic condition of the wetlands with dominant species

Site name	Dominant Species	Substrata	Class	Water quality	Trophic conditions
Vedapatti wetland	*Diadesmis confervaceae, Gomphonema turris, G. gracile*	Aquatic plant	3-4	Moderate to poor quality	Meso-eutrophic to mesotrophic
Pallapalayam wetland	*Aulocosiera granulata, Nitzschia sp., Cyclotella meneghiniana*	Stone	3-5	Moderate to bad quality	Mesotrophic to eutrophic
Sundakamuthur wetland	*Sellaphora pupula, Navicula rostellata*	Sediment	4-5	Bad quality	Eutrophic
Pallapalayam wetland	*Cyclotella meneghiniana,*	Aquatic plant	3-5	Moderate to bad	Mesotrophic to Eutrophic

	Aulocosira granulata			quality	
Singanallur wetland	*Cyclotella meneghiniana*	Aquatic plant	5	Bad quality	Eutrophic
Sundakamuthur wetland	*Sellaphora pupula, Gomphonema parvulum, Gomphonema sp.*	Aquatic plant	4-5	Bad to poor quality	Eutrophic
Perur wetland	*Gomphonema parvulum, Cymbella turgida, Nitzschia obtuse, Nitzschia clausii*	Aquatic plant	4	Moderate to Poor quality	Meso-eutrophic
Noyyal River	*Nitzschia sp. Navicula sp.*	Aquatic plant	4-5	Bad to poor quality	Meso-eutrophic

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 unique to that habitat. In all these habitats, *Gomphonema affine, G.parvulum, Aulocosira granulata* and *Navicula roetellata* were common, while *G. parvulum* and *A. granulata* were abundant.

Table 8 lists species with their habitats, shows that majority of the diatom species are epiphytes. Diatoms specific to epilithic habitats are *Fragilaria ungeriana, Thalassiosira duostra, Navicula anthracis, Eolimna subminuscula, Amphora veneta, Navicula veneta* and *Nitzschia sigma*. Epilithic habitat supports both centric and pennate diatoms. Episammic habitat supported 10 species which includes *Navicula viridula, Aulacoseira muzzanensis,* *Gomphonema pseudoaugar, Hantzschia sp., Anomoeoneis sphaerophora, Pinnularia microstauron, P.graciloides, P.interrupta, Caloneis bacillum* and *Rhopalodia sp.*

Cyclotella meneghiniana and *Nitzschia obtuse* 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.

Table 8 Species list with their occurrence in three habitats

Species	Epiphytic	Epilithic	Episammic
Gomphonema affine Kutzing	+	+	+
Gomphonema parvulum Kutzing *var. parvulum*	+	+	+
Aulacoseira granulata (Ehr.) Simonsen	+	+	+
Navicula rostellata Kutzing	+	+	+
Cyclotella meneghiniana Kutzing	+	+	-
Craticula accomoda (Hustedt) Mann	+	+	-
Nitzschia obtusa W.M.Smith	+	+	-
Nitzschia frustulum(Kutzing) Grunow *var.frustulum*	+	+	-
Eunotia mesiana Cholnoky	+	+	-
Fragilaria biceps (Kutzing) Lange-Bertalot	+	+	-
Navicula erifuga Lange-Bertalot	+	+	-
Fragilaria ulna var.acus (Kutz.)Lange-Bertalot	+	+	-
Nitzschia sp.	+	+	-
Seminavis D.G. Mann	+	+	-
Navicula symmetrica Patrick	+	+	-

Tryblionella calida (Grunow in Cl. & Grun.	+	-	+
Gomphonema sp.	+	-	+
Sellaphora laevissima (Kutzing) D.G. Mann	+	-	+
*Fallacia pygmaea (*Kützing) Stickle & Mann	+	-	+
Surirella tenera Gregory	+	-	+
Sellaphora pupula (Kutzing) Mereschkowksy	+	-	+
Luticola acidoclinata Lange-Bertalot	+	-	+
Pinnularia acrospheria Rabenhorst	+	-	+
Nupela sp.	+	-	+
Nitzschia palea (Kutzing) W.Smith	+	-	+
Placoneis sp.	+	-	+
Navicula gregaria Donkin	+	-	+
Pinnularia sp.	+	-	+
Craticula ambigua (Ehrenberg) Mann	+	-	+
Amphora copulata (Kutz) Schoeman & Archibald	+	-	+
Caloneis molaris (Grunow) Krammer	+	-	-
Nitzschia umbonata (Ehrenberg)Lange-Bertalot	+	-	-
Navicula trivialis Lange-Bertalot *var. trivialis*	+	-	-
Aulacoseira ambigua (Grun.) Simonsen	+	-	-
Bacillaria paradoxa Gmelin	+	-	-
Navicula zanoni Hustedt	+	-	-

Nitzschia pumila Hustedt	+	-	-
Craticula sp.	+	-	-
Cymbella turgidula Grunow in A. Schmidt & al.	+	-	-
Navicula germainii Wallace	+	-	-
Cocconeis sp.	+	-	-
Cocconeis placentula Ehrenberg *var. placentula*	+	-	-
Nitzschia liebetruthii Rabenhorst *var.liebetruthii*	+	-	-
Surirella angusta Kutzing	+	-	-
Rhopalodia gibba (Ehr.) O.Muller *var.gibba*	+	-	-
Pinnularia viridiformis Krammer	+	-	-
Surirella sp.	+	-	-
Amphora montana Krasske	+	-	-
Actinocyclus normanii (Greg. ex Grev.) Hustedt	+	-	-
Pleurosigma salinarum (Grunow) Cleve & Grunow	+	-	-
Aulacoseira distans (Ehr.)Simonsen	+	-	-
Pinnularia species	+	-	-
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 species	+	-	-
Encyonema mesianum (Cholnoky) D.G. Mann	+	-	-
Eunotia sp.	+	-	-
Eolimna sp.	+	-	-
Fragilaria ulna (Nitzsch.) Lange-Bertalot	+	-	-
Diploneis puella (Schumann) Cleve	+	-	-
Encyonema minutum (Hilse in Rabh.) D.G. Mann	+	-	-
Eunotia minor (Kutzing) Grunow in Van Heurck	+	-	-
Lemnicola hungarica (Grunow) Round & Basson	+	-	-
Cymbella turgida Gregory	+	-	-
Nitzschia clausii Hantzsch	+	-	-
Nitzschia amphibia Grunow f.amphibia	+	-	-
Navicula sp.	+	-	-
Cymbella tumida (Brebisson)Van Heurck	+	-	-
Placoneis sp.	+	-	-
Navicula sp.	+	-	-
Nitzschia capitellata Hustedt in A.Schmidt & al.	+	-	-

Fragilaria ungeriana Grunow	-	+	-
Thalassiosira duostra Pienaar	-	+	-
Navicula anthracis Cleve et Brun	-	+	-
Eolimna subminuscula (Manguin) Moser Lange- -Bertalot & Metzeltin	-	+	-
Amphora veneta Kutzing	-	+	-
Navicula veneta Kutzing	-	+	-
Nitzschia sigma (Kutzing)W.M.Smith	-	+	-
Navicula viridula (Kutzing) Ehrenberg	-	-	+
Aulacoseira muzzanensis (Meister) Krammer	-	-	+
Gomphonema pseudoaugur Lange-Bertalot	-	-	+
Hantzschia sp.	-	-	+
Anomoeoneis sphaerophora (Ehr.) Pfitzer	-	-	+
Caloneis bacillum (Grunow) Cleve	-	-	+
Pinnularia microstauron (Ehr.) Cleve	-	-	+
Pinnularia graciloides Hustedt	-	-	+
Pinnularia interrupta W.M.Smith	-	-	+
Rhopalodia sp.	-	-	+

Conclusion

Samples collected from six wetlands of Coimbatore, records 27 dominant species of 96 Species belonging to 34 genera. Dominant species that are cosmopolitan include *Cyclotella meneghiniana, Nitzschia sp., Sellaphora pupula, Gomphonema parvulum* and *Navicula sp.* Singanallur wetland and Noyyal river stretches are characterised 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* was determined by high electrolyte conductivity and *Gomphonema* and *Nitzschia* were distributed in all pH and conductivity ranges, where *Fragilaria* is restricted to neutral alkaline pH and moderate electrolytic waters. With respect to habitat preference epiphytic, epilithic and episammic habitats contained 50%, 10.4%, and 7.2% of taxa unique to that habitat. Diatom indices reveal that water quality of the sampled wetlands are moderate (mesotrophic) to heavily polluted (eutrophic).

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Annexure: I - List of Species

Achnanthidium exiguum (Grunow) Czarn.	AEHE
Actinocyclus normanii (Greg. ex Grev.) Hustedt morphotype *normanii*	ANMN
Amphora copulata (Kutz) Schoeman & Archibald	ACOP
Amphora montana Krasske	AMMO
Amphora veneta Kutzing	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
Caloneis bacillum (Grunow) Cleve	CBAC
Caloneis molaris (Grunow) Krammer	CMOL
Carticula sp.	CRAT
Cocconeis placentula Ehrenberg var. placentula	CPLA
Cocconeis sp.	COCS
Craticula accomoda (Hustedt) Mann	CRAC
Craticula ambigua (Ehrenberg) Mann	CAMB
Cyclotella meneghiniana Kutzing	CMEN
Cyclotella woltereckii Hustedt	CWOL
Cymbella tumida (Brebisson)Van Heurck	CTUM
Cymbella turgida Gregory	CTUR
Cymbella turgidula Grunow in A.Schmidt & al.	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 sp.	EOLI
Eolimna subminuscula (Manguin) Moser Lange-Bertalot & Metzeltin	ESBM
Eunotia mesiana Cholnoky	EMES
Eunotia minor (Kutzing) Grunow in Van Heurck	EMIN
Eunotia sp.	EUNO
Fallacia pygmaea (Kützing) Stickle & Mann	FPYG
Fragilaria biceps (Kutzing) Lange-Bertalot	FBCP
Fragilaria ulna (Nitzsch.) Lange-Bertalot *var. ulna*	FULN
Fragilaria ulna var.acus (Kutz.)Lange-Bertalot fo. teratogene	FUAT
Fragilaria ungeriana Grunow	FUNG
Geissleria decussis(Ostrup) Lange-Bertalot & Metzeltin	GDEC
Gomphonema affine Kutzing	GAFF
Gomphonema gracile Ehrenberg	GGRA
Gomphonema parvulum Kutzing *var. parvulum f. parvulum*	GPAR
Gomphonema pseudoaugur Lange-Bertalot	GPSA
Gomphonema sp.1	GOMS
Gomphonema sp.2	GOMS
Gomphonema turris Ehr.	GTUR
Hantzschia sp.1	HAN1
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 Kutzing	NROS
Navicula sp.1	NASP

Navicula sp.2	NAVI
Navicula symmetrica Patrick	NSYM
Navicula trivialis Lange-Bertalot *var. trivialis*	NTRV
Navicula veneta Kutzing	NVEN
Navicula viridula (Kutzing) Ehrenberg	NVIR
Navicula zanoni Hustedt	NZAN
Nitzschia amphibia Grunow f.amphibia	NAMP
Nitzschia capitellata Hustedt in A.Schmidt & al.	NCPL
Nitzschia clausii Hantzsch	NCLA
Nitzschia frustulum (Kutzing) Grunow var.frustulum	NIFR
Nitzschia liebetruthii Rabenhorst *var.liebetruthii*	NLBT
Nitzschia obtusa W.M.Smith	NOBT
Nitzschia palea (Kutzing) W.Smith	NPAL
Nitzschia pumila Hustedt	NPML
Nitzschia sigma(Kutzing)W.M.Smith	NSIG
Nitzschia sp.	NZSS
Nitzschia supralitorea Lange-Bertalot	NZSU
Nitzschia umbonata(Ehrenberg)Lange-Bertalot	NUMB
Nupela sp.	NUPE
Pinnularia acrospheria Rabenhorst	PACR
Pinnularia graciloides Hustedt	PGRO
Pinnularia interrupta W.M.Smith	PINT
Pinnularia microstauron (Ehr.) Cleve	PMIC
Pinnularia sp.	PINS
Pinnularia sp.1	PIN1
Pinnularia viridiformis Krammer	PVIF
Placonesi sp.1	PLAS
Placonesi 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 sp.	RHOS
Sellaphora laevissima (Kutzing) D.G. Mann	SELA
Sellaphora pupula (Kutzing) Mereschkowksy	SPUP
Seminavis sp.	SMNA
Surirella angusta Kutzing	SANG
Surirella sp.	SURS
Surirella tenera Gregory	SUTE
Thalassiosira duostra Pienaar	TDUO
Tryblionella calida (grunow in Cl. & Grun.) D.G. Mann	TCAL

Annexure: II - Illustrations

This report is based on one time sampling and may not reflect the entire diatom flora of Coimbatore. This report is written keeping in mind the requirement of beginner's who have started the journey with diatoms. It is important not to adopt "nearest match" approaches in identification of diatom flora. Photographs included here were taken using a camera attached with bright field microscope (scale bars are equal to 10 µm) and some are using scanning Electron Microscope (SEM) available at **Institute Nanoscience Initiative (INI), Indian Institute of Science**. Identification of diatom taxa and ecological information provided in this report are based on the following literatures:

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NOTE: This document does not provide comprehensive list of all diatom species. If particular taxon is not found in this report, researchers are advised to refer diatom floras listed above. If this is not possible, it is appropriate to leave the specimen catalogued as “unidentified” with illustrations or photographs for future references.