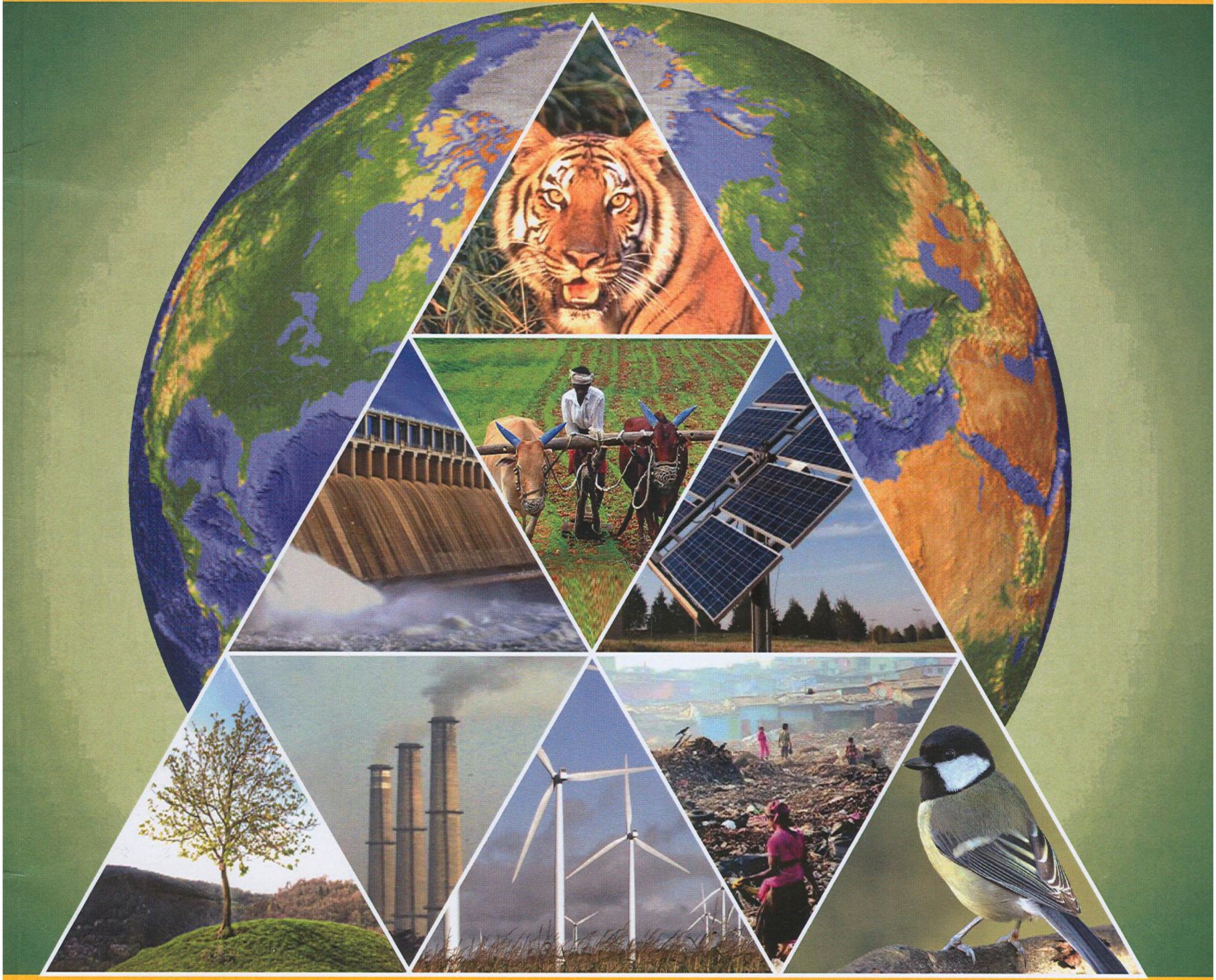
Volume 2 (3) July - September 2013

ISSN 2249-2127

International Journal of Environmental Sciences



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Original Research Paper

ISSN 2249-2127

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Alakananda B et al
Int. J. Environmental Sciences
Vol 2 (3) : pp 165-178 (2013)

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

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ABSTRACT

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

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

INTRODUCTION

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

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

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

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

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

Study area

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

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

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

METHODS

Diatom Sample Analysis

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

Water sampling

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

Data Analysis

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

Results

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

Prior- and Post-Restoration Diatom Assemblages

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

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

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

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

Comparison among wetland types

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

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

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

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

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

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

DISCUSSION

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

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

Figure 1 Bangalore Map showing studied wetlands

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

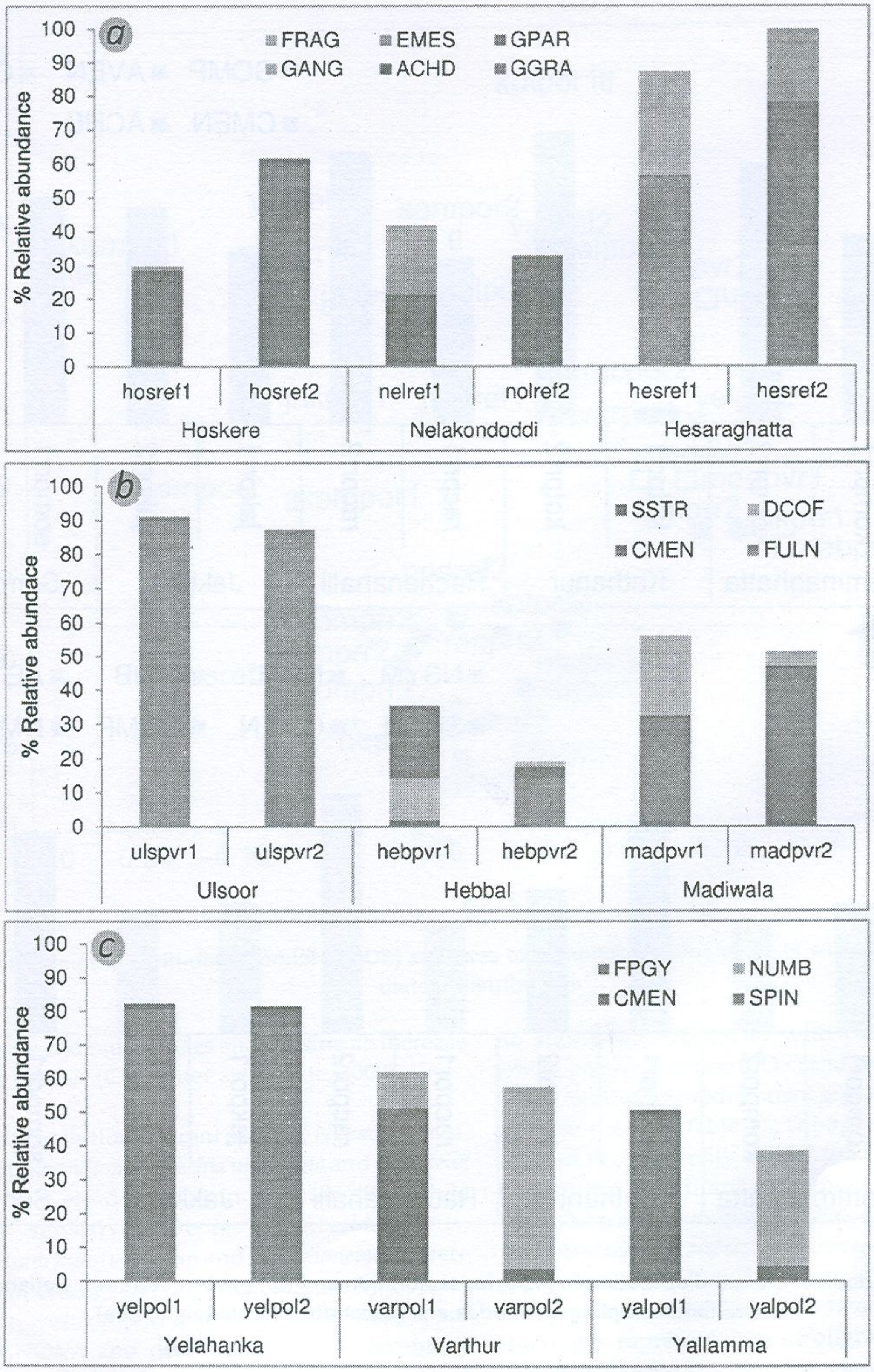

Figure 2 Diatom distribution in different wetlands (a.) reference wetlands, (b.) polluted wetlands and (c.) previously restored wetlands. (See Table 1 for wetland sampling site codes).

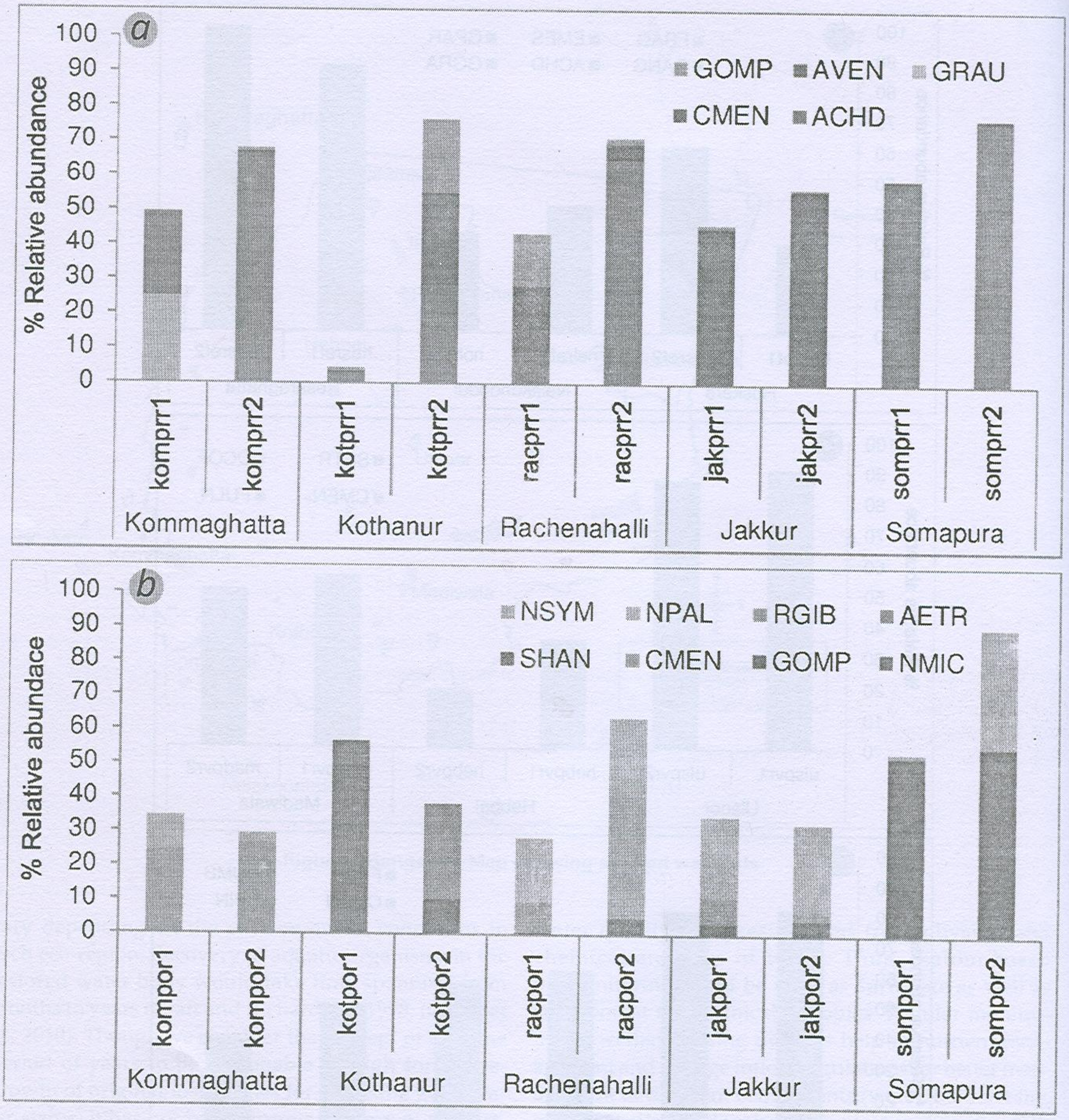

Figure 3 Comparison of diatom distribution in (a.) prior-restoration and (b.) post- restoration wetlands (See Table 1 for wetland sampling site codes and Appendix 1 for diatom codes)

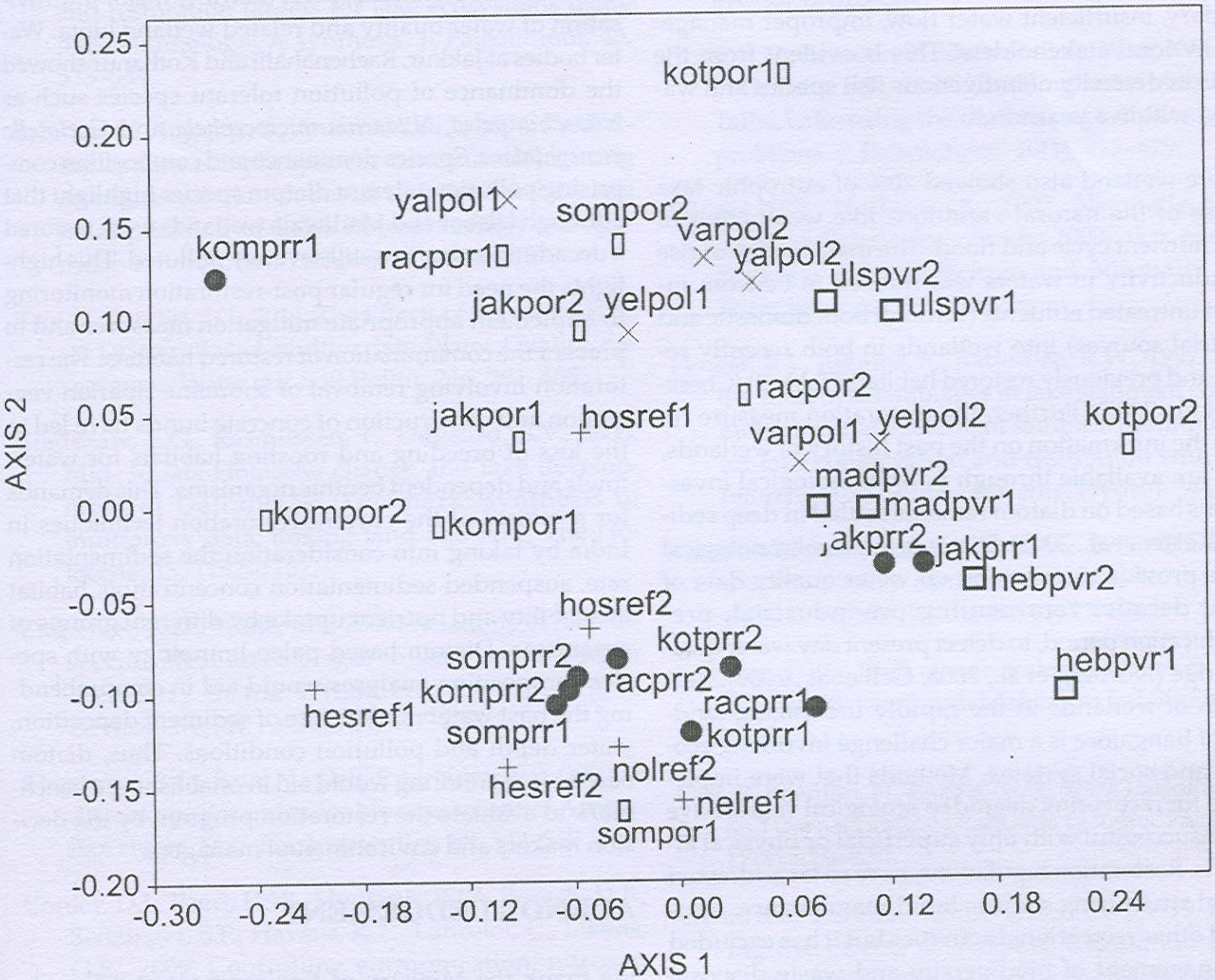

Figure 4 Non-metric multi-dimensional (NMDS) analyses to demonstrate clustering of wetlands based on the diatom distribution.

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

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

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

CONCLUSION

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

ACKNOWLEDGEMENT

We thank the Ministry of Environment and Forests, Government of India and Indian Institute of Science for financial and infrastructure support. We thank Supriya, Meera and Yallappa for their assistance during fieldwork and Susanto Sen for language editing.

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