EFFICACY OF CURRENT RESTORATION APPROACHES - BANGALORE WETLANDS

Ramachandra T V	Alakananda B	Supriya G

ENVIS Technical Report 73
January 2015

Energy & Wetlands Research Group [CES TE15]
Centre for Ecological Sciences,
Indian Institute of Science,
Bangalore - 560012, INDIA
Web: http://ces.iisc.ernet.in/energy/, http://ces.iisc.ernet.in/biodiversity
Email: cestvr@ces.iisc.ernet.in, energy@ces.iisc.ernet.in

EFFICACY OF CURRENT RESTORATION APPROACHES - BANGALORE WETLANDS

Ramachandra T V **Alakananda B** **Supriya G**

Citation: Ramachandra T V, Alakananda B and Supriya G, 2015. Efficacy of current restoration approaches - Bangalore wetlands, ENVIS Technical Report 73, CES, Indian Institute of Science, Bangalore 560012

ENVIS Technical Report 73
January 2015

Energy & Wetlands Research Group, Centre for Ecological Sciences,
TE 15, New Bioscience Building, Third Floor, E Wing,
Indian Institute of Science, Bangalore 560012, India
http://ces.iisc.ernet.in/energy
http://ces.iisc.ernet.in/biodiversity
E Mail: cestvr@ces.iisc.ernet.in; wetlands@ces.iisc.ernet.in

EFFICACY OF CURRENT RESTORATION APPROACHES - BANAGLORE WETLANDS

Ramachandra T V **Alakananda B** **Supriya G**

Energy & Wetlands Research Group,
Centre for Ecological Sciences,
Indian Institute of Science
Bangalore 560012, India

Citation: Ramachandra T V, Alakananda B and Supriya G, 2015. Efficacy of current restoration approaches - Bangalore wetlands, ENVIS Technical Report 73, CES, Indian Institute of Science, Bangalore 560012

ENVIS Technical Report 73
January 2015

Energy & Wetlands Research Group,
Centre for Ecological Sciences, TE 15
New Bioscience Building, Third Floor, E Wing
Indian Institute of Science
Bangalore 560012, India
http://ces.iisc.ernet.in/energy
http://ces.iisc.ernet.in/biodiversity

Email: cestvr@ces.iisc.ernet.in,
energy@ces.iisc.ernet.in
sahyadri@ces.iisc.ernet.in

EFFICACY OF CURRENT RESTORATION APPROACHES - BANGALORE WETLANDS

Contents

EFFICACY OF CURRENT RESTORATION APPROACHES - BANGALORE WETLANDS

1. Summary

Wetlands (including ponds, lakes, rivers, etc. as per Ramsar Convention, 1971) are ecologically vital freshwater resources, which provide wide array of ecological services, such as recharge of groundwater resources, remediation, mitigation of floods, etc. Investigations of alteration on environmental conditions (such as water flow, retention time, temperatures, availability of habitat, light penetration and nutrient dynamics) and their impact on ecosystem's flora and fauna would aid in evolving appropriate conservation and sustainable management strategies.

During the twentieth century, with the rapid urbanisation and consequent increases in human settlements have altered the physical and chemical integrity of wetlands evident from a decline in number of water bodies and also the presence of eutrophic lakes. These are responsible for the decline in birds, fish, and imbalances in the entire food chain. Even though wetland's water quality is restored and monitored, quality of wetland continue to show declining trend due to the insufficient knowledge on wetland's biodiversity and lack of ecological approaches in wetlands restoration. The flora and fauna reflects the ecological status apart from physical and chemical integrity of an ecosystem. Thus, use of biological organisms in monitoring and wetland management has proved to be cost effective to reflect ecologically degraded ecosystem than water quality (chemical and metal) analysis. The current study describes

- water quality before and after restoration of select lakes;
- diatom assemblage before and after restoration and
- strategies for conservation of wetlands.

Bangalore, previously known as garden city (due to its lush greenery and salubrious climate) and fifth among the most populous metropolitan area in India consequent to rapid urbanisation subsequent to globalization and spurt in IT and BT sectors. Decline of wetlands (79%), initiated inquisitiveness to study biological organisms along with water quality in recent times. Water quality and ecology of wetlands like Sankey, Ulsoor, Yadiyur etc. has not distinctly different from polluted wetlands due to lacunae in the restoration measures. This study reports a detailed survey of flora and fauna commonly found in all wetlands together with physical, chemical and biological exploration prior to restoration of 11 wetlands (grouped under Hebbal valley, Vrishabhawati valley and K&C valley). These wetlands are being restored by Bangalore development authority (BDA). Water samples were collected during February 2009 to September 2011 once in a 6 month period to reflect conditions before restoration (February – September 2009) and after restoration (February 2011- September 2012) (Table 1 and 2).

Water samples and bio-indicator organisms such as diatoms, mollusks, aquatic insects, butterflies and birds details were recorded prior and post wetland restoration with the objective of assessing biodiversity and effectiveness of wetlands restoration. Results showed a significant variation in water chemistry across sampling sites. Water chemistry variables such as pH, BOD, COD and chlorides were found to be high, exceeding BIS permissible surface water standards limit at Thalghattapura (TA), Mallathally (ML) (Vrishabhavati valley), Jakkur (JK), Rachenahalli (RC) (Hebbal valley) and Kothanur (KT) (K&C valley) wetlands. Consequent decrease in dissolved oxygen at JK, RC and ML was recorded prior to restoration. The pre restoration results showed a significant relationship between water quality and community structure. Among all wetlands belonging to 3 valleys of Bangalore, Vrishabhavathi valley wetlands were less polluted compared to Hebbal and K&C valley wetlands. These wetlands comprised of sensitive diatom and mollusk taxa while, pollution tolerant taxa at Hebbal and K&C valley valleys reflected water pollution and contamination. There was no prominent pollution indicating birds and butterflies pattern observed. The treated sewage inflow is considered as a key step in restoration, but sustained inflow of untreated sewage has led to eutrophication at Kothanur. Due to the removal of all riparian vegetation, less/no birds, mollusks and insects were recorded.

A total of 91 diatom taxa, 13 mollusk species, 10 groups of aquatic insects, 12 groups and 89 varieties of birds (20, aquatic birds and 69, terrestrial birds) were recorded, which include cosmopolitan groups of mollusks, aquatic insects, diatoms and butterflies. Among birds, all are categorized as least concern, common species, except White tailed swallow at JK is categorized as vulnerable taxa and listed under C2a (ii) as per IUCN red list. The highest bird population was recorded at Ramasandra, Kommaghatta, Jakkur and Rachenahalli. Diatom community structure and distribution pattern reflected heavy organic pollution at sampling sites such as JK, RC, ML and KT with low species richness and high dominance index. Taxa such as *Nitzschia palea*, *Nitzschia umbonata*, *Cyclotella meneghiniana*, *Diadesmis confervaceae* and *Gomphonema parvulum* were abundant indicating the level of pollution. Post restoration investigations were carried out during 2011-2012 to understand the effectiveness of wetlands restoration.

The post restoration results showed a similar water quality and diatom community structure at sampling sites of Kothanur and Mallatahally. Continued inflow of untreated sewage has defeated the purpose of the restoration. The diatom taxa, *Nitzschia palea,* which is a pollution tolerant taxa was found abundant at Kotahnur Inflow region during pre and post restoration periods. The restoration work was affected by rain (before September 2011) at Jakkur and Rachenahlli wetlands.

This study emphasizes the need for scientific restoration adopting both ecological and engineering approaches. It is necessary to treat the sewage before letting into wetlands. Construction of sewage treatment plants at decentralized levels is necessary to minimize the degradation of wetlands ecosystem and subsequent contamination of groundwater resources. Also there is a need to demarcate buffer region of 200 m with riparian vegetation and minimal human activities to sustain water in wetlands. The results of water quality and diatom analysis during pre and post restoration investigations are used to summarize knowledge about impact of restoration on biological community. Management during post restoration plays an important role in retaining wetland's quality. The later part of this report, lists recommendations and restoration measures to be implemented for the conservation and sustenance of ecosystem services of these fragile ecosystems.

3. Introduction

Wetlands include marsh, fen, peat land/ open water, flowing water (rivers and streams) or static (lakes and ponds) aquatic habitats, which are fresh, brackish or salt water. They are ecologically vital systems with respect to stability and biodiversity of a region and also in terms of energy and material flow. Wetlands are often described as "Kidneys of the landscape" as they aid in the remediation with the uptake of nutrients, purification of water, recharge groundwater aquifers and protect shorelines. These fragile ecosystems act as giant sponges, soaking up runoff water originating with rainfall which helps in slowing floodwaters, lower flood heights, reduce shoreline and stream bank erosion.

The non-stratified photic zone extends up to sediment layer enhancing the growth of photosynthetic benthic and planktonic algae. Wetlands with the higher photosynthetic activities sequester carbon (2.23-3.71 metric tons/acre/year) higher than terrestrial forests (0.05-3.9). The interactions among basic components (soil, water, animals and plants) of wetlands aid in sustaining diverse life. Wetlands are often branded as "ecological super complexes" as they aid in maintaining trophic levels and a repository of rich biodiversity (Ramachandra, 2001, Prasad et al., 2002, Ramachandra et al., 2002, Ramachandra 2005). Characteristics of wetlands depend on its physical (sediments deposition, water depth, etc.), chemical (organic matter, etc.) and biological components (macrophytes type).

Wetlands are threatened due to the disturbance caused by flooding, sustained inflow of domestic sewage, industrial effluents (in urban environment), agricultural runoff containing inorganic fertilisers and pesticides (rural environment). Ancient human societies have traditionally recognised wetlands resources in practical as well as symbolic ways. Failure by modem societies to deal with water as a finite resource is leading to the destruction of rivers, lakes and marshes that provide us with water. This failure in turn is threatening all options for the survival and security of plants, animals, humans, etc. There is an urgent need [Ramachandra, 2005] for

- *Restoring and conserving the actual source of water*-the water cycle and the natural ecosystems that support it, which is the basis for sustainable water management;
- *Environmental degradation is preventing us from reaching goals* of good public health, food security, and better livelihoods worldwide;
- *Improving the human quality of life* can be achieved in ways that also maintain and enhance environmental quality;
- *Reducing greenhouse gases to avoid the dangerous effects of climate change* is an integral part of protecting freshwater resources and ecosystems.

Enhanced anthropogenic activities consequent to the burgeoning population and unplanned rapid urbanization have led to the reclamation of wetlands and freshwater resources. Several wetlands have been encroached resulting in either drastic shrinkage or deterioration of water quality; sedimentation and shrinkage; decrease in productivity along with flora and fauna; loss of aesthetic values and decrease in tourism potential. These acting stressors, along with climate variability, can synergistically contribute to the degradation of biological diversity at the species, genetic, and/or habitat– ecosystem levels and thus are a primary cause of the present extinction crisis (Collinge, 1996; Adriaensen *et al.*, 2003). Subtle changes in water chemistry constitute ecological barrier for the interaction of species/ species assemblages with their immediate ecology. Thus, water quality is one among the numerous crucial factors and nutrients as resource for the primary producers for their distribution due to their high sensitivity and tolerance responses to sudden shifts in immediate environment. Long term monitoring, bio-monitoring of wetlands are required for the maintenance of wetland ecology, towards the sustainable management of wetlands (Alakananda *et al.*, 2011).

The biological structure of a wetland depends on its water retaining capacity, water flows, and seasonal alterations. Study of wetlands begins from its basic hydrological characteristics like depth, sediment texture, photic zone, temperature and subsequently towards the understanding of biological existence like bacteria, protozoa, planktonic, benthic/littoral representing the ecosystem diversity. The diverse groups of organisms contribute in wetland functioning by water purification (nutrients uptake, Friedrich et al., 2003; Ying et al., 2011); carbon dioxide sequestration (phytoplanktons, Kenning, 2009); balancing food chain (ESA, 2003); sediment erosion; habitat for flora and fauna diversity and balancing the ecosystem health (Townsend and

Gell, 2005). Although, many wetland functioning processes benefited human civilization, knowledge about wetland dynamics is scanty compared to its exploitation.

Initial wetland investigations have often been made in isolation, specific to a river-drainage system, region/ community, without adequately considering the synergistic relationships. Later, it was extended to every geographic region and information compiled on individual wetlands at the regional scale. In late 20th century extensive wetland studies unraveled of human intrusion, unanticipated anthropogenic activities and population stress lead to unplanned urban expansion (Ramachandra and Kumar, 2008). Anthropogenic activities like construction of roads, agriculture, removal of vegetation cover in the catchment, and others imbalances the nutrient input rate and organic content of wetlands often increasing the overall productivity of wetland (Ramachandra et al., 2011). At present, many wetlands, ponds and wetlands are in the verge of extinction resulting in either drastic shrinkage of water bodies or major impacts being deterioration of wetland water quality; sedimentation and shrinkage; decrease in productivity along with flora and fauna; loss of aesthetic values and decrease in tourism potential. These acting as stressors, along with the climate variability, leading to the degradation of biological diversity at the species, genetic, and/or habitat– ecosystem levels (Collinge, 1996; Adriaensen *et al.*, 2003). Water quality is one among the numerous crucial factors and nutrients as resource for the primary producers for their distribution due to their high sensitivity and tolerance responses to sudden shifts in immediate environment. Subtle changes in water chemistry constitute an ecological barrier for the interaction of species/ species assemblages with their immediate ecology (Alakananda *et al.*, 2011). For the monitoring and management of water bodies and its ecosystems, Ramsar convention defined water bodies (with depth less than 6 m) like marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, including fresh, brackish or salt, as *Wetlands.* For the purpose of restoration of degraded wetlands, Ramsar convention (since 1981 in India) includes 25 wetlands among several polluted wetlands of India for monitoring restoration and sustainable water use by humans. However, yet hundreds of wetlands decline every year without appropriate management.

3.1 Significance of Restoration

Wise-use of wetlands entails the maintenance of ecological character. This requires the implementation of ecosystem approaches, within the context of sustainable development. Restoration is a significant step in ecosystem management for recapturing the ecosystem assets to a close approximation of its condition prior to disturbance. This ensures that the ecosystem structure with functional abilities are recreated or restored, and that natural dynamic ecosystem processes operate effectively again. The main component of the wetland restoration involves either diverting contaminations like sewage flows (as distinct from rainwater), road runoff, away from the wetlands or construction of waste water treatment plant for sewage and industrial waste surrounding the wetland. Current approaches of wetland restoration involve engineering techniques such as plugging agricultural ditches, sediment disturbance, nutrient mixing, constructing percolation tanks etc., in order to restore the hydrology of that area. Many wetlands fails in regaining the desired water quality as ecological components (ex., biological such as disruptions in the food chain - birds, amphibians, planktons, etc. and microhabitat) are affected (Zheng and Stevenson, 2006). Ecological restoration techniques include regular biomonitoring, developing biotic indices, accessibility of substrata for growth of primary producers, maintaining riparian vegetation, ensuring appropriate slope, etc. This will be the definitive way to preserve freshwater environment alive and with them the algae, fish, birds, and other creatures which balance ecology. The precautions to be taken in retaining the natural ecosystem during restoration program includes,

- Existing tanks riparian vegetation should not be disturbed to retain and enhance aquatic life;
- Tanks should not be breached but retained as water bodies
- De-silting to enhance the recharge of ground water sources
- Introduction of fish species to control mosquito larvae and associated health hazards
- Treatment of sewage with the conventional treatment plants and constructed wetlands and shallow algae ponds for removal of nutrients (before treated sewage is let into the lake.
- Verification of water quality regularly and
- Removal of illegal encroachments and slum development.

Even though chemical assessment of water was initiated 200 years ago, it doesn't capture complete condition of an ecosystem enabling both preventive as well as restorative measures. The better realization of interactions between environmental quality and ecosystem integrity has increased the interest in finding biological indicators that provide a more accurate guide to changes in ecological conditions and biodiversity (Lavoie *et al.*, 2003). A survey was carried out (1984-1987), with the objectives to document and analyze the flora, fauna and habitats of only the protected areas such as wild life and statuaries of India. In 1995, the entire extend of Krishna river system was assessed for the content and quality of the bioresources (Jayaram, 1995). Pollution loads from the urban sources at several sampling sites signaled to minimize the contamination load through waste water treatment though; the maintenance of river system was not referred to. Xianguo and Rongfen, (1996) studied biodiversity of wetlands accounting for the floral and faunal diversity and thus suggested the investigation of environmental function of wetland, the influence of human impacts on wetland resources and polices for species protection 'prior to restoration measures'. Investigation of flora and fauna of Gujarat appended 732 species and subspecies of fauna and 180 species of flora to be known (Subba Rao and Sastry, 2005). Determining the variation in environmental conditions and subsequent impairment in biotia during restoration has been studied extensively through algal species composition. Janousek *et al.*, 2007 assessed the variation in microalgal and phototrophic bacterial at a restoration site by sampling for a period of 3 yr.

3.2 Bangalore wetlands

Even though, threats to the environment and associated biodiversity have been identified, the already fragmented/degraded wetlands such as Bangalore ecosystem, are still experiencing degradation due to unplanned urbanization. Bangalore, once was known as city of wetlands comprising more than 400+ wetlands in 19th century has dwindled from 250 to 81 (1985) and 33 in 2006 (Ramachandra and Uttam kumar, 2008). A large number of water bodies (locally called wetlands or tanks) in the City had ameliorated the local climate, and maintained a good water balance in the neighborhood. Wetlands in Bangalore has been grouped into 3 valleys viz., Hebbal valley; Vrishabhavathi Valley and the Koramangala and Challaghatta Valleys. These form important drainage courses for the interconnected wetlands, which carry storm water beyond the city limits. Government committee was constituted in 1986 to record the water quality of several wetlands which was followed by a series of studies (Ramachandra et al., 1998-2008) explaining the physical and chemical variables of wetlands. These studies recommend the need for conserving biological diversity and the ecological integrity of wetlands. The sustained inflow of untreated sewage, industrial effluents, etc. has deteriorated water quality, evident from the results of regular water quality monitoring (Rajinikanth and Ramachandra, 2000; Ramachandra and Malvika solanki, 2007 & Ramachandra, 2008). Comparative analysis of water quality estimation resulted with the impact of pollution on the quality as well as the decrease in wetland catchment. Degradation of wetlands environs resulted in flooding (Krishna et al., 1996) mass fish kill (Benjamin et al., 1996) reduction of migratory bird population (Kiran and Ramachandra, 1999) and ground water contamination (Shankar et al., 2008). These studies lack the comprehensive account of the ecosystem biodiversity with the implementation of restorative measures. Therefore the investigation was carried out on water analysis accounting flora and fauna of wetlands, chosen for restoration by Bangalore development authority – BDA. 11 wetlands considered for restoration with detailed pollution problems in watershed are listed in table 1 and sampling codes are listed in Table 2. Wetlands were considered for restoration following the engineering techniques. Steps involved in current process of restoration in Bangalore are,

- De-silting
- Construction of cement bund
- Prevention of Wastewater entering into the Wetland
- Improvements of outlet waterway (waste weir) and sluice
- Development of storm water inlets and catchments area
- Silt trap and Screen Barrier
- Kalyani for idols Immersion
- Islands for birds roosting
- Boundary protection, Landscaping, beautification of the garden region
- Development of surroundings for recreational purposes.

NOTE: Documentation of flora and fauna of post restoration was not fulfilled because of (1) decreased floral and faunal diversity or unavailability of aquatic birds, aquatic insects and mollusks, and (2) incomplete restoration (as per the date announced). Post restoration wetland quality was investigated using diatoms as bioindicators of ecosystem integrity as they form the basis of the food chain.

3.3 Diatoms for post restoration studies

Diatoms, the unicellular group of algae have so far been widely recognized as an easy and simple proxy for environmental changes (Zalack *et al.,* 2010). Few species of diatom community grows and reproduce quickly to the changes in nutrients, salinity, pH or a number of other factors. Hence the community composition as a whole changes in response to changes in environmental conditions. Diatoms are the most diverse and dominant group of algae in rivers, streams, wetlands and wetlands forming an important component of the aquatic ecosystem (Stoermer and Smol, 1999). Shift in diatom community structure is used to detect changes in the environmental condition such as pH, conductivity and organic nutrients (Bennion et al. 2000, Potapova and Charles, 2003), eutrophication (Kitner and Poulícková, 2003) and global warming problems (Leelahakriengkrai and Peerapornpisal, 2010). Diatoms have been used successfully in water assessments across different habitats such as streams, (Simkhada et al. 2006); ponds, (Poulíčková et al. 2008); wetlands, (Blanco et al. 2004). In this context, diatom distribution before and after restoration provides insights to the efficacy of wetlands restoration.

Ecological monitoring programs that include diatoms are exceptional and in many cases uncertain especially in India. Though diatom study was initiated with expedition of different ecosystems, ecological values of diatoms and its diversity in India is yet to be explored. In this scenario, there is a need for taxonomical, systemic, ecology and biomonitoring studies in diatom field to evolve appropriate management and restoration strategies of urban wetlands, which in turn aid in protecting flora, fauna and habitats.

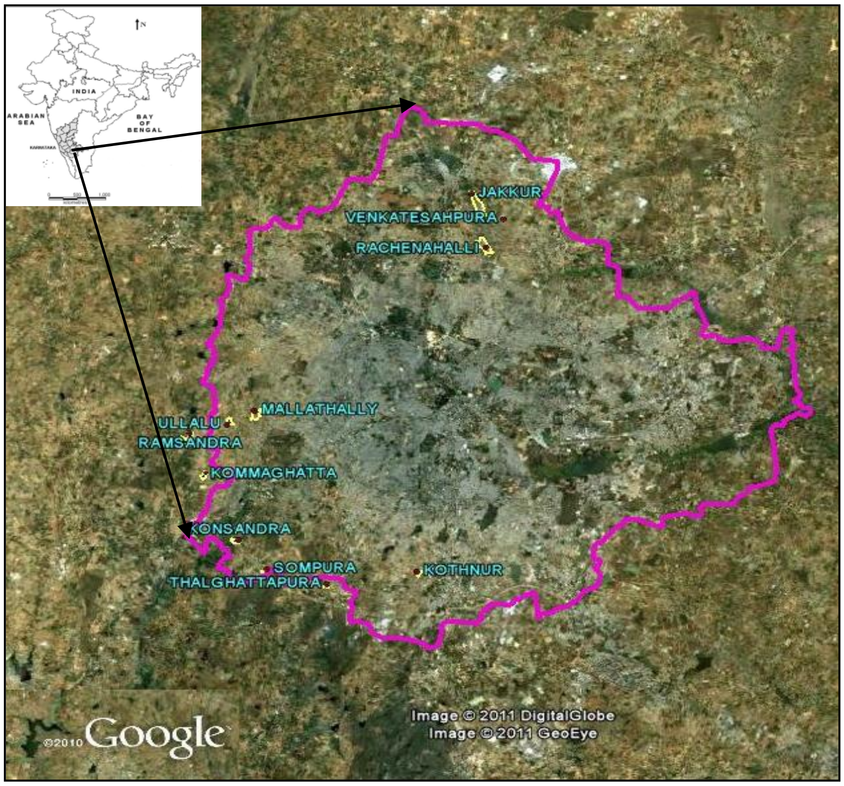
Table 1 Details of wetlands selected for the study. (*compiled by BDA.** data compiled by BBMP)

Wetland	Geographic co-ordinates (Lat/long)*	Depth (m)+	Spatial extent in Ha (Weed cover in Ha)+	Catchment area in Ha+	Remarks+
Jakkur	13^0 04' N/ 77^0 36' E	1.25	59 (5.1)	806	Domestic run-off, urbanization, agriculture, plantations
Rachenahalli	13^o03' N/ 77^0 37'E	1.7	44.35 (2.1)	850	Domestic runoff, urbanization, agriculture, plantations
Venkateshpura	13^o03' N/ 77^0 37'E	2.33	4.4 (0.1)	109.5	Domestic runoff, urbanization, agriculture, plantations, quarry
Ullalu	--	2.91	12.64	342.8	Vacant land, less human density, less vegetation, road run-offs, soil erosion
Mallathally	--	1.54	23.516	618	Domestic run-off, defecation
Ramasandra	12^0 55' N/ $77^0$27' E	3.2	54.77 (1)	1629	Agriculture, plantations runoff, undeveloped areas
Konasandra	12^0 53'N/ 77^0 29' E	1.4	15.11 (5.5)	128	Forest, urbanization
Kommaghatta	--	2.51		553	Domestic run-off , plantations, road run-offs
Somapura	12^0 52'N/ 77^0 30' E	1	7.49 (1.29)	93	Urbanization, road run-offs
Thalghattapura	12^0 59'N/ 77^0 32' E	2.5	7.85 (1)	217.45	Open fields, forest, Layout run-off
Kothnur	12^0 52'N/ 77^0 34' E	1.75	7.375 (0.5)	89.9	Urbanization

Codes	Sampling site	Codes	Sampling site	Codes	Sampling site
JK	Jakkur	KMO1	Kommaghatta outlet 1	KT	Kothanur
JKI1	Jakkur inlet 1	ML	Mallathally	KTI1	Kothanur inlet 1
JKI2	Jakkur inlet 2	MLI1	Mallathally inlet 1	KTO1	Kothanur outlet 1
JKO1	Jakkur outlet 1	MLO1	Mallathally outlet 1	KN	Konasandra
RC	Rachenahalli	UL	Ullalu	KNFN	Konasandra fencing
RCI1	Rachenahalli inlet 1	ULI1	Ullalu inlet 1	KNL1	Konasandra layout
RCI2	Rachenahalli inlet 2	ULO1	Ullalu outlet 1	KNI1	Konasandra inlet 1
RCO1	Rachenahlalli outlet 1	TA	Thalghattapura	KNO1	Konasandra outlet 1
VN	Venkateshapura	TAI1	Thalghattapura inlet 1	RM	Ramasandra
VNI1	Venkateshapura inlet 1	TAI2	Thalghattapura inlet 2	RMI1	Ramasandra inlet 1
VNO1	Venkateshapura outlet 1	TAO1	Thalghattapura outlet 1	RMA1	Ramasandra animal grazing 1
KM	Kommaghatta	SM	Somapura	RMO1	Ramasandra outlet 1
KMI1	Kommaghatta inlet 1	SMI1	Somapura inlet 1	RML1	Ramasandra layout 1
KMI2	Kommaghatta inlet 2	SMO1	Somapura outlet 1	RMB1	Ramasandra boat 1

Table 2 List of Bangalore wetland sampling sites with codes

Figure 1: Bangalore map showing sampling sites and Bangalore boundary (Courtesy: BBMP).


N
INDIA
ARABIAN SEA
BAY OF BENGAL
JAKKUR
VENKATESAHPURA
RACHENAHALLI
MALLATHALLY
ULLALU
RAMSANDRA
KOMMAGHATTA
KONSANDRA
SOMPURA
THALGHATTAPURA
KOTHNUR
Image © 2011 DigitalGlobe
Image © 2011 GeoEye
©2010 Google

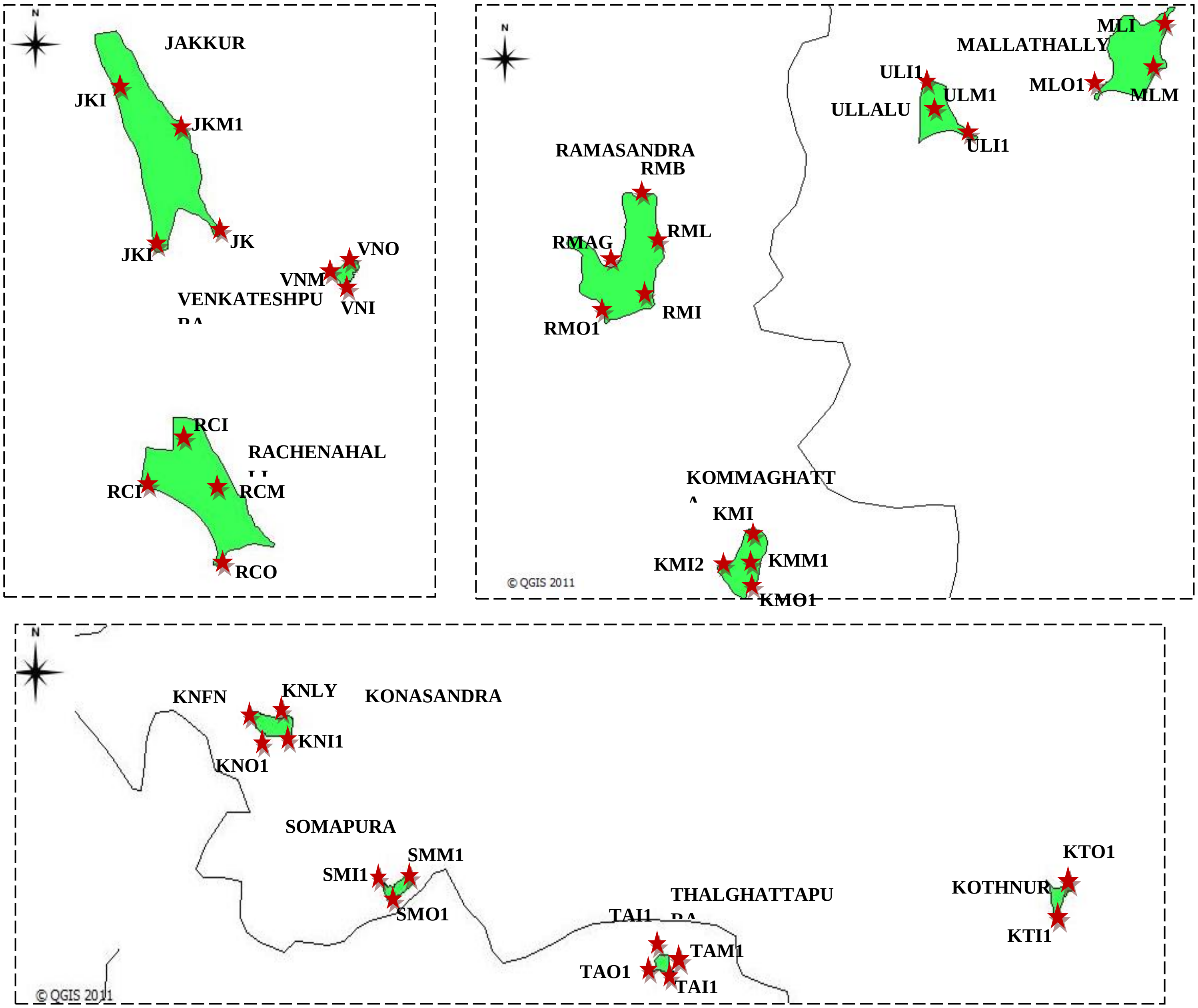


Figure 2 Detailed view of sampling sites with codes (Codes- Refer Table 2)

3.4 Objectives

To evaluate wetland restoration in maintaining characteristic ecosystem functions, objectives covered (1) documentation of flora and fauna of 11 wetlands prior to restoration, (2) water quality before and after restoration; (3) diatom assemblages before and after restoration and (4) conservation priority of wetlands. This helps in understanding about the effectiveness of restoration.

4. Study Area

Wetlands in greater Bangalore are one of the severely polluted expanses in India due to rapid urbanization and urban sprawl. Bangalore once known for its lush greenery and also for its water bodies with rich biodiversity. The city harbors many man-made wetlands to meet the domestic and agricultural needs. Wetlands of Bangalore occupy about 4.8% of the geographical area (741sq km) covering both urban and non-urban areas. They were built for various hydrological purposes, mainly to serve agriculture activities. Studies on wetlands of Bangalore during the past decade show that 35% tanks were lost owing to various anthropogenic pressures. (Ramachandra et al., 2002). There were 262 wetlands (in 1960) within the Green belt area of the city (161 sq.km spatial extent), which has fallen to 81 (Lakshman Rau, et al., 1986). Temporal analysis of wetlands recently indicates a sharp decline of 58% in Greater Bangalore attributing to intense urbanization processes, evident from a 46% increase in built-up area from 1973 to 2007 (Ramachandra and Uttam Kumar, 2008). The undulating terrain in the region facilitated the creation of a large number of tanks in the past, providing for the traditional uses of irrigation, drinking, fishing and washing.

5. Methods

5.1. Water quality investigations

Eleven wetlands were monitored during February to April 2009. Three replicates of water samples were collected from inlets, outlets and other sites (such as centre, depending on the accessibility) to observe the effect of sewage and effluents as well as to understand the quality variations at the regional scale. Onsite variables like pH, electric conductivity (EC), salinity (SAL), total dissolved solids (TDS), water temperature (WT) (Extech pH/conductivity EC500) and dissolved oxygen (DO) were measured. The samples were stored at 40C in laboratory and analyzed for nitrates (N), inorganic phosphates/or phosphorous (P), total hardness (TH), calcium hardness (CaH), magnesium hardness (MgH), chlorides (CHL), alkalinity (ALK), chemical oxygen demand (COD) and biological oxygen demand (BOD) following standard protocols (Trivedy and Goel, 1986 and APHA, 1998).

5.2. Documentation of flora

5.2.1. Diatoms

Diatom sampling was done following Taylor et al., 2005, covering available habitats such as plants (epiphytic diatoms), stones (epilithic diatoms) and sediments (episammic diatoms). The stem and root portion of submerged plants were collected in a polythene cover and crushed. The sample was then transferred into a sample bottle. Epilithic diatoms were collected from 5-8 stones in a tray and brushed using a toothbrush. The upper 0.5 cm layer of soil was collected as episammic diatom sample. Diatom frustules were cleaned from the organic material using hot HNO3 and HCl method. The cleaned samples were then used to prepared slides with the help of Pleurax as mounting agent and observed under Olympus light microscope at 1000X. Taxa were identified mainly according to Krammer and Lange-Bertalot (1991-1997) and Lange-Bertalot (2001).

5.3. Documentation of fauna

5.3.1. Mollusks:

Mollusks in the littoral zone were collected by employing 2 methods viz., quadrat method where, aquatic vegetation and other objects were collected in an area of 25 × 25 cm and transferred to a container and filtered through 0.5 mm sieve by thorough washing and time constrained method which includes mollusks were sampled by search and handpick along the shore littoral zone for five minutes. These samples were kept in separate glass/plastic bottles and preserved with 70% alcohol. Collected samples were examined under a stereo zoom microscope (10X) and identified using standard taxonomic literatures (Ramakrishna and Dey, 2007 and Subba Rao, 1989).

5.3.2. Aquatic insects

Aquatic insects were sampled using a D-net sampler holding against water current and dragged along the shore of the wetlands up to a distance of 1m (Subramanian and Sivaramakrishnan, 2007) followed by preserving in 70% ethanol. Collected samples were examined under a stereo zoom microscope (10X) and identified using standard taxonomic literatures (Fraser, 1933-36, Morse et al. 1994 and Subramanian and Sivaramakrishnan, 2007).

5.3.3. Butterflies

Butterflies were observed from 11 wetlands of Bangalore between February and April 2009. Survey was conducted only once in the surrounding area of the wetlands. Butterflies were observed for half an hour in the morning between 8 am and 9 am. The species were identified in the field following Kunte (2000). The characters of species, which could not be identified in the field, were noted down and identified in the laboratory.

5.3.4. Birds

Bird survey was conducted as a time survey method wherein one hour observations (including calls) were done in the morning between 6 am and 8 am using binoculars. Common birds were identified in the field while the characters of rare birds, were recorded and identified using field guide of Salim Ali (1996) and Grimith et al. (1999).

6. Results

6.1. Pre-restoration

6.1.1. Water quality

Physical and chemical parameters of water samples indicate significant variations across wetlands (Table 3, 4 and 5). pH, EC, BOD and COD values indicated marked difference among and as well as within wetlands. pH was lowest at Jakkur outlet (JKO1, 7.89), highest being at Mallathally inlet (MLI1, 10.30) and exceeding the BIS limits at Kommaghatta (KM), Kothanur (KT) and Rachenahalli (RC). Jakkur (JK) comprised high electric conductivity (1267.44 μScm^{-1}) followed by Somapura (SM) (1022.67 μScm^{-1}) and lowest observed at Venkateshpura (VN, 351.75 μScm^{-1}). Sampling sites such as RC, VN, KM, RM and SM reflected low organic matter concentration in terms of BOD whereas high at JK, ML, Thalghattapura (TH), Ullau (UL), Kothanur (KT) and Konasandra (KN). A consistent high organic pollution in terms of COD was recorded at all wetlands with exception at RCI1, KMI1, SMO1, KNO1, RMA1 and RMB1 (refer table 2 for codes). Nitrates and phosphates concentration were within the permissible limits ranging between 0.015 to 0.092 mgL^{-1} and 0.001 to 0.064 mgL^{-1} respectively. Total hardness ranged between 67.5 mgL^{-1} (KTO1) to 346.67 mgL^{-1} (JKI2) and increased at MLO1 and JKI1. Chlorides level at KNI1 (41.75 mgL^{-1}), JK, RCI2, MLI1 and JKI2 (295.36 mgL^{-1}) reflected rigorous inflow of sewage due to densely built up catchment area. PCA biplot (Figure 3) explained 44.799% and 12.453 % variance from 1st and 3rd components respectively. PC1 explained influence of P at RC, KTI1, TAO1 and KMI1 sites. EC, TH, CaH, MgH and CHL were significantly high at right side of PC1 influencing ML, UL, JK and TH inlet sites where inflow of sewage with high ionic concentrations was apparent. The high alkalinity was evident through PC3 at RM and KN sites.

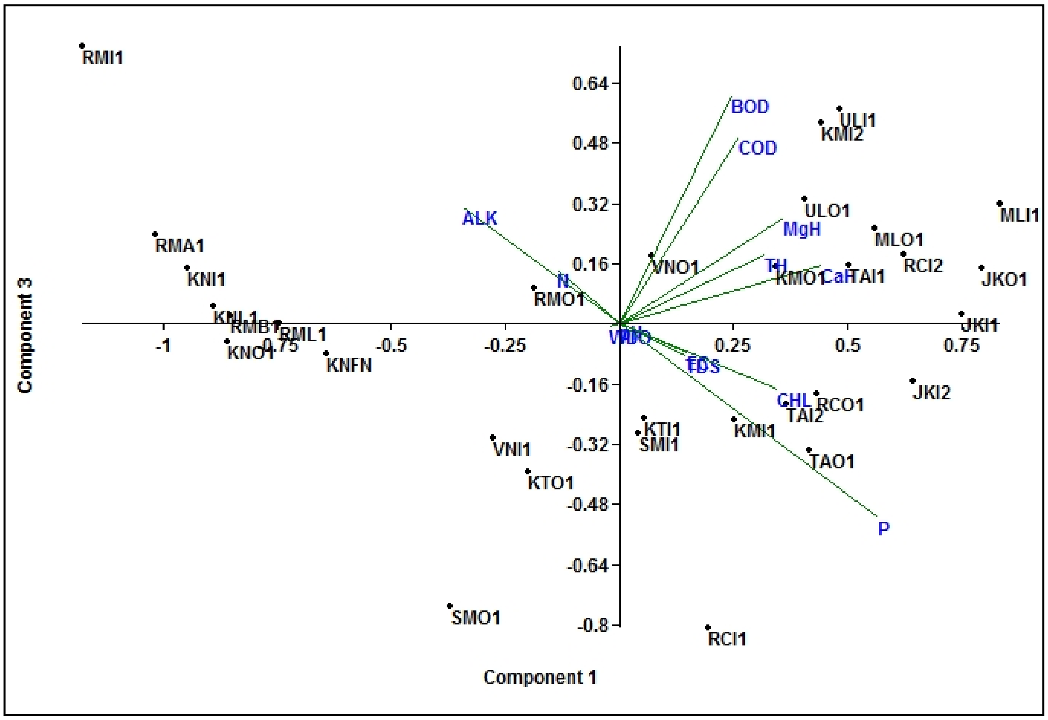


Figure 3 PCA tri-plot of water quality results analyzed from 11 Bangalore wetlands

Table 3: Water quality of Jakkur, Rachenahalli and Venkateshapura (HEBBAL VALLEY WETLANDS)

	JAKKUR				RACHENAHALLI				VENKATESHPURA		
	JKI1	JKI2	JKO1	JKM1	RCI1	RCI2	RCO1	RCM1	VNI1	VNI2	VNM1
pH	7.98	8.1	7.9	8.3	9.2	9.1	9.0	9.0	8.54	8.21	8.41
Temperature(˚C)	24.00	28.8	28.6	30.7	30.3	30.1	31.3	31.1	28.15	24.95	25.70
EC (µScm^{-1})	1158.00	1325.7	1236.3	1239.3	871.3	885.7	854.3	884.7	342.00	361.50	346.50
Salinity (ppm)	580.00	672.7	617.7	629.3	440.3	436.0	432.0	489.7	169.00	174.00	171.50
TDS (ppm)	815.00	947.0	869.3	885.7	625.0	620.0	609.3	614.3	239.00	247.50	243.50
DO(mgL^{-1})	3.25	6.9	4.8	8.0	6.1	7.8	7.3	9.3	8.13	6.18	7.40
BOD(mgL^{-1})		3.2	2.6	2.4	3.1	3.7	4.3	1.9	3.02	2.74	2.29
COD(mgL^{-1})	101.40	48.7	65.1	75.6	11.7	77.5	35.9	66.8	26.88	83.45	60.33
Nitrates(ppm)	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.02	0.02
Phosphates(ppm)	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.03	0.06
Sodium (ppm)	77	79.7	78.0	79.7	72.5	62.2	57.6	66.4	16.8	17.0	17.2
Potassium(ppm)	5.3	6.0	5.7	5.7	4.3	3.7	3.5	4.1	5.1	6.3	6.3
Total hardness (mgL^{-1})	332.00	346.7	325.3	329.3	221.3	221.3	222.7	214.7	122.00	152.00	130.00
Ca hardness(mgL^{-1})	104.00	100.0	85.3	84.0	84.7	72.7	80.0	68.0	63.33	56.00	64.00
Mg hardness(mgL^{-1})	55.63	60.2	58.6	59.9	33.3	36.3	34.8	35.8	14.31	23.42	16.10
Alkalinity(mgL^{-1})	160.00	163.3	160.0	156.7	126.7	120.0	120.0	133.3	100.00	95.00	80.00
Chlorides(mgL^{-1})	303.88	295.4	267.9	273.6	196.0	191.2	208.3	200.7	45.44	44.02	35.50

Table 4: Water quality of Kommaghatta, Thalgattapura, Mallathally and Ullalu **(K & C VALLEY WETLANDS)**

	KOMMAGHATTA				THALGHATTPURA				MALLATHALLY			ULLALU		
	KMI1	KMI2	KMO1	**KMM1**	**TAI1**	**TAI2**	**TAO1**	**TAM1**	**MLI1**	**MLO1**	**MLM1**	**ULI1**	**ULO1**	**ULM1**
pH	9.3	9.0	9.0	9.1	9.0	9.13	8.5	9.1	10.30	9.28	10.37	8.80	8.97	8.70
Temperature(˚C)	28.1	29.1	29.1	28.1	30.1	32.20	29.6	27.9	26.65	31.45	28.30	28.75	26.05	25.65
EC (μScm^{-1})	812.0	782.0	782.0	791.5	779.0	763.00	790.5	784.0	1160.00	1105.00	1128.00	747.50	587.00	605.00
Salinity (ppm)	400.5	394.0	394.0	385.5	385.0	383.00	388.5	388.0	574.00	553.50	566.00	511.50	295.50	348.00
TDS (ppm)	594.0	558.0	558.0	552.0	536.0	527.00	670.0	544.0	807.00	803.00	783.50	514.00	416.50	495.00
DO(mgL^{-1})	6.0	4.6	4.6	8.1	11.5	13.33	5.6	11.5	9.39	7.44	10.28	7.03	6.59	7.24
BOD(mgL^{-1})	2.9	3.2	3.2	1.2	--	--	--	--	4.18	2.23	3.10	--	--	--
COD(mgL^{-1})	24.0	84.0	84.0	60.0	70.0	40.00	30.0	40.0	10.00	12.00	30.00	106.00	82.00	22.00
Nitrates(ppm)	0.0	0.1	0.1	0.1	0.0	0.05	0.0	0.1	0.07	0.06	0.07	0.09	0.08	0.06
Phosphates(ppm)	0.0	0.0	0.0	0.0	0.0	0.05	0.0	0.1	0.06	0.05	0.12	0.04	0.04	0.03
Sodium (ppm)	17.2	14.6	14.6	16.9	15.4	15.20	15.9	14.9	29.70	27.95	27.50	15.15	10.30	13.90
Potassium(ppm)	0.7	0.7	0.7	0.7	7.7	7.40	7.6	7.4	4.50	4.50	4.10	0.35	0.40	0.30
Total hardness (mgL^{-1})	264.0	298.0	298.0	285.0	178.0	188.00	180.0	164.0	278.00	302.00	330.00	298.00	224.00	255.40
Ca hardness(mgL^{-1})	24.0	15.2	15.2	21.6	36.9	35.27	36.9	35.3	32.87	24.05	27.25	23.25	20.04	25.65
Mg hardness(mgL^{-1})	58.5	69.0	69.0	64.3	34.4	37.27	34.9	31.4	59.81	67.82	73.87	67.04	49.77	56.06
Alkalinity(mgL^{-1})	276.0	248.0	248.0	253.0	252.0	386.00	163.0	396.0	252.00	301.00	270.00	315.00	210.00	297.00
Chlorides(mgL^{-1})	121.4	109.5	109.5	113.6	185.3	198.80	184.6	185.7	214.42	106.50	228.62	80.94	80.94	88.89

Table 5: Water quality of Sompura, Kothanur, Konasandra and Ramasandra wetlands (**VRISHABHAVATHI VALLEY WETLANDS)**

	SOMAPURA			**KOTHNUR**		**KONASANDRA**				**RAMASANDRA**				
	SMI1	**SMO1**	**SMM1**	**KTI1**	**KTO1**	**KNFN**	**KNL1**	**KNI1**	**KNO1**	**RMI1**	**RMI1**	**RMI1**	**RMI1**	**RMI1**
pH	8.8	8.7	8.6	9.1	9.1	8.8	8.8	9.0	8.7	8.85	8.96	8.60	8.88	8.86
temperature(˚C)	29.5	30.2	31.9	30.1	29.2	33.4	31.5	32.4	31.7	31.00	31.10	31.10	28.97	30.07
EC(µScm-1)	1020.7	1024.7	1021.5	681.0	653.0	792.0	718.0	766.0	825.7	490.00	466.00	496.00	516.67	503.33
Salinity (ppm)	504.0	500.7	506.5	338.0	329.5	397.0	387.3	385.3	414.3	242.00	230.00	249.00	257.67	248.33
TDS (ppm)	708.7	709.7	721.0	472.0	467.0	551.3	548.0	537.7	582.0	343.00	369.33	356.00	357.67	353.67
DO(mgL^{-1})	6.7	6.3	7.6	6.9	7.6	6.4	6.4	7.3	6.1	6.67	6.05	7.06	6.21	6.37
BOD(mgL^{-1})	3.3	0.9	2.7	4.9	4.0	4.0	3.3	3.2	4.4	3.95	5.51	8.83	2.60	4.67
COD(mgL^{-1})	36.0	26.7	18.0	31.0	12.0	38.7	30.7	49.3	26.7	44.89	19.11	58.67	36.44	17.79
Nitrates(ppm)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.07	0.04	0.05	0.03
Phosphates(ppm)	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.00	0.00	0.02	0.01	0.01
Sodium (ppm)	43.2	40.7	38.4	21.2	21.0	28.5	26.4	18.5	22.1	18.5	14.5	17.6	20	18.56
Potassium(ppm)	1.6	1.7	1.5	5.5	5.4	6.2	6.8	5.56	5.75	2.5	2.19	3.45	3	2.49
Total hardness (mgL^{-1})	112.7	109.3	112.0	82.5	67.5	88.7	86.0	80.0	85.3	113.33	129.33	164.00	112.67	107.33
Ca hardness (mgL^{-1})	31.0	33.7	34.5	25.1	23.0	23.0	23.0	24.0	24.9	30.73	33.13	41.28	34.20	33.67
Mg hardness(mgL^{-1})	19.9	18.5	18.9	14.0	10.8	16.0	15.4	13.7	14.7	20.16	23.47	29.94	19.15	17.97
Alkalinity(mgL^{-1})	265.3	286.7	192.0	194.0	192.0	406.0	334.7	327.3	398.0	1088.67	788.67	744.00	974.00	1100.67
Chlorides(mgL^{-1})	120.7	82.4	115.0	142.0	139.2	69.2	57.5	41.7	71.9	59.92	61.53	100.82	65.13	64.89

6.1.2. Diatoms

Forty diatom genera comprising 91 species were identified from 33 sampled habitats (epiphytic, epilithic and episammic), with 10 species occurring at ≥10% relative abundances (RA) in at least one sample (Table 6). The most common and abundant species were *Achnanthidium* Kützing, *Cyclotella meneghiniana* Kützing, *Diadesmis confervaceae* Kützing, *Gomphonema* Ehrenberg, *Nitzschia palea* (Kutzing) W. Smith, *Halamphora veneta* Kützing, *Gyrosigma rautenbachiae* Cholnoky and *Cymbella kappi* (Cholnoky) Cholnoky, *Achnanthidium* species was not further identified due to complexity and its wide range of occurrence. Two *Gomphonema* sp. could not be identified to species level (as this could be new records) and needs further taxonomic stuides.

Diatom assemblage was compared for its dominance, evenness and species richness (Table 6). Shannon diversity index value for diatoms was highest at JK (2.27) and lowest at ML (1.10). Dominance ranged from 0.18 to 0.58 with highest dominance of *C. meneghiniana* Kützing at ML (0.58). None of the sampling sites except VN (0.58) had evenness index more than 50%. VN being the least polluted site with low ionic concentrations inhabit pollution sensitive species such as *Achnanthidium* sp., and *Cymbella* sp.

Table 6: Dominance, Diversity indices of diatoms across Bangalore wetlands

Sampling site	JK	RC	VN	KM	MA	UL	KT	TA	SM	KN	RA
Taxa S	24	18	**25**	20	**14**	21	19	20	24	23	22
Dominance D	0.20	0.26	0.51	0.27	**0.58**	0.31	**0.18**	0.25	0.34	0.25	0.30
Shannon H	**2.27**	1.97	1.38	2.08	**1.10**	1.88	2.12	1.88	1.78	1.99	1.87
Simpson	0.80	0.74	**1.36**	0.73	**0.42**	0.69	0.82	0.75	0.66	0.75	0.70
Evenness	0.42	0.42	**0.79**	0.46	**0.28**	0.35	0.44	0.33	0.29	0.36	0.31

Minimum and Maximum values are in Bold font. Sampling codes as mentioned in Table 2.

6.1.3. Mollusks

13 taxa of mollusks, of which 11 gastropods and two bivalves were found across sampling sites (Table 7). Among the surveyed wetlands, Ullalu had the highest number of species (7) and lowest at Thalghattapura (1), where as maximum abundance was found at Mallathahally (330) and minimum at Kommaghatta (11). Ullalu had the highest Shannon and Simpson diversity value, and lowest dominance. As single species was recorded at Thalghattapura, Shannon and Simpson diversity values were zero and dominance and evenness values accounted to be 1. The genus *Physa* was dominated (256 individuals) in Mallathahally wetland which leads to the lowest evenness value (0.52) (Table 8). *Lymnaea* and *Melanoides* were widely presented in nine wetlands followed by Gyraulus (7), *Segmentina* (5), *Indoplanorbis* and *Bellamya* (4), and rest were at only one wetland (Table 7). Presence of genus *Lymnaea*, *Melanoides* (Synonym *Thiara*), Physa and Indoplanorbis indicate that all the studied wetlands were polluted.

Table 7: Diversity, richness, evenness and dominance value of mollusk across 11 selected wetlands.

Sampling site	JA	RC	VN	KM	MA	UL	TA	SM	KN	RM	KT
Taxa S	5	4	2	3	4	**7**	**1**	3	5	5	6
Individuals	61	56	24	**11**	**330**	92	32	39	55	43	33
Dominance D	0.34	0.31	0.92	0.69	0.62	**0.26**	**1.00**	0.51	0.32	0.27	0.30
Shannon H	1.27	1.23	0.17	0.60	0.74	**1.55**	**0**	0.84	1.31	1.38	1.39
Evenness	0.71	0.86	0.59	0.61	**0.52**	0.67	**1.00**	0.77	0.74	0.80	0.67

Minimum and Maximum values are in Bold font. Sampling codes as mentioned in Table 2.

6.1.4. Aquatic Insects

A total of ten groups of aquatic insects were recorded from 11 wetlands (Table 9). Among the entire, dominant groups were Corixidae (54.4%), Notonectidae (19%) and Nepidae (14%). MA sampling site was dominated by Corixidae with 305 individuals while Notonectidae with 142 and Nepidae with 51 individuals at JKO and JKI respectively. Contrastingly VN accounted only 1 taxon and JK with 6 taxa. Dominance was high at VN (Less polluted site) and less at RM with 0.2. Shannon and Simpson diversity indices showed a higher value for RM (1.6 and 0.8) and less was at VN (0).

Table 8: Presence (+) of mollusks in 11 wetlands of Bangalore (Refer codes in Table 1 & 2).

Genus/Tribe (T)	**JA**	**RC**	**VN**	**KM**	**MA**	**UL**	**TH**	**SO**	**KN**	**RM**	**KT**
Bellamya	+					+			+	+	
Gabbia						+					
Gyraulus		+		+	+	+		+	+		+
Indoplanorbis	+		+			+					+
Lymnaea	+	+		+		+	+	+	+	+	+
Melanoides	+	+	+	+		+		+	+	+	+
Physa					+						
Segmentinieae (T)					+						
Segmentina	+	+			+				+		+
Tarebia										+	
Thiara											+
Lamellidens										+	
Pisidium						+					

Table 9: Diversity, richness, evenness and dominance value of aquatic insects for 11 wetlands (Refer codes in Table 1 & 2).

Sampling sites	JK	RC	VN	KM	MA	UL	TA	SM	KN	RM	KT
Taxa	**6**	2	**1**	2	5	2	3	2	2	5	3
Dominance	0.57	0.68	**1**	0.41	0.53	0.34	0.53	0.67	0.53	**0.2**	0.37
Shannon	0.83	0.47	**0**	0.51	0.9	0.45	0.31	0.52	0.67	**1.60**	1.04
Simpson	0.42	0.32	**0**	0.33	0.46	0.23	0.32	0.33	0.47	**0.8**	0.62
Evenness	0.49	0.82	**1**	0.75	0.57	**0.36**	0.48	0.83	0.97	**1**	0.94

6.1.5. Butterfly

In the present study 12 species were observed which belong to Lycaenidae (three species), Nymphalidae (4), Pieridae (4), and one unidentified species. Pachliopta hector were observed from all the wetlands, Danaus chrysippus (9), Jamides celeno and Euploea core (8), Ariadne merione (4), Catopsilia pomona (3), Tirumala septentrionis (2), and rest were found in only one wetland. Catopsilia pomona, Tirumala septentrionis, Prosotas nora, Pseudozizeeria maha were found only from the K and C Valley, where as Colotis eucharis and one unidentified species at the Vrishabhavathi Valley (Table 10). In cluster analysis, three groups were formed at euclidean distance three. The first group consist K and C Valley wetlands, which had high number of taxa than the other valley wetlands, Venkateshpura (8), Jakkur (7), and Rachenahalli (7). The second group consist mainly Hebbal Valley wetlands and one Vrishabhavathi Valley wetland (Somapura), where as third group consist mainly Vrishabhavathi Valley wetlands and one Hebbal Valley wetland (Thalghattapura). The wetlands of second group had four similar species in each, where as only Pachliopta hector were common to the third group wetlands. If the sampling time extended, and all seasons and more number of habitats will be sampled, it may reveal the true picture of butterfly richness of the studied area.

Table 10: Presence (+) of butterflies across wetlands (Sampling codes as mentioned in Table 2)

Common names	**Scientific names**	**Sampling sites**										
		JA	**RC**	**VE**	**UL**	**MA**	**KM**	**TH**	**RA**	**SO**	**KT**	**KN**
Crimson Rose	*Pachliopta hector*	+	+	+	+	+	+	+	+	+	+	+
Plain Tiger	*Danaus chrysippus*	+	+		+	+	+		+	+	+	+
Common Cerulean	*Jamides celeno*	+	+	+	+	+	+			+		+
Common Indian Crow	*Euploea core*	+	+	+	+	+	+			+	+	
Common Castor	*Ariadne merione*	+	+	+					+			
Common Emigrant	*Catopsilia pomona*	+	+	+								
Dark Blue Tiger	*Tirumala septentrionis*	+		+								
Common Grass Yellow	*Eurema hecabe*			+								
Common Lineblue	*Prosotas nora*		+									
Pale Grass Blue	*Pseudozizeeria maha*			+								
Plain Orange Tip	*Colotis eucharis*											+
Unidentified											+	

6.1.6. Birds

Birds belonging to both quatic and terrestrial habitats across three valleys in Bnagalore have been listed in Table 11- 13. Within the studied sampling sites, 89 bird species were recorded among those, 20 were identified as aquatic birds and 69 as terrestrial birds. Common aquatic birds found in wetlands were common coot, little cormorant, little grebe, Indian pond heron, median egret, purple heron and Cattle egret. Common terrestrial birds were Ashy prinia, Black kit, Blyths reed Warbler, Common Myna, House Crow, White breasted Kingfisher, Brahminy kit, Indian robin, lesser Koukal, Purple sunbird and White browed wagtail. Wetlands such as RM (34), JK (33) and RC (30) comprised taxa more than 30 species. Fewer birds were recorded at Ullalu (11) and Mallathally (15). Birds that are found at single sampling site have been listed in Table 14. The migratory birds were as well observed at few wetlands such as Booted warbler and White tailed swallow at JK; Thick billed warbler at ML; Wood sandpiper at KM; Brown shrike at TA; Garganey, Osprey and Wire tailed swallow at RM; Rosy starling at KT and Great tit at KN. White tailed swallow as observed at JK is noted as vulnerable and listed under C2a (ii) as per IUCN red list.

Table 11 List of water and terrestrial birds across Hebbal Valley Wetlands

Common name	Scientific name	Red list status	JK	RC	VN
WATER BIRDS					
Black crowned night heron	*Nycticorax nycticorax*	Least Concern		+	
Cattle egret	*Bubulcus ibis*	Least Concern		+	+
Common coot	*Fulica atra*	Least Concern	+	+	+
Great white Pelican	*Pelecanus onocrotalus*	Least Concern	+		
Great egret	*Casmerodius albus*	Least Concern		+	
Grey heron	*Ardea cinerea*	Least Concern	+		
Indian Pond - Heron	*Ardeola grayii*	Least Concern	+	+	+
Large Egret	*Casmerodius albus*	Least Concern	+		+
Little Cormorant	*Phalacrocarax niger*	Least Concern	+	+	+
Little Grebe	*Tachybaptus ruficollis*	Least Concern	+		+
Median Egret	*Mesophoyx intermedia*	Least Concern	+	+	
Purple Heron	*Ardea purpurea*	Least Concern	+	+	

Purple Moorhen	*Porphyrio porphyrio*	Least Concern	+	+	
Red-wattled lapwing	*Vanellus indicus*	Least Concern	+		
White breasted water hen	*Amaurornis phoenicurus*	Least Concern		+	
TERRESTRIAL BIRDS					
Asian koel	*Eudynamys scolopaceus*	Least Concern		+	
Ashy drongo	*Dicrurus leucophaeus*	Least Concern	+	+	
Ashy prinia	*Prinia socialis*	Least Concern	+	+	+
Black kite	*Milvus migrans*	Least Concern	+	+	+
Blue rock pigeon	*Columba livia*	Least Concern	+		
Blyths reed Warbler	*Acrocephalus dumetorum*	Least Concern	+	+	+
Booted warbler	*Hippolais caligata*	Least Concern	+		
Brahminy kite	*Haliastur anth*	Least Concern	+	+	
Brain fever bird	*Cuculus varius*	Least Concern	+		
Brown headed starling				+	
Common Myna	*Acridotheres tristis*	Least Concern	+	+	+
Common sandpiper	*Actitis hypoleucos*	Least Concern	+		
Gargey	*Anas querquedula*	Least Concern			
Greater Coucal	*Centropus sinensis*	Least Concern		+	
House crow	*Corvus splendens*	Least Concern	+	+	+
House martin	*Delichon urbicum*	Least Concern			+
Hoopoe	*Upupa epops*	Least Concern			+
House swift	*Apus affinis*	Least Concern	+	+	
Indian roller	*Coracias benghalensis*	Least Concern	+		
Indian blue robin	*Luscinia brunnea*	Least Concern			+
Jungle Myna	*Acridotheres fuscus*	Least Concern	+	+	
Little green bee eater	*Merops orientalis*	Least Concern			+
Large pied wagtail	*Motacilla maderaspatensis*			+	+
Marsh Sandpiper	*Tringa stagnatilis*	Least Concern	+		
Oriental Magpie Robin	*Copsychus saularis*	Least Concern			+
Paddyfield Pipit	*Anthus rufulus*	Least Concern	+		+
Pied Kingfisher	*Ceryle rudis*	Least Concern	+	+	
Pied bushchat	*Saxicola caprata*	Least Concern			+
Purple sunbird	*Nectarinia asiatica*	Least Concern		+	
Red rumped swallow	*Cecropis daurica*				+
Red vented bulbul	*Pycnonotus cafer*	Least Concern		+	+
Rose- ringed Parakeet	*Psittacula krameri*	Least Concern	+	+	
Spotted dove	*Streptopelia chinensis*	Least Concern	+	+	
Tickell's flowerpecker	*Dicaeum erythrorhynchos*	Least Concern			
Western marsh Harrier	*Circus aeruginosus*	Least Concern		+	
White breasted kingfisher	*Halcyon smyrnensis*	Least Concern	+	+	+
White cheeked barbet	*Megalaima viridis*	Least Concern	+		
White tailed Swallow	*Hirundo megaensis*	Vulnerable C2a(ii)	+		

Table 12 List of water and terrestrial birds across K and C Valley Wetlands

Common name	Scientific name	Red list status	UL	ML	KM	TA

WATER BIRDS						
Common coot	*Fulica atra*	Least Concern	+		+	
Cattle egret	*Bubulcus ibis*	Least Concern			+	+
Greater cormorant					+	+
Little Grebe	*Tachybaptus ruficollis*	Least Concern	+	+		+
Little Cormorant	*Phalacrocarax niger*	Least Concern	+	+		
Little egret	*Casmerodius albus*	Least Concern			+	+
Median egret	*Mesophoyx intermedia*	Least Concern	+	+		
Indian Pond-heron	*Ardeola grayii*	Least Concern			+	+
Purple heron	*Ardea purpurea*	Least Concern		+		+
White breasted water hen	*Amaurornis phoenicurus*	Least Concern				+
TERRESTRIAL BIRDS						
Ashy prinia	*Prinia socialis*	Least Concern			+	+
Ashy drongo	*Dicrurus leucophaeus*	Least Concern			+	
Blyths reed warbler	*Acrocephalus dumetorum*	Least Concern	+		+	+
Black headed cuckoo shrike	*Coracina melanoptera*	Least Concern	+		+	
Black winged stilt	*Himantopus himantopus*	Least Concern		+		
Black shoulder kite	*Elanus axillaris*	Least Concern				+
Black kite	*Milvus migrans*	Least Concern				+
Blue rock pigeon	*Columba livia*	Least Concern				+
Brahminy kite	*Haliastur anth*	Least Concern			+	+
Brown shrike	*Lanius cristatus*	Least Concern				+
Coppersmith barbet	*Megalaima haemacephala*	Least Concern			+	
Common Myna	*Acridotheres tristis*	Least Concern	+	+	+	+
Common sandpiper	*Actitis hypoleucos*	Least Concern			+	
Chestnut Headed bee eater	*Merops antherntia*	Least Concern		+		
Common swallow	*Hirundo rustica*	Least Concern		+		
Greater couckal	*Centropus sinensis*	Least Concern		+		
House swift	*Apus affinis*	Least Concern	+	+		+
House crow	*Corvus splendens*	Least Concern		+		+
House sparrow	*Passer domesticus*	Least Concern				+
Indian blue robin	*Luscinia brunnea*	Least Concern		+	+	+
Jungle crow	*Corvus macrorhynchos*	Least Concern	+			
Jungle myna	*Acridotheres fuscus*	Least Concern				+
Lesser Couckal	*Centropus bengalensis*	Least Concern	+			
Marsh sandpiper	*Tringa stagnatilis*	Least Concern		+		
Paddyfield pipit	*Anthus rufulus*	Least Concern				+
Pied kingfisher	*Ceryle rudis*	Least Concern			+	+
Pied bushchat	*Saxicola caprata*	Least Concern	+			
Purple sunbird	*Nectarinia asiatica*	Least Concern		+		
Rose ringed parakeet	*Psittacula krameri*	Least Concern			+	+
Red whiskered bulbul	*Pycnonotus Jocosus*	Least Concern	+		+	
Spotted dove	*Streptopelia chinensis*	Least Concern	+	+		
Small green bee eater	*Merops orientalis*	Least Concern		+		
Tree pipit	*Anthus trivialis*	Least Concern	+			

Thick billed warbler	*Acrocephalus aedon*	Least Concern		+		
White breasted kingfisher	*Halcyon smyrnensis*	Least Concern	+			
White browed wagtail	*Motacilla maderaspatensis*			+	+	
Wood sandpiper	*Tringa glareola*	Least Concern		+	+	

Table 13 List of water and terrestrial birds across Vrishabhavathi valley wetlands

Common names	Scientific name	Red list status	RM	SM	KT	KN
WATER BIRDS						
Common coot	*Fulica atra*	Least Concern			+	
Cattle egret	*Bubulcus ibis*	Least Concern	+	+	+	
Great cormorant	*Phalacrocorax carbo*	Least Concern	+	+		
Grey heron	*Ardea cinerea*	Least Concern	+			
Little egret	*Egretta garzetta*	Least Concern		+	+	
Little cormorant	*Phalacrocorax niger*	Least Concern	+	+		+
Little grebe	*Tachybaptus ruficollis*	Least Concern	+			+
Median egret	*Mesophoyx intermedia*	Least Concern				+
Asian Open billed stork	*Anastomus oscitans*	Least Concern	+			
Indian Pond-heron	*Ardeola grayii*	Least Concern		+	+	+
Purple heron	*Ardea purpurea*	Least Concern	+	+		+
White breasted water hen	*Amaurornis phoenicurus*	Least Concern				+
TERRESTRIAL BIRDS						
Asian Koel	*Eudynamys scolopaceus*	Least Concern			+	
Ashy prinia	*Prinia socialis*	Least Concern		+	+	
Blyths reed warbler	*Acrocephalus dumetorum*	Least Concern	+		+	+
Black headed Cuckoo shrike	*Coracina melanoptera*	Least Concern		+		
Black kite	*Milvus migrans*	Least Concern	+	+	+	+
Brahminy Kite	*Haliastur anth*	Least Concern	+		+	+
Blue rock pigeon	*Columba livia*	Least Concern			+	
Common Myna	*Acridotheres tristis*	Least Concern	+	+	+	+
Common swallow	*Hirundo rustica*	Least Concern			+	
Darter	*Anhinga melanogaster*	Near Threatened	+			
Garganey	*Anas querquedula*	Least Concern	+			
Green billed Malkoha	*Phaenicophaeus tristis*	Least Concern	+			
Greater couckal	*Centropus sinensis*	Least Concern		+		
Great tit	*Parus major*	Least Concern				+
Grey francolin	*Francolinus pondicerianus*	Least Concern	+			
House swift	*Apus affinis*	Least Concern	+		+	
House crow	*Corvus splendens*	Least Concern		+	+	+
House sparrow	*Passer domesticus*	Least Concern				+
Indian robin	*Saxicoloides fulicatus*	Least Concern	+	+	+	
Indian great reed warbler	*Acrocephalus arundinaceus*	Least Concern		+		
Jungle babbler	*Turdoides striata*	Least Concern	+		+	
Jungle crow	*Corvus macrorhynchos*	Least Concern	+			
Lesser Couckal	*Centropus bengalensis*	Least Concern	+		+	+
Oriental magpie Robin	*Copsychus saularis*	Least Concern		+		
Osprey	*Pandion haliaetus*	Least Concern	+			

Indian Peafowl	*Pavo cristatus*	Least Concern		+		
Pied kingfisher	*Ceryle rudis*	Least Concern	+		+	
Pied bushchat	*Saxicola caprata*	Least Concern		+		
Paddyfield pipit	*Anthus rufulus*	Least Concern	+	+	+	
Purple Sunbird	*Nectarinia asiatica*	Least Concern	+	+		+
Red vented bulbul	*Pycnonotus leucotis*	Least Concern	+		+	+
Red whiskered bulbul	*Pycnonotus Jocosus*	Least Concern	+			
Red wattled Lapwing	*Vanellus indicus*	Least Concern	+	+		+
River tern	*Sterna aurantia*	Least Concern	+	+		
Rosy starling	*Sturnus roseus*	Least Concern			+	
Rose ringed parakeet	*Psittacula krameri*	Least Concern	+	+		
Small green bee-eater	*Merops orientalis*	Least Concern	+			
Small Kingfisher	*Alcedo atthis*	Least Concern				+
Tickell's blue flycatcher	*Cyornis tickelliae*	Least Concern				+
White cheeked barbet	*Megalaima viridis*	Least Concern			+	
White browed wagtail	*Motacilla maderaspatensis*	--	+	+	+	+
Wire tailed swallow	*Hirundo smithii*	Least Concern	+			
White breasted kingfisher	*Halcyon smyrnensis*	Least Concern	+	+		+
Wood sandpiper	*Tringa glareola*	Least Concern	+			

Table 14 List of birds recorded at single wetland (Bold- Migratory birds)

SAMPLING SITES	WATER BIRDS	TERRESTRIAL BIRDS
JK	Great white Pelican, Red-wattled lapwing	**Booted warbler**, Brain fever bird, Indian roller, **White tailed Swallow**
RC	Black crowned night heron	Brown headed starling, Western marsh Harrier
VN	--	Hoopoe, Indian blue robin, Red rumped swallow
UL	--	Tree pipit
ML	--	Black winged stilt, Chestnut Headed bee- eater, **Thick billed warbler**
KM	--	**Wood sand piper**
TA	Great cormorant	Black shoulder kite, **Brown shrike**, Paddy field pipit
RM	Great cormorant, Asian Open billed stork	Darter, **Garganey,** Green billed Malkoha, Grey francolin, **Osprey, Wire tailed swallow**
SM	--	Black headed Cuckoo shrike, Indian great reed warbler, Indian Peafowl, River tern
KT	--	**Rosy starling**
KN	--	**Great tit,** Tickell's blue flycatcher

6.2. Post- restoration

As the restoration work at Ramasandra, Venkateshapura, Konasandra, Mallathahally and Ullalu wetlands was in progress/not completed, these wetlands were excluded from post-restoration monitoring. Ramsandra, Venkateshpura, Konsandra, Mallathally and Ullalu were still under construction process (during November 2011) though the time limit was mentioned as September- October 2010.

6.2.1. Water quality

Physical and chemical parameters analyzed after wetland restoration are listed in Table 14 (Hebbal valley), 15 (K & C valley) and 16 (Vrishabhavathi valley). pH at all valleys ranged from neutral of 7.14 at KTO1 to slightly alkaline i.e., 8.5 KMI2. Electric conductivity was well within the BIS standards at all sites except at Kothanur showing a highest of 1110 μScm^{-1} followed by 911 at Rachenahalli inlet (RCI1). Dissolved oxygen ranged from 0.97 at KTI1 to 8.94 at KMO1 site with low levels at wetlands such as JK, RC and KT. Biological oxygen demand (BOD) and Chemical oxygen demand (COD) were recorded as exceeding the BIS limits at all samplings sites of JK, RC, KT and TAI1. This may be due to the continued untreated sewage inflow into the wetland bed during restoration. BOD ranged from 6.2 mgL^{-1} (RCO1) –10.2 mgL^{-1} (JKI2); 4.6 (KMI1) –10.2 mgL^{-1} (TAI1) and 4.4(SMI1) –14.5 mgL^{-1} (KTI1) at Hebbal, K&C and Vrishabhavathi valleys respectively while, 31(RCO1) –51 mgL^{-1} (JKI2); 23 (KMI1) – 51 mgL^{-1} (TAI1) and 22(SMI1) –72.5 mgL^{-1} (KTI1) at Hebbal, K&C and Vrishabhavathi valleys respectively. There was no nutrient limitation condition observed at any of the sampling site which showed nitrates ranging from 0.02 (RCO1, TAI1) to 0.17 ppm at KMO1 followed by 0.15 ppm at (KTO1) and, phosphates ranging from 0.02(JKI1) to 0.37 ppm at KT sampling sites. Somapura wetland showed a lowest value of 33.4 ppm sodium (Na) and Kommaghatta inlet (KMI1) with 6.43ppm of potassium (K) while the highest values were recorded at RCO1 with 78.11 ppm of sodium and JKI1 with 11.5 ppm of potassium respectively. Total hardness was recorded as lowest of 30 mgL^{-1} at Talghattapura and highest of 198.66 mgL^{-1} at JKI2 followed by 180.5 mgL^{-1} at KTO1. The subsequent rise in calcium hardness was as well observed at JKI2 with 99.38 mgL^{-1} of Ca and lowest of 28.54 mgL^{-1} at TAI1 site. Chlorides ranged from 103.2–189.43 mgL^{-1} at Hebbal valley; 30.21– 87.4 mgL^{-1} at K &C valley and highest being, 32.2– 276.5 mgL^{-1} at Vrishabhavathi valley. PCA biplot (Figure 4) explains 47.631 % and 24.997 % variance from 1st and 2nd components respectively. The significant influence of CHL, BOD, COD, EC, TDS and K on Kothanur wetland and influence of total hardness on JKI1 was observed through PC1 axis. While, PC2 explained alkalinity at Kommaghatta wetland and high magnesium hardness at Rachenahalli and JKI1 sites. There was no or less influence of any of the variables on TA sites. PC1 showed the more influence of sewage at Kothanur wetland followed by Jakkur inlet.

Table 15: Water quality of Jakkur and Rachenahalli wetlands (HEBBAL VALLEY wetlands)

	JAKKUR		**RACHENAHALLI**			**VENKATESHAPURA**
	JKI1	**JKI2**	**RCO1**	**RCI1**	**RCI2**	**NO DATA COLLECTED BECAUSE OF INCOMPLETE RESTORATION**
pH	7.89	7.96	8.02	8.43	8.36	
Temperature(˚C)	23	23.5	24.3	24.6	25.6	
EC (μScm^{-1})	889	865	844	911	890	
Salinity (ppm)	--	--	--	--	--	
TDS (ppm)	635	617.8571	602.8571	650.7143	635.7143	
DO (mgL^{-1})	5.691057	5.325203	4.878049	5.772358	4.390244	
BOD (mgL^{-1})	8.2	10.2	6.2	7	8.1	
COD (mgL^{-1})	41	51	31	35	40.5	
Nitrates (ppm)	0.072	0.065	0.02	0.095	0.04816	
Phosphates (ppm)	0.020164	0.044124	0.042416	0.034	0.053945	
Sodium (ppm)	64.5	63.6	78.11	74.89	69.23	
Potassium (ppm)	11.5	11.4	10.4	10.22	9.3	
Total hardness (mgL^{-1})	178.6667	198.6667	174.6667	73.33333	82.574	
Ca hardness (mgL^{-1})	99.38425	84.87875	88.28535	40.44652	37.11	
Mg hardness (mgL^{-1})	19.34491	27.76425	21.07704	8.024382	11.09	
Alkalinity (mgL^{-1})	120	128	134	150	178	
Chlorides (mgL^{-1})	189.43	187.23	167.3	103.2	111.3	

Table 16: Water quality of Kommaghatta and Talghattapura wetlands (K & C VALLEY wetlands)

	KOMMAGHATTA	**TALGHATTAPURA**	**MALLATHA-**	**ULLALU**

							HALLY	
	KMI1	KMI2	KMO1	TAI2	TAO1	TAI1		
pH	8.60	8.50	8.10	8.14	8.45	7.89	NO DATA COLLECTED BECAUSE OF INCOMPLETE RESTORATION	
Temperature(°C)	22.00	24.11	24.70	25.50	25.00	25.70		
EC (µScm^{-1})	675.00	690.00	612.00	827.00	877.00	835.00		
Salinity (ppm)	--	--	--	--	--	--		
TDS (ppm)	482.14	492.86	437.14	590.71	626.43	596.43		
DO (mgL^{-1})	7.24	7.48	8.94	5.37	6.14	6.59		
BOD (mgL^{-1})	4.60	7.30	4.71	9.20	8.52	10.20		
COD (mgL^{-1})	23.00	36.50	23.55	46.00	42.60	51.00		
Nitrates (ppm)	0.05	0.04	0.17	0.15	0.11	0.02		
Phosphates (ppm)	0.08	0.03	0.05	0.04	0.12	0.10		
Sodium (ppm)	44.50	42.30	42.78	58.20	51.70	51.89		
Potassium (ppm)	6.43	7.45	7.30	8.40	8.10	7.89		
Total hardness (mgL^{-1})	116.00	150.00	138.00	42.00	32.00	30.00		
Ca hardness (mgL^{-1})	52.17	61.51	58.21	31.84	29.09	28.54		
Mg hardness (mgL^{-1})	15.57	21.59	19.47	2.48	0.71	0.36		
Alkalinity (mgL^{-1})	240	210	196	88	70	84		
Chlorides (mgL^{-1})	30.21	33.2	34.11	87.4	75.3	53.2		

Table 17: Water quality analysis of Kothanur, Somapura, Konasandra and Ramasandra wetlands (VRISHABHAVATHI VALLEY wetlands)

	KOTHANUR		SOMAPURA		KONASANDRA	RAMASANDRA
	KTI1	KTO1	SMI1	SMO1		
pH	7.2	7.14	8.3	8.23	NO DATA COLLECTED BECAUSE OF INCOMPLETE RESTORATION	
Temperature(°C)	26.5	26.5	22.9	22		
EC (µScm^{-1})	1110	968	574	522		
Salinity (ppm)	--	--	--	--		
TDS (ppm)	792.85	691.428	410	372.85		
DO (mgL^{-1})	0.975	2.195	7.154	6.82		
BOD (mgL^{-1})	24.5	20.33	4.4	4.6		
COD (mgL^{-1})	72.5	66.65	22	23		
Nitrates(ppm)	0.078	0.15	0.12	0.08		
Phosphates(ppm)	0.298	0.3667	0.09	0.13		
Sodium (ppm)	71.02	75.43	47.67	33.4		
Potassium (ppm)	7.43	8.3	8.8	9.1		
Total hardness (mgL^{-1})	165	180.5	56.7	67.8		
Ca hardness (mgL^{-1})	65.62	129.88	35.87	38.92		
Mg hardness (mgL^{-1})	24.24	12.34	5.08	7.04		
Alkalinity (mgL^{-1})	130	80	60	40		
Chlorides (mgL^{-1})	235.63	276.5	34.2	32.2		

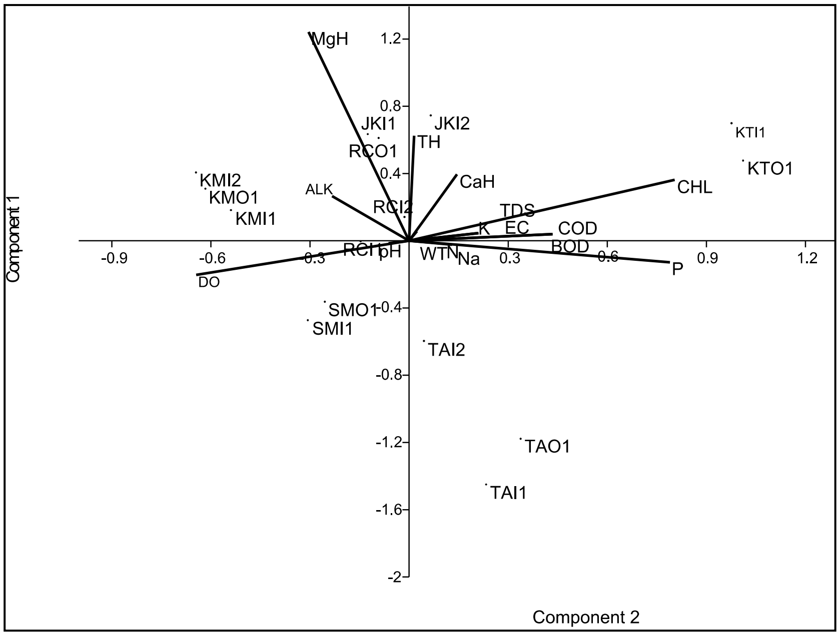


Figure 4 PCA tri-plot of water quality results analyzed from 11 Bangalore wetlands

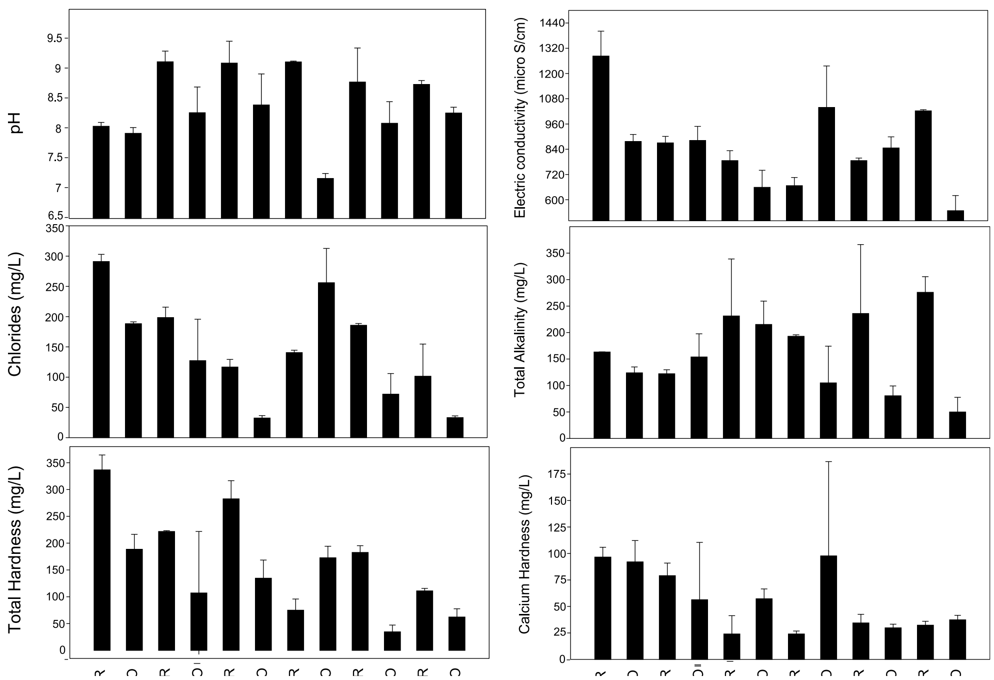


Figure 5 Bar plot explaining water quality variation during pre-restoration and post restoration studies across selected wetlands. (Codes as in text). a= variation in pH; b= electric conductivity; c= Chlorides; d= total alkalinity; e= total hardness and f= Calcium hardness.

Figure 5 explains variation in water chemistry within and among six wetlands during pre (PRR) and post (POR) restoration period. pH ranged from 8.02-9.315 and 7.14 to 8.6 during PRR and

POR respectively which infers a higher pH range in former study period than in later stages (fig. 5a). Conductivity was found to be highest of 1325.67 µScm^{-1} at JK during PRR sampling sites compared to the EC concentration during POR (range, 522- 1110 µScm^{-1}) (Fig. 5b) which also reflected the ioninc levels i.e., cations and anions.

6.2.2. Variation in water chemistry among Pre-restoration (PRR) and Post-restoration (POR) period

Total hardness (range, 67.5- 346.67 ppm) and calcium hardness (range, 15.23- 100 ppm) during PRR of water decreased drastically during post restoration i.e., TH ranging 28.542- 129.89 ppm and CaH ranging 28.542- 129.89 ppm, excluding higher calcium hardness at KT with 129.89 ppm (figs. e & f). Kothanur wetland sampling after restoration resulted in high chlorides when compared to pre- restoration period, i.e., ranging from 235.63- 276.5 mgL^{-1}.

However, there was no variation in alkalinity during PRR (120- 293 mgL^{-1}) and POR (40- 240 mgL^{-1}) (fig. d). Lower dissolved oxygen levels (<5 mgL^{-1}) was recorded at JK, KM and TA during PRR and at wetland KT during POR studies which shows the higher amount of oxygen deficiency in wetlands. The overall BOD concentration ranged from 2.96- 34.35 ppm in PRR sites while it was decreased all through POR with a range of 4.4-14.5 ppm. The COD as well constituting for high organic matter was found to be exceeding BIS limits at all sampling sites except at Kommaghatta wetland and Somapura wetland during POR. No nutrient limiting condition was observed at any of the site which had nitrates of 0.015-0.079 ppm (PRR), 0.02- 0.17 ppm (POR) and phosphates of 0.02- 0.056 ppm (PRR) and 0.02- 0.366 ppm (POR).

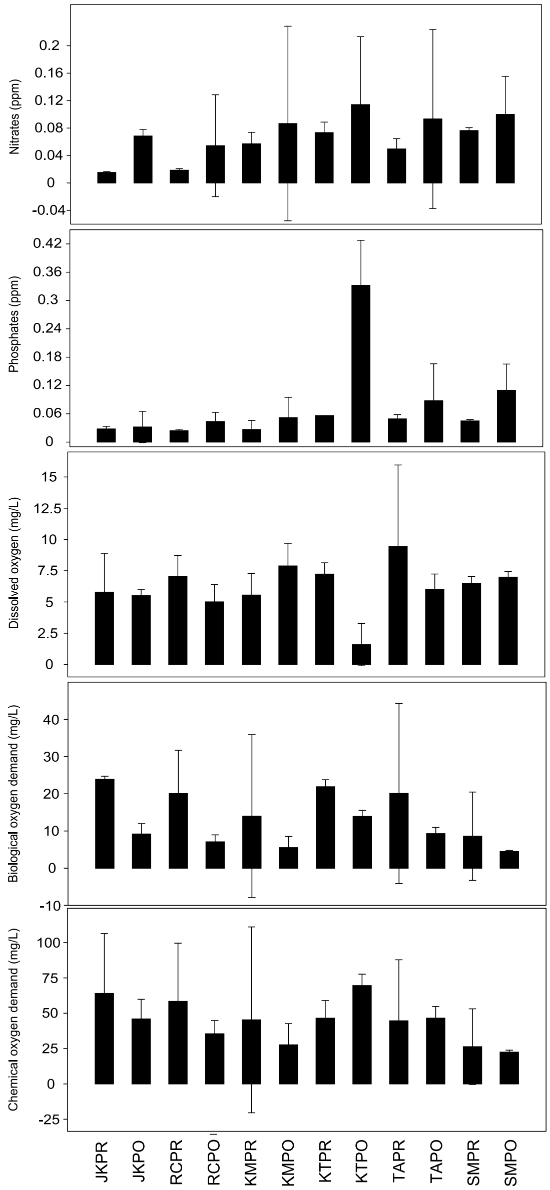


Figure 6 Bar plot representing comparison of variation in water quality across selected Bangalore wetlands during PRR and POR. Top to bottomin order = Nitrates, Phosphates, dissolved oxygen, biological oxygen demadn & chemical oxygen demand.

6.2.3. Diatom distribution

A total of 103 taxa from 29 genera have been recorded during post restoration analysis. The dominant genera were *Rophalodia* sp., *Nitzschia* sp., *Achnanthidium* sp., *Gomphonema* sp., *Navicula* sp., *Mastagloia* sp. and *Staphanodiscus* sp. Diatom diversity indices were calculated across 5 wetlands for post restoration analysis (Table 18). Among these, highest taxa was recorded at Kommaghatta (41), followed by rest which showed less than 50% of taxa compared to former. A successive high Shannon index, low dominance value was recorded from Kommaghatta and high evenness at Jakkur (0.6). A significant variation in diversity indices could be observed in PRR and POR analysis. Shannon diversity and taxa number has been increased in POR while, no taxa was found dominating any of the sampling sites. Somapura wetland which comprised of 24 taxa before restoration showed a decreased in taxa number.

Table 18 Diatom diversity indices at 6 selected Bangalore wetlands during Post restoration water quality studies

Wetland name	Taxa	Dominance (D)	Shannon (H)	Evenness (E)
Jakkur	18.00	0.13	2.37	0.60
Rachenahalli	20.00	0.16	2.27	0.50
Thalghattapura	14.33	0.24	1.86	0.48
Komaghatta	41.00	0.11	2.75	0.43
Somapura	9.67	0.26	1.54	0.60
Kothanur	9.00	0.38	1.43	0.64

6.2.3a. Diatom community structure during Pre and Post restoration studies

In order to investigate persistence of diatom taxa throughout restoration program, only those taxa which are more than 50% RA in at least one sampling site were considered for further analysis. A change in diatom community composition could be observed within wetlands and was significant with post-restoration water quality analysis. Wetlands such as JK, RC and KT which were dominated with *C. meneghiniana* (CMEN), *Achnanthidium* sp. (ACHD) and, ACHD and A. granulate (AGRA) respectively during PRR was later in POR replaced with *N. palea* (NPAL). Kommaghatta (KM) sampling sites were later in POR dominated with *G. angustum* and *R. gibba* (RGIB). Even though Somapura (SM) wetland had lowest species richness (Table 18), the community composition continued with *Staphanodiscus hantzschii* (SHAN) followed by ACHD and *N. phylipta* (NPHY). *Achnanthidium* sp. persistent to be dominant at Talghattapura wetland (TA) even after restoration together with *M. smithii* (MSMI) with a RA of 24%. The other dominating taxa found during post-restoration diatom analysis were *N. pura* (NPUR, 9%), *N. gregaria* (NGRE, 9%) at JK; CMEN (12%), N. gracilis (NGRA, 5%) at RC; *A. veneta* (AVEN, 10%), *E. sorex* (ESOR, 9%) at KM; *Gomphonema* sp. (GOMP, 16%) at SM; ACHD (37%) at TA and *N. umbonata* (NUMB, 29%) along with NPAL (26%) at KT wetlands.

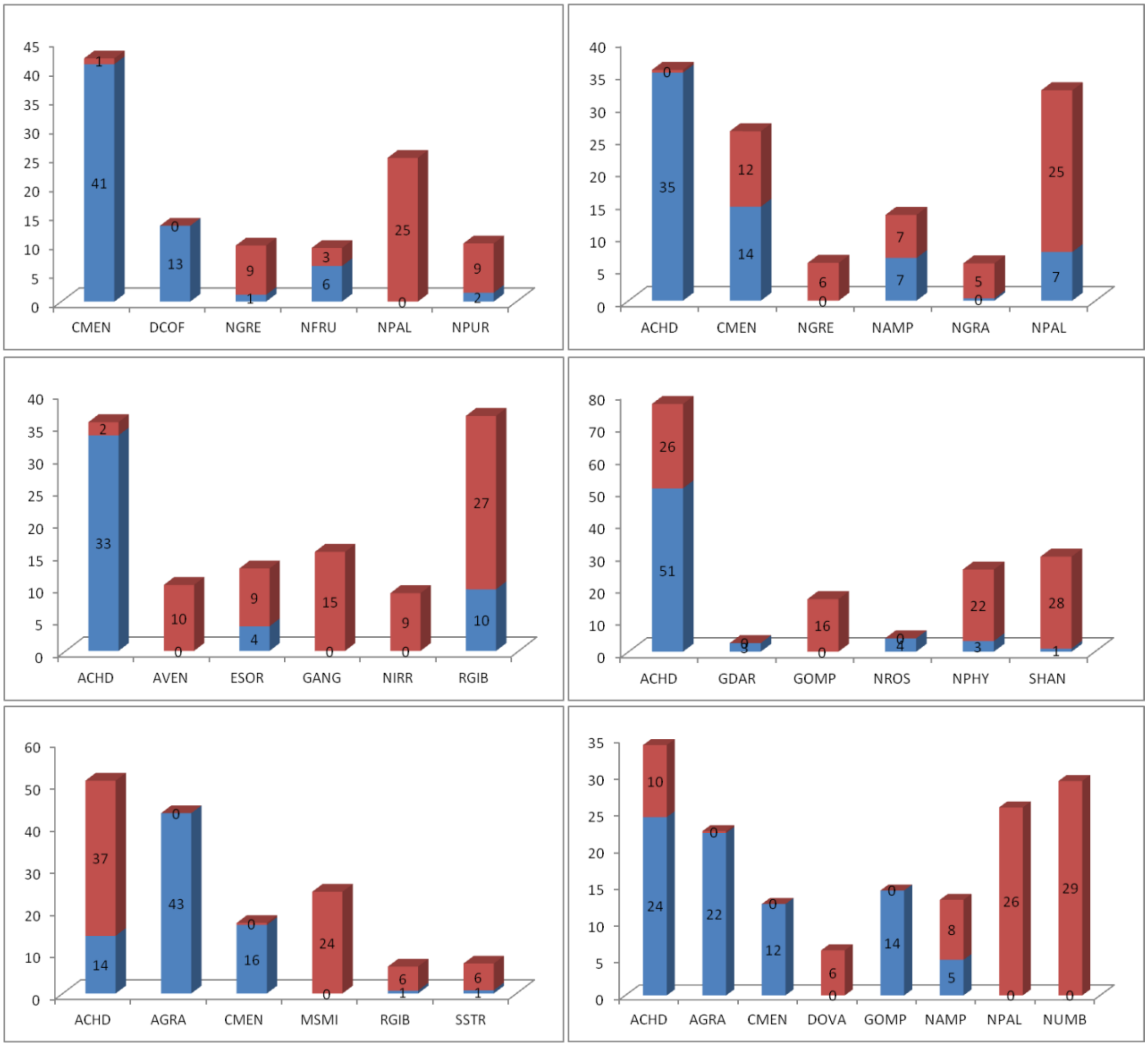


Figure 7 Column graph plot representing diatom species composition and a comparison between pre (BLUE) and post restoration (RED) studies. The numbers on columns indicate its %Relative abundance (RA). The diatom taxa codes are as elaborated in text.

7. Discussion

7.1. Pre-Restoration

A total of 91 diatom taxa, 13 mollusk species, 10 groups of aquatic insects, 12 birds and 89 varieties of birds (20 aquatic and 69 terrestrial birds) were recorded from 11 monitored wetlands of Bangalore during 2009. Among these, diatom flora, mollusks, aquatic insects were documented for the first time from Bangalore. Wetlands such as Jakkur (JK), Ullalu (UL), Ramasandra (RM) and K & C valley wetlands showed highest richness of diatoms, mollusks, aquatic insects and butterflies respectively. Among birds record, all are categorized as least concern, common sp. while, White tailed swallow as observed at JK is noted as vulnerable and listed under C2a (ii) as per IUCN red list. Ramasandra, Jakkur and Rachenahalli accounted for highest bird population.

Water quality results revealed the high influence of conductivity, organic matter (BOD and COD levels), nutrients (phosphates and nitrates) and chlorides at Jakkur, Rachenahalli, Mallathahally, Ullalu and Talghattapura wetlands. This is because of inflow of untreated sewage and dumping of waste through local disturbances which is the main source of pollution in urban wetlands (Naselli-Flores, 2008). The high pollution is responsible for low species richness among aquatic insects (Bonada et al., 2008). Excess accumulation of nutrient, due to the sustained inflow of untreated domestic sewage (N & P) is the main cause of eutrophication of water bodies. This large fluctuation in N & P can cause decline in wetland tropic status and amplified algal blooms in several cases (Oram, http://www.water-research.net/phosphate.htm accessed on February 10th 2012). The amount of solids dissolved in water inhibits light penetration thereby decreases the photic zone. In addition, prolific growth of aquatic weed such as *Eichornia* sp. covered the entire water surface at Konasandra, Kothanur, Mallathally and Jakkur wetlands inhibiting light penetration, oxygen saturation, less photosynthetic activities, thus affect basic of the food chain and higher organisms (Ricklefs, 1993; Helfrich *et al.*, 2009).

7.2. Pos- Rrestoration

During post restoration period, among 11 wetlands only five were selected to investigate impact of restoration on water quality and biological components of wetland ecosystem. Instead of decrease in ionic levels in Kothanur wetland, a high ionic concentration along the inflow region could be observed. Within few months of restoration, the wetland was covered by macro algal growth due to the availability of nutrients such as N and P. Thus, temperature, electrons present and organic matter regulates the wetland productivity which may lead to increased algal blooms (Lewis, 2010). A week nutrient supply at high temperature suppresses the photosynthetic activity (Falkowski & Raven 2007). But, if the available forms of either of these elements are retained through treatment of water effective restoration could be achieved. Even after restoration, wetlands such as JK, RC, KT and Talghattapura inlet-1 (TAI1) were with high BOD due to the oxygen requirement for decomposition of organic matter. This reveals the improper de-silting/ mixing of organic matter (due to untreated sewage inflow), increasing high anoxic conditions. One of the sources of pollution in form of organic matter could be the use of soaps and detergents for washing near wetland bed (Observation during study, 2011). However, Bharadwaj, 2005 shows the trends of decreasing pollution obtained during 1994-2004 in India with respect to BOD, Total Coliform and Fecal Coliform. But the circumstances are different for urban wetlands where the continued inflow of untreated sewage could be main source of pollution. Chlorides concentration in water, another component of domestic sewage, is indicative of presence of its salts such as sodium, potassium and calcium which was found to be abundant at Kothanur and Jakkur wetlands.

The water quality influence on composition of primary producers such as diatoms effectively proved the degradation of wetland ecosystem. The community composition before restoration comprised of alkaliphilic CMEN which was later replaced by pollution tolerance NPAL representing pollution status. This was specific at Jakkur, Rachenahalli and Kothanur reflecting continued water contamination. Even though the pollution status was lowered at Somapura and Kommaghatta wetlands the taxa richness has reduced drastically. The removal of microhabitats is the major responsible reason for decreased benthic diatoms and thus was lately replaced with planktonic forms after restoration. There was no macroinvertebrate recorded either due to the unstable ecosystem or due to unavailability of major primary producers. Imbalances in the food chain has also lead to the decline in bird diversity as well (http://bangalorebuzz.blogspot.com/ and http://www.indiawaterportal.org/node/21183 on February 21, 2012).

7.3. Qualitative restoration of Bangalore wetlands

Restoration of Bangalore lakes included de-silting, removal of macrophytes and construction of bund. Lake restoration (POR –Post restoration) has helped evident from water quality and respective diatom community (Fig. 7). The pH has reached neutral range in POR while it was alkaline before restoration (PRR). This could be due to the rainwater during August- November 2010 and 2011. Electric conductivity (EC), total alkalinity (ALK) and total hardness concentrations reduced after restoration although; there were few sampling sites (KT & JK) which attained higher concentration and failed to re-establish the clean water status. The similar results with other environmental factors like dissolved oxygen, BOD and COD, and Calcium hardness. Even after an attempt to restore/ bring back the lost water condition, hitherto the oxygen saturation and oxygen demand remained alike, exceeding the BIS limits for surface standards. Nitrates and phosphates ranged high during POR when compared to PRR analysis.

These results highlight the inflow of sewage into the wetlands such as Kothanur and Jakkur. The threat of eutrophication due to nutrient enrichment, particularly nitrates and phosphates affects the productivity resulting in the excessive growth of phytoplanktons, macrophytes and weeds. Many other impacts on wetlands in Bangalore include introduced invasive fish species, which has removed the native species affecting the livelihood of dependent population (Ramachandra et al., 2011). This study demonstrates the organic matter, ionic concentrations and chlorides are the important variables to be monitored to assess restoration efficacy.

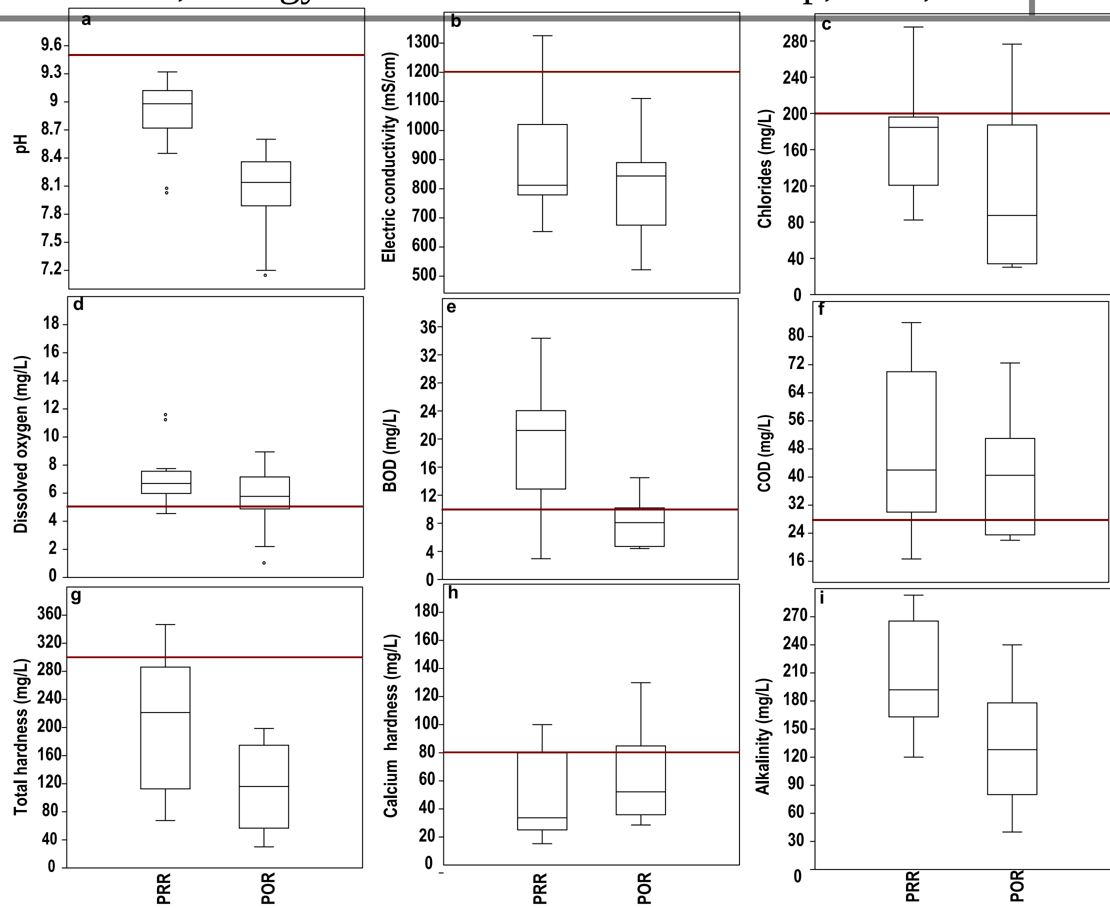


Figure 9 Box plot of overall water quality of Bangalore wetlands and comparison between pre-restoration and post-restoration studies. The **red** horizontal line in box plot indicates the BIS standard limits for surface water quality. From top a= pH; b= electric conductivity; c= Chlorides; d= dissolved oxygen; e= biological oxygen demand (BOD); f= chemical oxygen demand (COD); g= total hardness; h= calcium hardness and i= alkalinity.

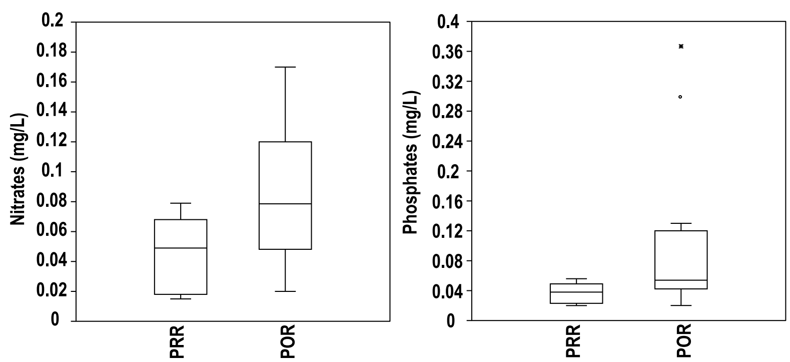


Figure 8 Box plot of overall water quality of Bangalore wetlands and comparison between pre-restoration and post-restoration studies. The red horizontal line in box plot indicates the BIS standard limits for surface water quality. From left- Nitrates and phosphates

8. Recommendations and Conservation priorities

One of the serious threats to aquatic ecosystems is the increasing expansion of human population and settlements. These demands for wetland resources such as water for domestic and irrigation, aesthetic values, food (Fish) and many more, which over a period of time inevitably disappear. Quantification of existing wetland resources and its restoration for future conservation is mandatory. We here, compile the recommendations discussed since 10 for the management of lakes and wetlands so as to prioritize the restoration and conservation policy.

1. Identify water bodies of biodiversity importance and declare them as wetland conservation reserves (WCR)

2. Climate change is a global phenomena and it also needs studies at local level. We should also focus on increasing the green cover especially in the urban areas which would help in carbon sequestration.

3. The laws regarding pollution problems already exist but they need to be implemented effectively. Collection and compilation of data of each wetland regularly to see how climatic changes alter water quality. There is need to develop network institutions at national levels.

4. The metal toxicity studies in the natural environments are also essential to analyse its effects on the biodiversity and hence, minimize the same.

5. Survey of biodiversity of every water body from schools, colleges and local people and should be updated in biodiversity bank. The local Biodiversity Management Committees should be formed and be given necessary financial support and scientific assistance in documentation of diversity. Wetlands with endemic, rare, endangered or threatened species and economically important species should be focused for conservation.

6. The taxonomy and systematic biology should be integrated with new developments and more opportunities are needed to be generated for the systematic biology in the country. It is also essential to facilitate the use of information technology for organizing the taxonomic data and also support the biodiversity portals to engage the local people for collating the highly dispersed and vast biodiversity information.

7. The biodiversity should also be linked with the environmental parameters to understand the ecology of the important species and to comprehend how climate change variations in water quality and metal concentrations impact on species level.

   Even though Bangalore lakes are man-made lakes and are formed in 16th century; there is no continuous data on each lake biodiversity. Paleolimnological studies explain us about the type of geology and diversity present. Collection of sediment samples and carbon dating could be applied for biomonitoring studies. Paleolimnological approaches could also be used to infer whether a lake has been restored to its predisturbance condition.

8. Catchment activities that degrade watershed, area must be identified and managed through mapping water bodies and changing land use/ land cover. Data collections on wetland drainage system along with regular water characteristics help in maintaining good water quality by 2015 and thus also aid in recharge ground water.

   Demarcation of the boundary of water bodies: The existing regulations pertaining to boundary demarcations within different states need to be reviewed according to updated norms and based on geomorphology and other scientific aspects pertaining to individual water bodies. Maximum Water Level mark should form the boundary line of the water body. In addition, a specified width, based on historical records/ survey records etc. may be considered for marking a buffer zone around the water body. In case such records are not available, the buffer zones may be marked afresh considering the flood plain level and also maximum water levels. The width of the buffer zone should be set considering the geomorphology of the water body, the original legal boundaries, etc. The buffer zone should be treated as inviolable in the long term interests of the water body and its biodiversity.

   The existing regulations pertaining to boundary demarcations within different states need to be reviewed according to updated norms and based on geomorphology and other scientific aspects pertaining to individual water bodies.

   Urban wetlands, mostly lakes to be regulated from any type of encroachments and pollutants (sewage, effluents) letting into the waterbody. Regulate the activity which interferes with the normal run-off and related ecological processes – in the buffer zone (200 m from lake boundary / flood plains is to be considered as buffer zone)

9. Quantification and appreciation of values of different components of aquatic biodiversity either directly or indirectly and its implication on livelihoods. Goods and services provided by the individual ecosystems and the respective species to be documented, evaluated through participatory approach and be made part of the Biodiversity Registers. Ecological values of lands and water within the catchment / watershed shall be internalized into economic analysis and not taken for granted. Pressure groups shall play as watchdogs in preventing industrial and toxic and persistent pollutants by agencies and polluters.

10. Habitat destruction is very critical problem faced by the biotic species and hence, the habitat conservation is very essential for sustainable management of species diversity.

11. Over exploitation of fishing in breeding season should be reduced. Habitat conservations for indigenous fish species and removal of exotic cat fish which not only leads to decline in native fishes but also affects human health with metal toxicities when consumed.

12. Study of aquatic food webs and the relationship between each organisms and overall productivity of the wetland is still unclear. Data collection on food web components e.g., planktons, invertebrates, amphibians and other predators. There is an urgent need for creating a `Data Bank' through inventorisation and mapping of the aquatic biota ranging from tiny microorganisms, algae to higher taxa like birds appreciate their values to the ecosystem.

13. Emphasis should shift from implementing expensive restoration methods (Dredging) towards sustainable use of lakes and wetlands algal growth for renewable biofuel production.

14. Holistic and Integrated Approaches –Integration of the activities with the common jurisdiction boundaries of Government parastatal Agencies for effective implementation of activities related to management, restoration, sustainable utilization and conservation.

This necessitates:

- To minimize the confusion of ownership – assign the ownership of all natural resources (lakes, forests, etc.) to a single agency – Lake Protection and Management Authority. This agency shall be responsible for protection, development and sustainable management of water bodies).

- Custodian shall manage natural resources - let that agency have autonomous status with all regulatory powers to protect, develop and manage water bodies.

- All wetlands to be considered as common property resources and hence custodians should carefully deal with these ensuring security.

- Management and maintenance of lakes to be decentralized involving stakeholders, local bodies, institutions and community participation without any commercialization or commoditization of lakes.

- Integrated aquatic ecosystem management needs to be implemented to ensure sustainability, which requires proper study, sound understanding and effective management of water systems and their internal relations.

- The aquatic systems should be managed as part of the broader environment and in relation to socio-economic demands and potentials, acknowledging the political and cultural context.

- Wetlands lying within the notified forest areas shall be regulated by the Indian Forest Act, 1927 and the Forest Conservation Act, 1980.

- Wetlands outside protected or notified forest areas shall be regulated by the relevant provisions of the Environment (Protection) Act, 1986.

- Immediate implementation of the regulatory framework for conservation of wetlands by the Ministry of Environment and Forests, GOI. Formulation and implementation of the National wetlands policy both at state and at national levels.

- Prohibit activities such as conversion of wetlands for non-wetland purposes, dumping of solid wastes, direct discharge of untreated sewage, hunting of wild fauna, reclamation of wetlands.

- Maintain Catchment Integrity to ensure lakes are perennial and maintain at least 33% land cover should be under natural Vegetation.

- Plant native species of vegetation in each lake catchment. Create new water bodies considering the topography of each locality.

- Establish laboratory facility to monitor physical, chemical and biological integrity of lakes.

15. Maintain physical integrity - Free storm water drains of any encroachments. Maintain and establish interconnectivity among water bodies to minimize flooding in certain pockets. The process of urbanization and neglect caused disruption of linkages between water bodies such as ancient lake systems of many cities. Wherever such disruptions have taken place alternative arrangements should be provided to establish the lost linkages.

- Encroachment of lake beds by unauthorized /authorized agencies must be immediately stopped. Evict all unauthorized occupation in the lake beds as well as valley zones.

- Any clearances of riparian vegetation (along side lakes) and buffer zone vegetation (around lakes) have to be prohibited

- Implement polluter pays principle for polluters letting liquid waste in to the lake either directly or through storm water drains.

- Appropriate cropping pattern, water harvesting, urban development, water usage, and waste generation data shall be utilized and projected for design period for arriving at preventive, curative and maintenance of aquatic ecosystem restoration action plan (AERAP).

- Proper restoration methods should be followed in order to keep not only the water but only the biodiversity and its ecological perspective in consideration. The restoration methods such as de-silting of lakes (for removal of toxic sediment, to control nuisance macrophytes) would remove the previous aquatic flora.

- Maintaining the sediment regime under which the aquatic ecosystems evolve including maintenance, conservation of spatial and temporal connectivity within and between watersheds.
- Maintaining overgrowth of aquatic weeds like Eichhornia, Azolla, Alternanthera etc. through manual operations.
- Aquatic plants greatly aid in retarding the eutrophication of aquatic bodies; they are the sinks for nutrients & thereby play a significant role in absorption & release of heavy metals. They also serve as food and nesting material for many wetland birds. Therefore, knowledge of the ecological role of aquatic species is necessary for lake preservation.
- Adopt biomanipulation (Silver carp and Catla– surface phytoplankton feeders, Rohu – Column zooplankton feeder Gambusia and Guppies – larvivorous fishes for mosquito control),aeration, shoreline restoration (with the native vegetation) in the management of lakes.

16. Environmental awareness programmes can greatly help in the protection of the water bodies. Government Agencies, Academies, Institutions and NGO's must co-ordinate grass-root level implementation of policies and activities related to conservation of lakes and wetlands (both Inland and Coastal), their sustainable utilization, restoration and development including human health. There is also a need for management and conservation of aquatic biota including their health aspects. Traditional knowledge and practices have to be explored as remedial measures. Cost-intensive restoration measures should be the last resort after evaluating all the cost-effective measures of conservation and management of the wetlands.

17. A National Committee be constituted consisting of Experts, Representatives of Stakeholders (researchers, industrialists, agriculturists, fishermen, etc.) and Line Agencies, in addition to the existing Committee(s), if any, in order to evolve policies and strategies for reclamation,

development, sustainable utilization and restoration of the wetlands and socio-economic development of the local people.

18. At regional level, Lake Protection and Management Authority (LPMA) with autonomy, corpus funds from plan allocations of state and center and responsibility and accountability for avoiding excessive cost and time over runs. LPMA shall have stakeholders-representatives from central and state and local body authorities, NGO's and eminent people and experts shall be constituted.

19. Generous funds should be made available for such developmental works through the National Committee. Local stakeholders should be suggested to generate modest funds for immediate developmental needs in the aquatic systems in their localities.

20. Public education and outreach should be components of aquatic ecosystem restoration. Lake associations and citizen monitoring groups have proved helpful in educating general public. Effort should be made to ensure that such groups have accurate information about the causes of lake degradation and various restoration methods.

21. Preparation of management plans for individual water bodies: Most large water bodies have unique individual characteristics. Therefore it is necessary to prepare separate management plans for individual water bodies.

22. Greater role and participation of women in management and sustainable utilization of resources of aquatic ecosystems.

23. Regulate illegal sand and clay mining around the wetlands.

24. Implementation of sanitation facilities: It was noted with grave concern that the water bodies in most of India are badly polluted with sewage, coliform bacteria and various other pathogens. In addition to this, all the settlements alongside the water body should be provided with sanitation facilities so as not to impinge in anyway the pristine quality of water.

25. Implementation of bioremediation method for detoxification of polluted water bodies.

26. The highly and irremediably polluted water bodies may be fenced off to prevent fishing, cattle grazing and washing, bathing and collection of edible or medicinal plants to prevent health hazards.

27. Based on the concept of polluter pays, a mechanism be evolved to set up efficient effluent treatment plants [ETP], individual or collective, to reduce the pollution load. Polluting industries be levied Environmental Cess, which can be utilized for conservation measures by the competent authorities. A `waste audit' must be made compulsory for all the industries and other agencies.

28. **Restoration of lakes:** The goals for restoration of aquatic ecosystems need to be realistic and should be based on the concept of expected conditions for individual eco-regions. Further development of project selection and evaluation technology based on ecoregion definitions and description should be encouraged and supported by the national and state government agencies. Traditional knowledge and practices have to be explored as remedial measures. Cost-intensive restoration measures should be the last resort after evaluating all the cost-effective measures of conservation and management of ecosystems. Lake privatised recently to be taken over and handed over to locals immediately thus restoring the traditional access to these lakes by the stakeholders.

29. Appropriate technologies for point and non-point sources of pollution and in situ measures for lake restoration shall be compatible to local ethos and site condition as well as objectives of Aquatic Ecosystem Restoration Action Plan (AERAP).

30. Public needs to be better informed about the rational, goal and methods of ecosystem conservation and restoration. In addition, the need was realized for scientist and researchers with the broad training needed for aquatic ecosystem restoration, management and conservation.

31. Improved techniques for littoral zone and aquatic microphytes management need to be developed. Research should go beyond the removal of nuisance microphytes to address the restoration of native species that are essential for waterfowl and fish habitat. Basic research is

necessary to improve the understanding of fundamental limnological processes in littoral zones and the interactions between littoral and pelagic zones of lakes.

32. Biomanipulation (food web management) has great potential for low-cost and long-term management of lakes, and research in this emerging field must be stimulated.

33. Innovative and low-cost approaches to contaminant clean up in lakes need to be developed.

34. The relations between loadings of stress-causing substances and responses of lakes need to be understood more precisely. Research should be undertaken to improve predictions of trophic state and nutrient loading relationships.

35. Improved assessment programmes are needed to determine the severity and extent of damage in lakes and wetlands and a change in status over time. Innovative basic research is required to improve the science of assessment and monitoring. There is a great need for cost effective, reliable indicators of ecosystems function, including those that would reflect long-term change and response to stress. Research on indicators should include traditional community and ecosystem measurements, paleoecological trend assessments and remote sensing. Effective assessment and monitoring programme would involve network of local schools, colleges and universities.

36. Procedures such as food web manipulation, introduction of phytophagous, insects and fish lining, and reintroduction of native species show promise for effective and long-lasting results when used alone or in combination with other restoration measures. Further research and development needs to be undertaken on these aspects.

37. Operation of motorized boats should not be permitted within lakes of less than 50 ha. In any case boating during the periods of breeding and congregations of birds should be banned.

38. The process of urbanization and neglect caused disruption of linkages between water bodies such as ancient lake systems of many cities like as in Bangalore. Wherever such disruptions have taken place alternative arrangements should be provided to establish the lost linkages.

39. Aquatic ecosystem conservation and management requires collaborated research involving natural, social, and inter-disciplinary study aimed at understanding various components, such as monitoring of water quality, socioeconomic dependency, biodiversity and other activities, as an indispensable tool for formulating long term conservation strategies. This requires multidisciplinary-trained professionals who can spread the understanding of ecosystem's importance at local schools, colleges, and research institutions by initiating educational programmes aimed at raising the levels of public awareness of aquatic ecosystems' restoration, goals and methods.

40. Actively participating schools and colleges in the vicinity of the water bodies may value the opportunity to provide hands-on environmental education, which could entail setting up of laboratory facilities at the site. Regular monitoring of water bodies (with permanent laboratory facilities) would provide vital inputs for conservation and management.

41. **Environment Education:** During the international conference lake 2000-2010 series, participants expressed that public needs to be better informed about the rational, goal and methods of ecosystem conservation and restoration. Public education and outreach should include all components of ecosystem restoration.

42. In addition, the need was realized for scientist and researchers with the broad training needed for aquatic ecosystem restoration, management and conservation.

43. Lake associations and citizen monitoring groups have proved helpful in educating the general public. Effort should be made to ensure that such groups have accurate information about the causes of lake degradation and various restoration methods.

44. Funding is needed for both undergraduate and graduate programmes in ecosystem conservation and restorations. Training programmes should cross traditional disciplinary boundaries such as those between basic and applied ecology: water quality management and fisheries or wildlife management: among lakes, streams, rivers, coastal and wetland ecology.

References

Ramachandra, T.V. (2001). Restoration and Management Strategies of Wetlands in Developing Countries, *The Greendisk Environmental Journal*. (International Electronic Jour. URL: http://egj.lib.uidho.edu/egj 15/ramacha l.html)

Prasad, S.N., Ramachandra, T.V., Ahalya, N., Sengupta, T., Alok Kumar, Tiwari, A.K., Vijayan V.S. and Lalitha Vijayan (2002). Conservation of wetlands of India-a review. *Tropical Ecology,* 43(1): 173-186.

Ramachandra, TV., Kiran R. and Ahalya, N. (2002). Status, Conservation and Management of Wetlands. Allied Publishers Pvt Ltd, Bangalore.

Ramachandra T.V., 2005. Conservation, Restoration and Management of Aquatic Ecosystems, In *Aquatic Ecosystems - Conservation, Restoration and Management*, Ramachandra, Ahalya N. and Rajasekara Murthy (ed), Capital Publishing Company, New Delhi.

Jakkur

Ramasandra

2014

)

Energy and Wetlands Research Group
CES
Indian Institute of Science
Bangalore-560012

ENERGY AND WETLANDS RESEARCH GROUP
CENTRE FOR ECOLOGICAL SCIENCES
NEW BIOSCIENCE BUILDING, III FLOOR, E-WING, LAB: TE15
Telephone : 91-80-22933099/22933503(Ext:107)/23600985
Fax : 91-80-23601428/23600085/23600683[CES-TVR]
Email : cestvr@ces.iisc.ernet.in, energy@ces.iisc.ernet.in
Web: http://ces.iisc.ernet.in/energy, http://ces.iisc.ernet.in/biodiversity
Open Source GIS: http://ces.iisc.ernet.in/grass