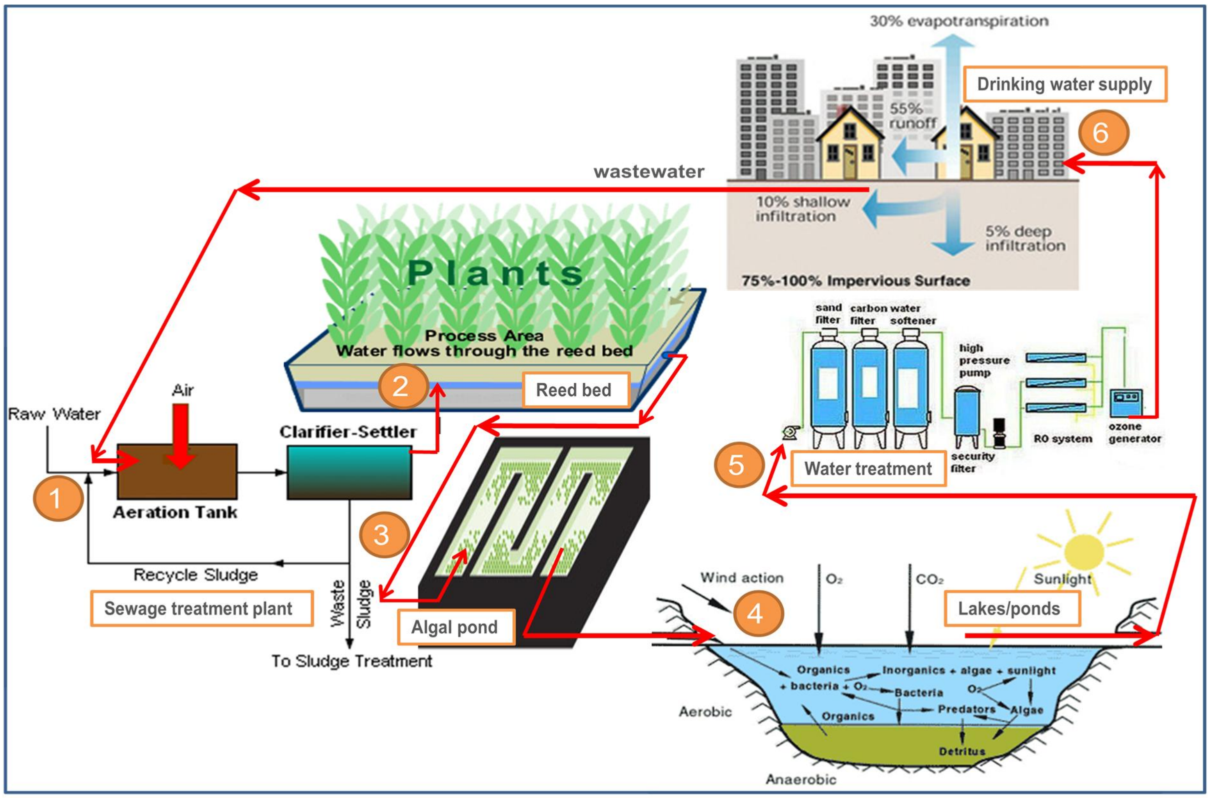
ENVIS Technical Report 76

INTEGRATED WETLANDS ECOSYSTEM: SUSTAINABLE MODEL TO MITIGATE WATER CRISIS IN BANGALORE

T V Ramachandra	Durga Madhab Mahapatra	Sudarshan P. Bhat
Asulabha K S	Sincy Varghese	Bharath H. Aithal



The Ministry of Science and Technology, Government of India
The Ministry of Environment and Forest, Government of India
Indian Institute of Science, Bangalore 560012

ENVIS Technical Report: 76

April 2014

Environment Information System [ENVIS]
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

INTEGRATED WETLANDS ECOSYSTEM: SUSTAINABLE MODEL TO MITIGATE WATER CRISIS IN BANGALORE

ENVIS Technical Report: **76**

April 2014

Citation: Ramachandra T.V., Durga Madhab Mahapatra, Sudarshan P. Bhat, Asulabha K.S., Sincy Varghese, Bharath H. Aithal, 2014. Integrated Wetlands Ecosystem: Sustainable Model to Mitigate Water Crisis in Bangalore, ENVIS Technical Report 76, Environmental Information System, CES, Indian Institute of Science, Bangalore 560012

Environmental Information System [ENVIS]
Centre for Ecological Sciences,
Indian Institute of Science,
Bangalore-560012

INTEGRATED WETLANDS ECOSYSTEM: SUSTAINABLE MODEL TO MITIGATE WATER CRISIS IN BANGALORE

Summary

Urbanisation involves changes in vast expanse of land cover with the progressive concentration of human population. The urbanized landscape provides to its inhabitants the complex social and economic environment leading to further increase in population. Bangalore had flourished in earlier times owing to its salubrious microclimate, availability of water and other resources in the city. Unplanned urbanisation leads to haphazard growth altering the local ecology, hydrology and environment. Consequences of the unplanned urbanisation are enhanced pollution levels, lack of adequate infrastructure and basic amenities. This is evident in Bangalore with severe scarcity of water, frequent flooding, enhanced pollution levels, uncongenial buildings, mismanagement of solid and liquid wastes, etc. Sewage generated in urban households is either untreated or partially treated, which is finally let into water bodies through trunk sewers and storm water network. Although sustained inflow of sewage into water bodies has maintained the water levels in the system of interconnected lakes but it has also contributed to the contamination of surface as well as groundwater sources. Bangalore city is facing severe water shortages today due to insufficient piped supply coupled with the fast decline of groundwater table. Cauvery River caters to only 55% of over 9 million population and balance is met through groundwater. Plummeting groundwater table is due to poor infiltration because of increasing paved surface and also over exploitation. This study explores the feasibility of reuse of water through integrated wetlands ecosystem to mitigate the water crisis in the city.

Integrated wetlands system consists of sewage treatment plant, constructed wetlands (with location specific macrophytes), algal pond integrated with a lake. This model is working satisfactorily at Jakkur. The sewage treatment plant removes contaminants ~ 76 % COD (380 mg/l – 88 mg/l); ~78 % BOD (220-47 mg/l); and mineralises organic nutrients (NO_3-N, PO_4^{3-}P to inorganic constituents. Integration of the conventional treatment system with wetlands [consisting of reed bed (with typha etc.) and algal pond] would help in the complete removal of nutrients in the cost effective way. Four to five days of residence time helps in the removal of pathogen apart from nutrients. However, this requires regular maintenance through

Ramachandra T.V., Durga Madhab Mahapatra, Sudarshan P. Bhat, Asulabha K.S., Sincy Varghese, Bharath H. Aithal, 2014. Integrated Wetlands Ecosystem: Sustainable Model to Mitigate Water Crisis in Bangalore, ENVIS Technical Report 76, Environmental Information System, CES, Indian Institute of Science, Bangalore 560012

harvesting macrophytes and algae (from algal ponds). Harvested algae would have energy value, which could be used for biofuel production. The combined activity of algae and macrophytes helps in the removal of ~45% COD, ~66 % BOD, ~33 % NO_3-N and ~40 % PO_4^{3}-P. Jakkur lake acts as the final level of treatment that removes ~32 % COD, ~23% BOD, ~ 0.3 % NO_3-N and ~34 % PO_4^{3}-P. The lake water with a nominal effort of sunlight exposure and filtration would provide potable water. Replication of this model in Bangalore would help in meeting the water demand and also helps in recharging of groundwater sources without any contamination.

Keywords: Wetlands, algae, nutrient removal, bioremediation, Jakkur Lake

1.0 Introduction

Wetlands include a wide range of aquatic habitats such as marsh, fen, peat land/open water, flowing water (rivers and streams) or static (lakes and ponds). These ecosystems being the transition zone between land and water are ecologically important in relation to stability and biodiversity of a region and also in terms of energy and material flow. These ecosystems perform a vital function of uptake of nutrients and bioremediation of heavy metals, volatile organics and other xenobiotic compounds and are aptly referred as "Kidneys of the landscape". They also aid in recharge of groundwater aquifers and stabilization of shorelines. These transitional zones or ecotonal region are repository of rich biodiversity and support food chain. Wetlands act as giant sponges, which helps in slowing runoff, lower flood heights, reduce shoreline and stream bank erosion. The functional ability of wetlands is dependent on the type of trophic structure and material exchange. The trophic structure includes various trophic levels as producers (algae, etc.), primary consumers (zooplanktons and grazers), secondary consumers (small fish), tertiary (large fish, birds, etc.). Algae being the primary producers synthesize carbohydrates during photosynthesis and give out oxygen along with the production of other essential metabolites. Bulk of the CO_2 gets sequestered into algal biomass in these wetlands systems that aids in combating global warming through reductions of GHG (Greenhouse gases) in the environment. However the stability of every system depends upon the balance between production and consumption of energy and matter at different trophic levels in any system. The functional aspects of wetlands are tied to the tradeoff between the ecosystem function and the anthropogenic impact that makes it very sensitive and delicate. Human impacts include altering the catchment (changes in land cover), encroachment, solid waste disposal in lake beds, sustained inflow of untreated sewage from urban localities, etc. (Ramachandra, 2002, 2009a, 2010; Ramachandra et al., 2003)

Increased and unprecedented population growth has resulted in enormous stress on potable water from a daily consumption point of view and also in regards to increased wastewater generated by the city. Bangalore had flourished during 19th and early 20th century owing to a salubrious microclimate and abundance of water in the city of lakes. Globalisation, liberalization, privatization are the agents fuelling urbanization in most parts of India during early 1990's. Unplanned growth has led to radical land use conversion of forests, surface water bodies, etc. with the irretrievable loss of land prospects (Ramachandra et al., 2013a). Land use analyses show 584% growth in built-up area during the last four decades with the decline of vegetation by 66% and water bodies by 74%. Analyses of the temporal data reveals an increase in urban built up area of 342.83% (during 1973 to 1992), 129.56% (during 1992 to 1999), 106.7% (1999 to 2002), 114.51% (2002 to 2006) and 126.19% from 2006 to 2010 (Ramachandra et al., 2012a).

Rapid urbanisation in recent times has led to the large scale generation of wastewater. Untreated or partially treated wastewaters are fed to surface water that finds its way into ground water sources. The sustained inflow of untreated or partially treated sewage to wetlands leads to the enrichment of nutrients such as nitrogen (N) and phosphorus (P), evident from the algae bloom and profuse growth of macrophytes. This has lead to the contamination of existing water resources with pathogens and nutrients resulting in algal bloom due to eutrophic status of surface water. This has also contaminated nearby groundwater sources affecting the human health. Nitrogen as nitrate-N pollution leads to physiological disorders including blue baby syndrome (methemoglobinemia) and the persistent assimilation of nitrate rich water leads to carcinogenic symptoms (as nitrates get reduced in the body forming nitrosamines, which are carcinogens). Macrophytes grow profusely in these nutrient rich environment and progressively cover the entire surface of the water body hindering the passage of sunlight and diffusion of gases to the underlying water layers. Absence of sunlight affects trophic levels with the reduced algae and photosynthetic O_2 generation depleting the dissolved oxygen concentration and thence affects the local biota.

Wetlands are the regional ecological barometers reflecting the health of a region due to the ecosystem services such as regulating the regional micro-climate (Benjamin et al. 1996; Ramachandra and Kumar 2010), recharging groundwater aquifers, thereby influencing the life of the people adjacent to it. There were 203 wetlands spread over an area of 2003 ha in 1973, that number declined to 93 (both small and medium size) with an area of 918 ha in the Greater Bangalore region in 2007 (Ramachandra and Kumar, 2008; 2010). Urban water bodies are prone to increased anthropogenic stress in recent times due to dumping of solid waste, encroachment of wetlands, sustained inflow of domestic sewage and industrial effluents leading to poor water quality. Untreated or partially treated wastewater has resulted in the enrichment of nutrients, leading to eutrophication with a very frequent algal blooms and rapid macrophyte growth with periodic successions (Mahapatra et.al, 2011). Influx of partially treated and untreated sewage has resulted in overgrowth, ageing, and subsequent decay of macrophytes creating anoxic conditions and devouring the system from life giving oxygen. This has impacted the food chain and hence the ecological integrity of the system.

Bangalore city is located on two ridges (North-Northeast and South-Southwest) with three watersheds (Hebbal-Nagavara, Koramangala-Bellandur, Vrishabhavathi). Northern and eastern parts of the city are with gentle slopes, while southern and western parts are very rugged Undulating terrain of the region has helped in the creation of interconnected water-bodies to meet the domestic and irrigation requirements during the pre-colonial period. These interconnected drainage system is supposed to transfer the storm water from one water-body to another, started receiving sewage with rapid population growth and lack of appropriate sewage treatment systems. Population in Bangalore has increased from 5.6 millions (2001) to 9.5 millions (2011). Population increase has led to large quantum of sewage influx into wetlands leading to contamination of wetlands and associated groundwater systems.

Collapse of land regulation is evident during the past two decades due to large scale unauthorized occupation of open spaces (wetlands, grasslands, parks) by the influential section of the society in collusion with the bureaucracy. Large scale land conversion of common lands to built-up in recent times further substantiates the nexus (Ramachandra et al., 2007, Ramachandra and Sudhira, 2007). Changes in the land cover have altered the regional hydrology evident from frequent floods, conversion of perennial wetlands to seasonal wetlands and decline of groundwater table. However authorities have kept some wetlands alive by diversion of sewage, which flows consistently and maintains the water levels in the system of interconnected lakes.

1.1 Water supply in Bangalore: Water is being pumped from Cauvery River ~100 km from the city with an electricity requirement of 75-100 MW. Bangalore is located at higher elevation (900 m above mean sea level) and Cauvery river courses are at 500 m above mean sea level. This exercise suffices the need for approximately 55 % of Bangalore city dwellers, while the rest are dependent on ground water and unauthorized drinking water supplies. Arkavathy River, with two reservoirs at Hesaraghatta (built in 1894, now dry) and Tippagondanahalli (built in 1933) insignificantly and irregularly contribute to a small fraction of the demand (30 MLD). The Chamrajasagar reservoir at Thippagondanahalli (or TG Halli reservoir), located at the confluence of the Arkavathy and Kumudavathy rivers, receives inflow mostly from the Kumudavathy but with a low flow rate (Sharachchandra Lele et. al, 2013, Ramachandra and Solanki, 2007). Water demand in Bangalore is roughly about 150 liters per day (lpd) per person and the total water requirement for domestic purposes is about 1,400 million liters per day (MLD). Water available from Cauvery (Stages I to IV, Phase I) and Arkavathy (Hesarghatta and Tippagondanahalli reservoirs) rivers is about 975 MLD. The loss of water during transportation and distribution is assumed to be ~30%. Significant portion is met from groundwater sources as indicated in Table 1 and Figure 1.

Table 1: Zone-wise piped water and ground water supply

Zone	Surface water	Groundwater	Total
Central	67.1	38.91	106.01
North	210.46	87.08	297.54
West	184.89	149.45	334.34
East	169.19	50.46	219.65
South	133.106	176.00	309.11
Southeast	104.79	67.80	172.59
Total	869.536	569.7	1439.24

Ramachandra T.V., Durga Madhab Mahapatra, Sudarshan P. Bhat, Asulabha K.S., Sincy Varghese, Bharath H. Aithal, 2014. Integrated Wetlands Ecosystem: Sustainable Model to Mitigate Water Crisis in Bangalore, ENVIS Technical Report 76, Environmental Information System, CES, Indian Institute of Science, Bangalore 560012

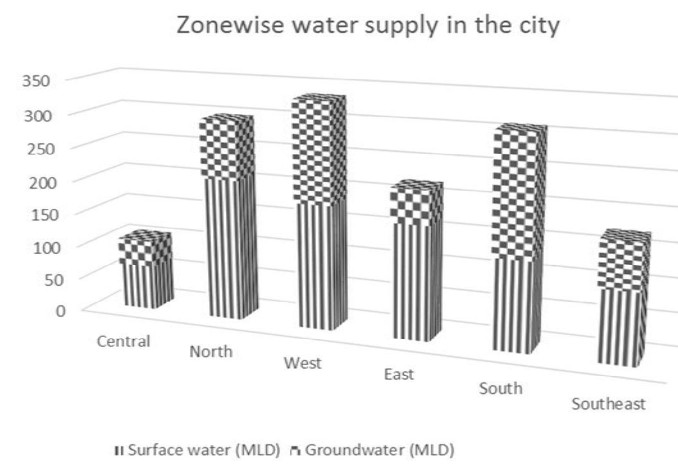


Figure 1: Water usage in Bangalore (piped water supply and from groundwater sources)

Due to insufficient water from Cuavery River, most of the new city municipal councils and town municipal council (merged with Bangalore city, in the formation of BBMP) are dependent on groundwater sources. A rapid increase in the number of borewells in Bangalore, was observed over the last three decades from 5,000 to around 4.08 lakh. It is estimated that 40% of population of Bengaluru are dependent on 750 MLD of ground water, which is extracted every day. According to the CGWB (Central Ground Water Board), between 2001 and 2007, the water level in Bengaluru has declined by 7 meters (m) at the rate of about 1m per year. Over exploitation of groundwater coupled with minimal recharge due to changes in land over (increase in paved surface with the loss of vegetation and water-bodies) has led to decline in groundwater table (as high as 500 to 600 m), evident from the prevalence of gray, dark and over-exploited groundwater blocks in the major part of Bangalore.

Communities have been dependent on wetlands for food, domestic, agricultural and industrial requirements. The economic benefits from wetlands to the society are in the form of water supply, commercial fisheries, agriculture, energy resource, wildlife resource, recreation, tourism, cultural heritage, biodiversity, etc. (Ramachandra et al., 2011). The myriad ways, in which wetlands are used, along with the numerous anthropocentric activities, have stressed wetlands in diverse ways. This has altered the wetlands quality disrupting its natural functions. Anthropogenic activities include direct physical destruction (drained for agricultural and developmental activities), siltation (soil erosion and removal of vegetative cover) and pollution from both point sources (municipal sewage and industrial effluents) and non-point sources (urban and agricultural runoffs) within the watershed (Kiran and Ramachandra, 1999, Ramachandra and Rajinikanth, 2003).

Treatment and disposal of wastewater generated in the neighbourhood constitute key environmental challenges faced in urban localities due to burgeoning population in the recent decade. Nutrient laden wastewater generated in municipalities is either untreated or partially treated and is directly fed into the nearby water bodies regularly, resulting in nutrient enrichment resulting in algal blooms. Conventional wastewater treatment options are energy and capital intensive apart from their inability to remove nutrient completely. In this backdrop, algal processes are beneficial and remove nutrients with carbon sequestration and resultant biomass production. Algae grows rapidly and uptakes nutrients (C, N and P) available in the wastewater (Ramachandra et al., 2013a; Mahapatra et al., 2013) and hence are useful in nutrient remediation. Treatment of sewage and letting into wetlands would help in further treatment (removal of N, P and heavy metals). This also prevents contamination of groundwater resources. Thus wetlands provide a cost effective option to handle sewage generated in the community and also helps in addressing the water crisis in the region.

Microalgae and native macrophytes of the wetlands help in the treatment due to abilities to uptake nutrients and heavy metals. Techniques have been developed for exploiting the algae's fast growth and nutrient removal capacity (Karin Larsdotter, 2006). The nutrient removal is basically an effect of assimilation of nutrients as the algae grow. Also, nutrient stripping happens the due to high pH induced by the algae as in ammonia volatilization, phosphorus precipitation, etc.

2.0 Constructed Wetlands: Reed bed (typha, etc.) with Algal pond as wastewater treatment systems

Wetlands aid in water purification (nutrient, heavy metal and xenobiotics removal) and flood control through physical, chemical, and biological processes. When sewage is released into an environment containing macrophytes and algae a series of actions takes place. Through contact with biofilms, plant roots and rhizomes processes like nitrification, ammonification and plant uptake will decrease the nutrient level (nitrate and phosphates) in wastewater (Garcia et.al, 2010). Algae based lagoons treat wastewater by natural oxidative processes. Various zones in lagoons function equivalent to cascaded anaerobic lagoon, facultative aerated lagoons followed by maturation ponds (Mahapatra et al., 2011b). Microbes aid in the removal of nutrients and are influenced by wind, sunlight and other factors (Mahapatra et.al, 2011, 2013a,b).

2.1 Nutrients as source of contamination: The conventional wastewater treatment systems (sewage treatment plants - STP) are expensive and require input of external energy sources (e.g.; electricity, organic carbon) and chemical additives. These treatment systems generate concentrated waste streams necessitating environmentally sound disposal.

There is an urgent need to develop an innovative, environmental friendly and cost effective sustainable technologies for treating sewage generated in the community every day. Untreated sewage leads to the neighborhood contamination of land and water resources (groundwater). An easy way to check the sewage contamination is to test the level of nutrients (nitrates and phosphates). Nitrate is a substance that develops from organic waste. Algae convert nitrate into organic compounds (proteins, lipids) through photosynthesis in the presence of sunlight. Algae can exhibit growth rates that are higher than other plants due to their extraordinarily efficient light and nutrient utilization. By taking advantage of rapid availability of nutrient enriched water, high solar intensity and favorable microclimate for algal growth, higher densities of algae can be grown continuously that provides ample biomass and at the same time treat wastewater within a short period of time.

Algal bacterial symbiosis is very effective in these tropical conditions. Algae the primary producers generate O_2 (during photosynthesis) which aid in the efficient oxidation of organic matter with the help of the chemo-organotrophic bacteria. The type and diversity of the algae grown are potential indicators of treatment process (Amengual-Morro et al. 2012; Mahapatra et al., 2013a,b; Mahapatra et al., 2014)) and bacterial system disintegrates and degrades the organic matter providing the algae with an enriched supply of CO_2, minerals and nutrients.

Focus of the current investigation is to assess the efficacy of wetlands in Jakkur lake system. This has been done through water quality assessment (physicochemical analysis) at various stages of the integrated wetland system consisting of sewage treatment plant (10 MLD), wetlands (with macrophytes), algal pond and Jakkur Lake. Nitrate and phosphate levels were monitored at various stages of wetlands ecosystem.

3.0 Study Area

Jakkur Lake (Figure 2) situated at 13º 04'N and 77° 36'E, North East of Bangalore. Ten MLD sewage treatment plant is functional in this locality. Partially treated water is let into Jakkur Lake through wetlands (consisting of emergent macrophytes and algae). Water samples were collected (figure 2) from Inlet (S6), outlets (S1, S2, S3), middle (S4, S5 and S9) and at treatment plant outlet (S6 and S7) totaling nine locations. The treated water from the treatment plant passes through the wetlands to Jakkur Lake.

4.0 Integrated Wetlands Ecosystem

Integrated wetlands system at Jakkur consists of i) treatment plant (treats sewage partially before letting to wetlands, ii) constructed wetlands consisting of macrophytes, iii) algal pond and v) lake (figure 2). Jakkur lake with wetlands is manmade and constructed about 200 years ago to meet the domestic and irrigation water requirement of Jakkur village located about hundred meters south west in the downstream of the lake (figure 3). The lake used to be perennial containing water all 12 months due to vegetation cover in its catchment. The lake was a source of livelihood to poor farmers and washer men. Even today during potential fish growth seasons, fish cash is estimated to be as high as 500 kgs per day. Twelve to fifteen dhobi (washer men) families are also dependent on the lake for washing cloth daily. In the command area of the lake agriculture and horticulture (coconut, banana and mango plantations) was practiced and remnants of these plantations could be seen even today in the region. Rapid urbanisation in recent times has led to large scale land use changes leading to an increase in paved surfaces. This has resulted in the decline of infiltration ability of the capacity resulting in lake retaining water for 8-9 months. Lake receives partially treated sewage daily with the implementation of sewage treatment plant in the upstream of the lake, near the inlet of constructed wetlands. Water flows from the treatment plant (in the north) towards the outlets in the south of the lake. Catchment and command area of the lake was mainly agrarian during pre-ninety's, are now dominated by urban land uses. Around the lake are different kinds of human activities, such as banana plantations, slums, a golf course, and newly built residential buildings.

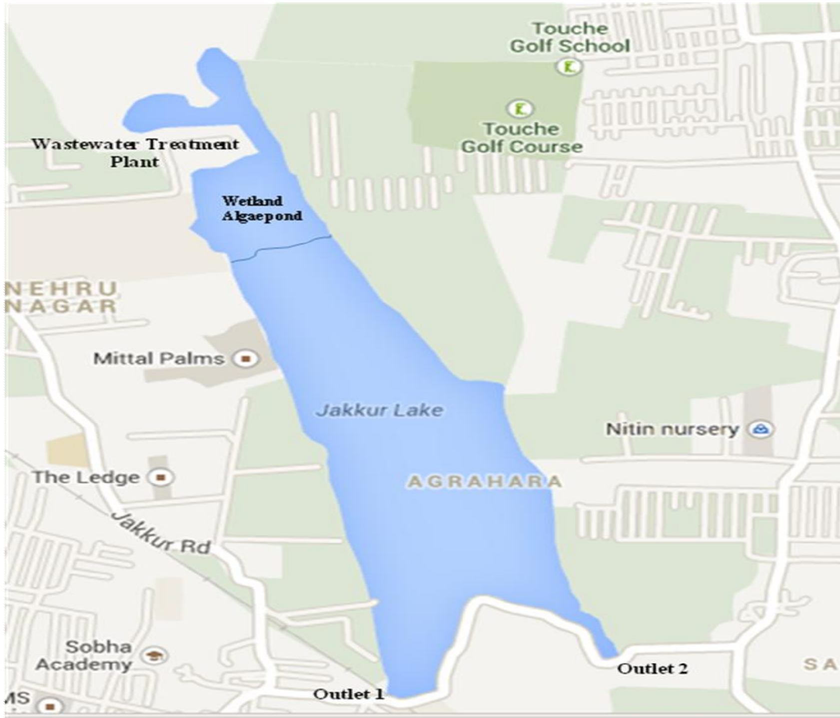


Figure 2: integrated wetlands ecosystem: Sewage treatment plant, wetlands (macrophytes and algae pond), Jakkur lake (source: Google map)

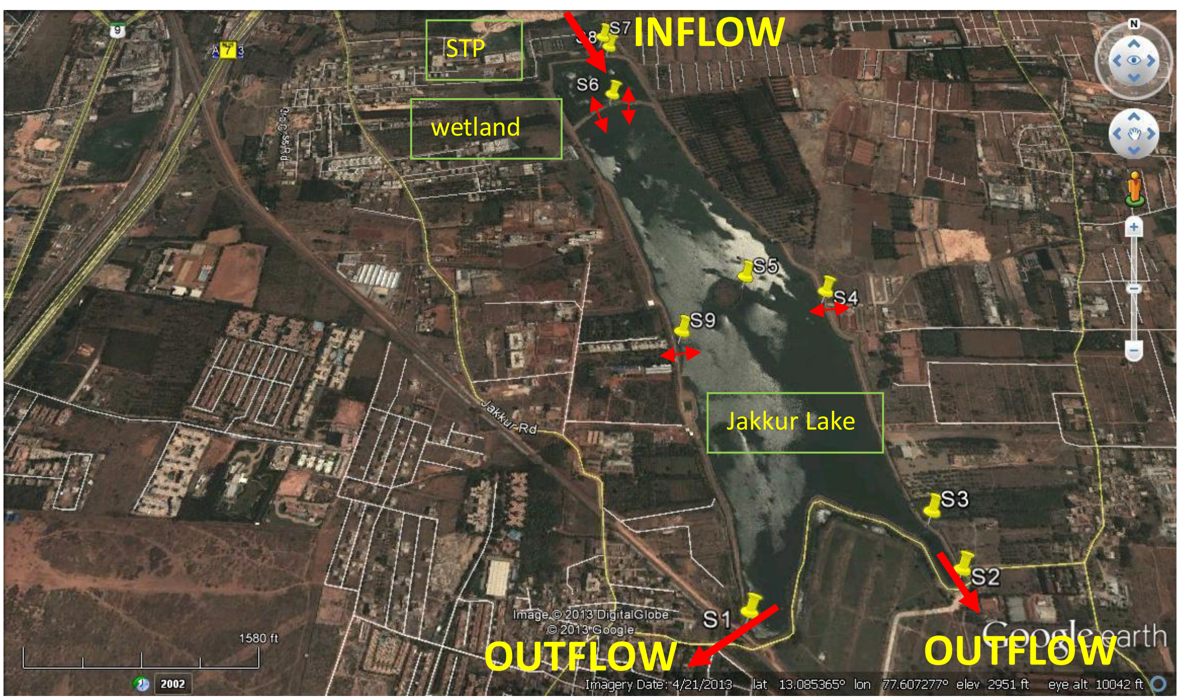


Figure 3: water sampling locations in wetlands system (source: earth.google.com)

5.0 Results and Discussion

Water quality analysis was carried out to assess physico-chemical and biological properties of water at various stages of the treatment and its suitability for domestic and irrigation purposes. Water samples were collected from nine locations (marked in Figure 2) twice at 45 days interval. The water samples were collected in clean acid washed one liter polythene bottles. Temperature, TDS, Conductivity and pH were measured on the site. Water quality parameters were analyzed as per the standard protocol (APHA, 1998). Algal samples collected from sampling locations were identified using standard keys (Prescott 1973;1982) based on their external appearance, colour, morphological characteristics, size, habitat, structure and orientation of chloroplast, cellular structure and pigments etc. Water samples collected were concentrated by centrifuging 15 ml volume.

5.1 Dissolved Oxygen: Dissolved oxygen (DO) is the most essential feature in aquatic system that helps in aquatic respiration as well as detoxification of complex organic and inorganic mater through oxidation. The presence of organic wastes demands high oxygen in the water leading to oxygen depletion with severe impacts on the water ecosystem. The DO of the analyzed water samples varied between 0 to 17.74mg/l. The higher variations of DO especially lower DO values are indicative of high organic matter in the immediate vicinity. The DO was very low at the inlets of wetlands and increased immediately after the algal pond. Lower DO values were observed near the macrophytes (invasive exotic weeds as water hyacinth, *Eichhornia crassipes*) infested regions at the outfalls outlets.

5.2 Total Dissolved Solids (TDS): Total dissolved solids present as as mineral matter in the form of dissolved cations and anions and to a smaller extent by organics, sourced from decomposing matter. Other sources include runoff from urban areas, road salts used on street, fertilizers and pesticides used on lawns and farms (APHA, 1998). TDS affect the water quality in many ways impacting the domestic water usage for cleaning, bathing etc as well as drinking purposes (Ramachandra et al., 2012). Surface as well as groundwater with high dissolved solids are of inferior flavor and induce an unfavorable physiological reaction to the dependent population. The TDS values in the samples analyzed, ranged from 612 to 710 mg/lacross all locations. It was higher in the inlets and reduced in the middle region of the lake. The TDS was little higher in the outlets than middle due to human activities (like washing, etc.), macrophyte and plankton cover etc.

Ramachandra T.V., Durga Madhab Mahapatra, Sudarshan P. Bhat, Asulabha K.S., Sincy Varghese, Bharath H. Aithal, 2014. Integrated Wetlands Ecosystem: Sustainable Model to Mitigate Water Crisis in Bangalore, ENVIS Technical Report 76, Environmental Information System, CES, Indian Institute of Science, Bangalore 560012

Table 1: Onsite parameters

Site	GPS	DO(mg/l)		Water Temp (°C)		TDS (mg/l)		pH		EC (µS)		Comments
Period		1	2	1	2	1	2	1	2	1	2	
S1	13.07931N, 77.61032E	5.08	7.26	24.3	25	637	636	7.8	8.4	1179	1160	Outlet, People washing clothes
S2	13.08019N, 77.61463E	--	3.71	--	24.4	--	631	--	8.2	--	1204	Outlet, after the cover of macrophytes
S3	13.08143N, 77.61428E	16.94	8.06	24	24.2	630	630	8	8.2	1213	1215	Outlet
S4	13.08670N, 77.61265E	16.53	8.06	24	--	629	643	8.1	--	1221	--	Middle
S5	13.08725N, 77.61060E	16.13	9.35	--	25	617	612	7.9	7.8	1134	1256	Middle
S6	13.09266N, 77.60769E	17.74	8.06	--	24.1	648	709	7.4	7.2	1213	1389	Inlet to the lake after algae pond
S7	13.09433N, 77.60767E	2.02	0.00	24.7	22.3	652	692	7.2	7.7	1293	1368	Untreated sewage water entering lake
S8	13.09423N, 77.60767E	5.40	4.60	23	24.9	683	630	7.8	8.2	1327	1244	Treated water from treatment plant
S9	13.08582N, 77.60922E	9.68	7.26	24.3	24.3	631	640	8	7.2	1228	1216	Middle

Table 2: Chemical parameters of Water analysis

Sites	Chloride (mg/l)		Total Hardness (mg/l)		Ca (mg/l)		Mg (mg/l)		Na (mg/l)		K (mg/l)		Total Alkalinity (mg/l)	
Period	1	2	1	2	1	2	1	2	1	2	1	2	1	2
S1	259.86	254.18	212	206	40.88	39.28	26.82	26.33	300.8	331.6	47.6	51.6	260	252
S2	--	249.92	--	204	--	40.08	--	25.36	--	367.6	--	56.4	--	252
S3	249.92	249.92	212	204	42.48	39.28	25.84	25.84	360	359.6	58	57.6	250	248
S4	166.14	190.28	208	200	43.29	40.08	24.38	24.38	343.6	334	52.8	54.4	260	256
S5	180.34	168.98	210	224	44.09	38.48	24.38	21.93	284.8	282.4	54.4	53.2	240	254
S6	251.34	249.92	240	256	59.32	59.93	22.42	22.90	293.6	260.4	53.2	56	290	310
S7	254.18	257.02	252	244	65.73	61.72	21.44	21.93	256.4	266	52.4	55.6	420	444
S8	252.76	254.18	256	254	71.34	67.71	19.00	24.87	268.8	320.8	56	54.8	440	448
S9	230.04	210.16	206	198	44.89	46.49	22.91	19.99	330.4	342.4	55.2	57.6	260	252

Table 3: Nutrient analysis of water

Sites	COD (mg/l)		BOD (mg/l)		Phosphate (mg/l)		Nitrate (mg/l)	
Period	1	2	1	2	1	2	1	2
S1	28	20	17.14	5.04	0.09	0.15	0.28	0.32
S2	--	20	--	9.58	--	0.20	--	0.34
S3	34	10	19.15	1.01	0.09	0.20	0.26	0.34
S4	30	14	22.18	5.04	0.10	0.25	0.26	0.36
S5	18	20	27.22	1.01	0.10	0.67	0.21	0.33
S6	16	48	25.20	16.13	0.21	1.00	0.24	0.27
S7	161.3	28	128	6.05	0.72	1.29	0.22	0.22
S8	88	16	46.37	4.54	0.35	0.27	0.36	0.38
S9	18	16	20.16	5.04	0.09	0.18	0.20	0.26

5.3 pH: pH is a numerical expression that indicates the degree to which water is acidic or alkaline, with the lower pH value tends to make water corrosive and higher pH has negative impact on skin and eyes. The pH value ranged from 7.2 to 8.4.

5.4 Chlorides: Chlorides are essentially anionic radical that imparts chlorosity to the water. An excess of chlorides leads to the formation of potentially carcinogenic and chloro-organic compounds like chloroform, etc. Chloride values in samples collected from Jakkur lake system ranged from 166-260mg/l. Chloride values were high at inlets (treated and untreated water) and relatively lower at the outlet of algal pond and the middle portion of Jakkur lake. At outlets, it is higher due to washing activities with the use of bleaching powder i.e. $CaO(Cl)_2$.

5.5 Sodium: Sodium (Na) is one of the essential cations that stimulate various physiological processes and functioning of nervous system, excretory system and membrane transport in animals and humans. Increase of sodium ions has a negative impact on blood circulation, nervous coordination, hence affecting the hygiene and health of the nearby localities. In this study the concentration of sodium ranged from 256 to 367 mg/land higher values were observed in samples collected at outlets.

5.6 Potassium: Potassium (K) is an essential element for both plant and animal nutrition, and occurs in ground waters as a result of mineral dissolution, decomposing of plant materials and also from agricultural runoff. Potassium ions in the plant root systems helps in the cation exchange capacity to transfer essential cations like Ca and Mg from the soil systems into the vascular systems in the plants in replacement with the potassium ions (APHA, 1998). Incidence of higher potassium levels in soil system affects the solute transfer (active and passive) through the vascular conducting elements to the different parts of the plants. The potassium content in the water samples ranges between 47-58mg/l. The potassium values were high at outlets due to decomposition of plant materials.

5.7 Alkalinity: Alkalinity is a measure of the buffering capacity of water contributed by the dynamic equilibrium between carbonic acid, bicarbonates and carbonates in water. Sometimes excess of hydroxyl ions, phosphate, and organic acids in water causes alkalinity. High alkalinity imparts bitter taste. The acceptable limit of alkalinity is 200mg/l. Alkalinity of the samples was in range 240-444 mg/l. High alkalinity of 448 and 444 mg/l was observed at the inlet of wetlands (or outlet of the treatment plant). These values declined after the water passed through wetlands (in particular the algal pond) and also in the middle of Jakkur lake.

5.8 Total hardness: Hardness is a measure of dissolved minerals that decides the utility of water for domestic purposes. Hardness is mainly due to the presence of carbonates and bicarbonates i.e temporary hardness and due to sulphates and chlorides i.e. permanent hardness. It is caused by variety of dissolved polyvalent metallic ions predominantly calcium and magnesium cation or other cations like barium, iron, manganese, strontium and zinc. In the present study, the total hardness ranged between 198 to 256mg/l. It was higher in the inlets. High values of hardness are probably due to the regular addition of sewage and detergents.

5.9 Calcium: Calcium (Ca) is one amongst the major macro nutrients which are needed for the growth, development and reproduction in case of both plants and animals. The presence of Ca in water is mainly due to its passage through deposits of limestone, dolomite, gypsum and other gypsiferous materials (APHA, 1998) along with the Ca (from sewage). It contributes to the total hardness of the water. Ca concentration in all samples analyzed periodically ranged between 39 to 71mg/l. Ca concentration was high in the sewage water (treated and untreated) entering into the lake.

5.10 Magnesium: Magnesium (Mg) in one of the most essential macro nutrients that helps as a co-factor in the enzyme systems and in the central metal ions that constitutes the chlorophyll molecule essential for plant photosynthesis. According to WHO guidelines the maximum admissible limit is 50mg/l. In this study the concentration of Magnesium ranged from 19–26.82 mg/l.

5.11 Nutrients (nitrates and phosphates): Nutrients essentially comprise of various forms of N and P that readily mineralizes (inorganic mineral ions) to enable uptake by microbes and plants. Accumulation of nitrates and inorganic P induces changes in water quality that affects its integrity leading to higher net productivity. Nitrates in excess amounts together with phosphates accelerate aquatic plant growth in surface water causing rapid oxygen depletion or eutrophication in the water. Nitrates at high concentrations (10 mg/l or higher) in surface and groundwater used for human consumption are particularly toxic to young children affecting the oxygen carrying capacity of blood cells (RBC) causing cyanosis (methemoglobinemia). In the present study, nitrate values ranged from 0.2 to 0.38 mg/land phosphate values ranged between 0.09 to 1.29mg/l. The nitrate and phosphate values are higher at the wetlands inlets and significantly reduce after the passage through wetlands and algal pond as elucidated in Figure 4.

5.12 BOD and COD: BOD and COD are important parameters that indicate the presence of organic content. Biochemical oxygen demand (BOD) is the amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions. It is required to assess the pollution of surface and ground water where contamination occurred due to disposal of domestic and industrial effluents. Chemical oxygen demand (COD) determines the oxygen required for chemical oxidation of most organic matter and oxidizable inorganic substances with the help of strong chemical oxidant. In conjunction with the BOD, the COD test is helpful in indicating toxic conditions and the presence of biologically resistant organic substances (Sawyer and McCarty 1978). In this study the BOD values ranged from 17-128 mg/l. There was reduction of 66% in BOD after the algal pond and 23% removal in the water which flows out of the lake. The COD values ranged from 16 to 161 mg/l. The COD reduced by 45% in the algae pond and 32 % in the lake as shown in Figure 4.

6.0 Integrated Wastewater Management System

The treatment of domestic sewage in natural systems such as constructed wetlands and lagoons is being practiced in developing nations. Significant advantages are its construction and operation are simple and economically viable. Lagoon systems are associated with a high growth rate of phytoplankton that are beneficial and are caused by the influence of light and the continuous nutrient inflow. Algal growth contributes towards the treatment of wastewater by transforming dissolved nutrients into particle aggregates (biomass). Algal retention in the lagoon helps in the treatment, which has to be harvested at regular interval to ensure effective treatment. Wetlands consisting of reed-bed and algal pond help in the removal of nutrients (Mahapatra et al., 2011; 2013).

Emergent macrophytes (such as Typha) act as a filter in removing suspended matter and avoiding anaerobic conditions by the root zone oxidation and the dissolved nutrients would be taken up by the lagoon algae. This type of treatment helps in augmenting the existing treatment system in complete removal of nutrients and bacteria. The combination of wetlands (with macrophytes assemblages), algal lagoon and a sustained harvesting of algae and macrophytes would provide complete solution to wastewater treatment systems with minimal maintenance. Integrated wetland system at Jakkur provides an opportunity to assess the efficacy of treatment apart from providing insights for replicating similar systems to address the impending water scarcity in the rapidly urbanising Bangalore.

6.1 Insights to the efficacy of treatment: The treatment plant (1.6 Ha) with an installed capacity of 10 MLD, comprises of an Upflow Anaerobic Sludge Balnket Reactor (UASB) with an extended aeration system for sewage treatment. The treatment effluent then gets into wetlands (settling basin) of spatial extent ~4.63 hecatres consisting of diverse macrophytes such as *Typha* sp., *Cyperus* sp., *Ludwigia* sp., *Alternanthera* sp., Water hyacinth sp., etc. in the shallow region (with an area of ~1.8 hectares) followed by deeper algal basin (covering an area of about 2.8 hecatre). This being the significant functional component with macrophytes and algae jointly helps in the nutrient removal and wastewater remediation. The water from the settling basin flow pases through three sluices of which only the middle one is functional (with moderate flow). This water flows into Jakkur lake that spans over 45 hectares. There were notably less occurance of floating macrophytes, except near the outfalls (~0.5 Ha) due to blockage of the ouflow channels by solid wastes and debris. These macrophytes are being managed by local fishermen. Water in the Jakkur lake is clear with abundant phytoplankton diversity and acceptable densities, which indicates of a healthy trophic status.

The nutrient analysis shows (illustrated in Figure 4), that treatment happens due to immergent macrophytes of the wetlands and algae, which removes ~45% COD, ~66 % BOD, ~33 % NO_3-N and ~40 % PO_4^{3-}P. Jakkur lake treats the water and acts as the final level of treatment which shown as stage two that removes ~ 32 % COD, ~23% BOD, ~ 0.3 % NO_3-N and ~34 % PO_4^{3-}P.. The synergestic mechanism of sewage treatment plants followed by wetlands helps in the complete removal of nutrients to acceptable levels according to CPCB norms.

Jakkur STP (of 10 MLD capacity) treats only6 MLD of sewage that is drawn from Yelhanka town. Yet, It is observed that sewer channel carrying voluminous wastewater with the treatment plant effluents into wetlands. The major nutrient removal and polishing is done by the manmade wetland and the lake. This wetland comprise of emergent macrophytes as *Typha augustata*, etc and plays a key role in oxygenation of soil subsystems through root zone oxidation and entrapment of necessary nutrients that otherwise would cause an algal bloom in the lake. The algal species in this manmade wetland region (Figure 5) primarily comprised of memebers of chlorophyceae followed by cyanophyceae, eugelnophyceae and bacillariophyceae (Figure 6). The relative abundances are provided in the pie-diagrams below. The detailed list of algal species, their presence and absence have been listed and provided in Table 4.

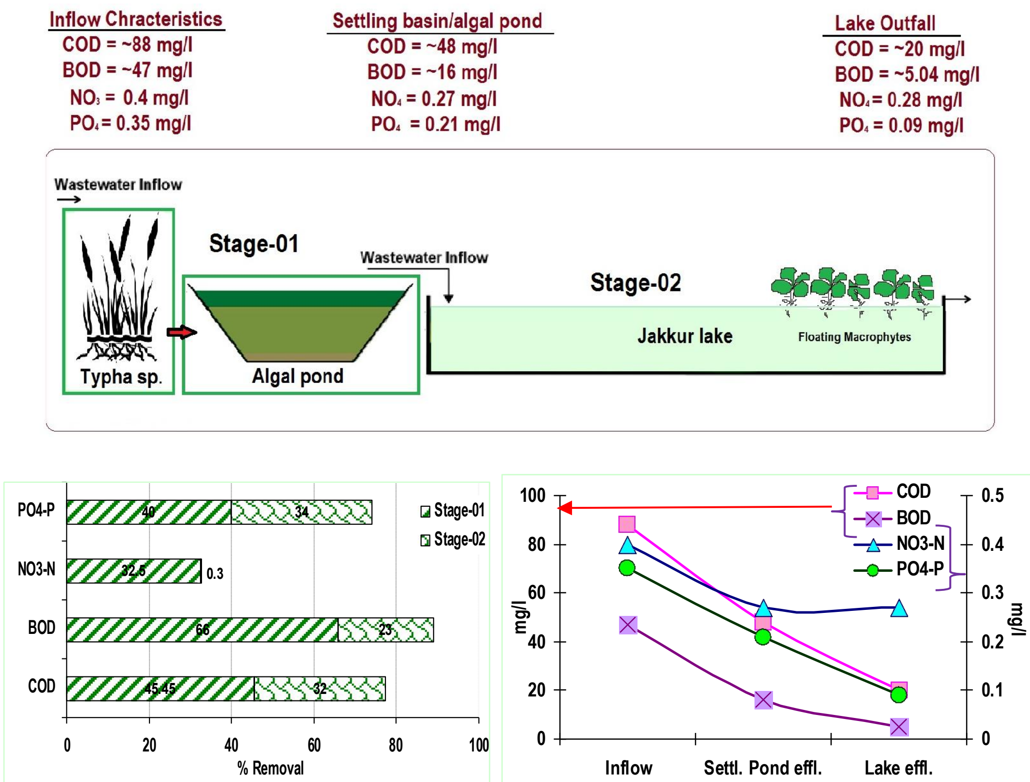


Figure 4: Integrated wastewater management system

Table 4: Algal species in Jakkur lake system

S.No	Algae	Site1	Site2	Site3	Site4	Site5	Site6	Site7	Site8	Site9
1	*Actinastrum* sp.	+	+	+	+	+	+	+	+	+
2	*Anabaena* sp.	+	+	+	+					
3	*Ankistrodesmus* sp.				+	+			+	+
4	*Aphanocapsa* sp.	+	+	+	+	+			+	+
5	Arthrodesmus sp.		+	+	+	+				+
6	*Asterococcus* sp.	+	+	+	+	+	+	+		+
7	*Chlorella* sp.	+	+	+	+	+	+	+	+	+
8	*Chroococcus* sp.	+		+	+	+		+	+	+
9	Cladophora sp.						+			
10	*Closterium* sp.	+	+	+	+	+	+	+	+	+
11	*Coelastrum* sp.		+	+	+	+	+	+	+	
12	*Coelosphaerium* sp.								+	
13	*Coenocystis* sp.								+	
14	*Cosmarium sp.*	+	+	+	+	+		+	+	+
15	*Crucigenia sp.*	+	+	+	+	+	+	+	+	+
16	*Cyclotella sp.*	+	+	+	+	+	+		+	+
17	Cymbella sp.			+	+					

Ramachandra T.V., Durga Madhab Mahapatra, Sudarshan P. Bhat, Asulabha K.S., Sincy Varghese, Bharath H. Aithal, 2014. Integrated Wetlands Ecosystem: Sustainable Model to Mitigate Water Crisis in Bangalore, ENVIS Technical Report 76, Environmental Information System, CES, Indian Institute of Science, Bangalore 560012

18	*Desmodesmus sp.*	+							+	+
19	Dictyococcus sp.		+	+	+	+	+	+		+
20	*Dictyosphaerium* sp.		+	+	+	+	+	+	+	+
21	Eudorina sp.			+						
22	*Euglena spp.*	+	+	+	+	+	+	+	+	+
23	*Glaucocystis sp.*	+	+		+	+				
24	*Gloeocystis* sp.								+	
25	*Golenkinia* spp.		+			+	+		+	
26	*Gomphonema sp.*							+		
27	*Gonium spp.*	+	+	+	+	+	+	+	+	+
28	Gyrosigma sp.					+				
29	*Krichenerilla sp.*	+	+	+	+	+	+	+	+	+
30	*Limnothrix sp.*		+		+	+	+			+
31	*Melosira sp.*	+	+	+	+	+			+	+
32	*Merismopedia* sp.		+	+	+	+	+	+	+	
33	Micracitinium sp.		+	+	+	+	+	+	+	+
34	*Microcystis sp.*	+	+	+	+	+			+	
35	*Monoraphidium sp.*	+	+	+	+	+	+	+	+	
36	*Navicula sp.*	+	+		+	+	+	+	+	
37	*Nephrocystis* sp.								+	
38	*Nitzschia sp.*	+	+		+	+		+	+	+
39	*Oocystis sp.*	+		+	+	+	+	+		+
40	*Ophiocytium* sp.								+	
41	*Oscillatoria sp.*	+				+	+	+		
42	Pandorina sp.					+	+	+		+
43	*Pediastrum sp.*	+	+	+	+	+	+		+	+
44	*Phacus spp.*	+	+	+	+	+	+	+	+	+
45	*Phormidium sp.*	+	+	+	+	+			+	+
46	Pinnularia sp.						+			+
47	*Plantothrix*	+			+			+		
48	*Pseudanabaena sp.*						+			
49	*Quadrigula sp.*	+	+	+	+	+				+
50	*Radiocystis sp.*	+	+	+	+	+		+		+
51	*Scenedesmus spp.*	+	+	+	+	+	+	+	+	+
52	Schroederia sp.		+	+	+	+		+		+
53	*Spirulina* sp.		+	+	+	+	+	+	+	
54	*Staurastrum* sp.								+	
55	*Stichococcus sp.*	+	+	+	+	+	+			+
56	Surirella sp.					+	+	+		
57	*Synechococcus* sp.								+	
58	Synedra sp.		+		+	+	+			
59	Synura sp.									+
60	*Tetraedron spp.*	+	+	+	+	+	+	+	+	+
61	*Tetraedron* spp.							+		
62	Tetrastrum sp.			+				+		
63	*Trachelomonas sp.*	+	+	+						
64	*Xanthidium sp.*	+								

Ramachandra T.V., Durga Madhab Mahapatra, Sudarshan P. Bhat, Asulabha K.S., Sincy Varghese, Bharath H. Aithal, 2014. Integrated Wetlands Ecosystem: Sustainable Model to Mitigate Water Crisis in Bangalore, ENVIS Technical Report 76, Environmental Information System, CES, Indian Institute of Science, Bangalore 560012

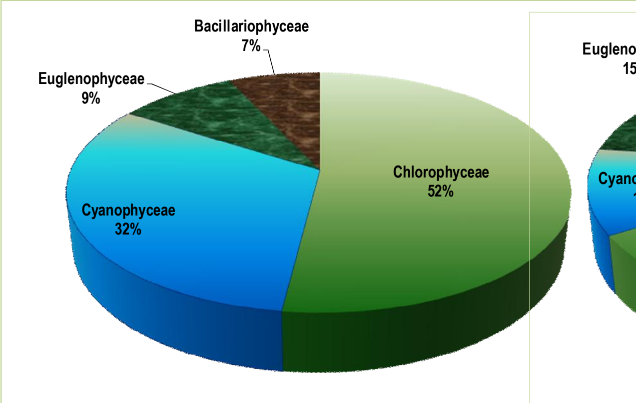


Figure 5: Composition of algae in Man Made Wetland System

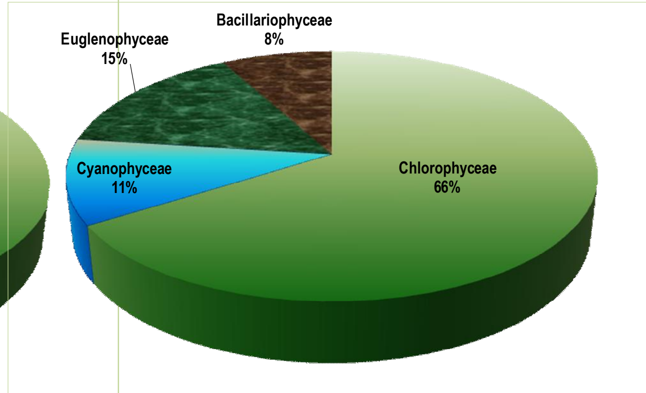


Figure 6: Composition of algae in Jakkur Lake

Similarly macrophytes play an important role in the effluent stabilisation. Table 5 lists the prominent macrophytes of wetlands ecosystem at Jakkur. The distribution of the macrophytes in the wetland area as well as at the outfalls of the lake is provided in Figure 7. *Typha augustata* species were dominating (54%) in the wetland area followed by *Alternanthera philoxeroides* (28%). However even though the macrophyte population was scarce in the lake, but still amongst them *Eicchornia crassipes* (84%) were dominating (Figure 8), which were only restricted to the outlet reaches due to fish nets, deployed for fishing in core area.

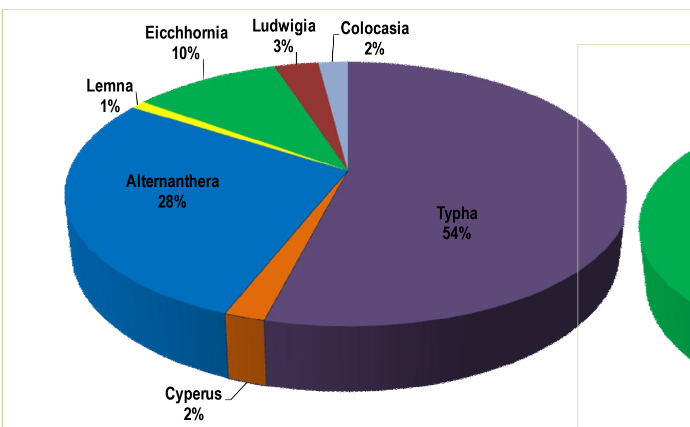


Figure 7: Composition of Macrophytes in Man Made Wetland System

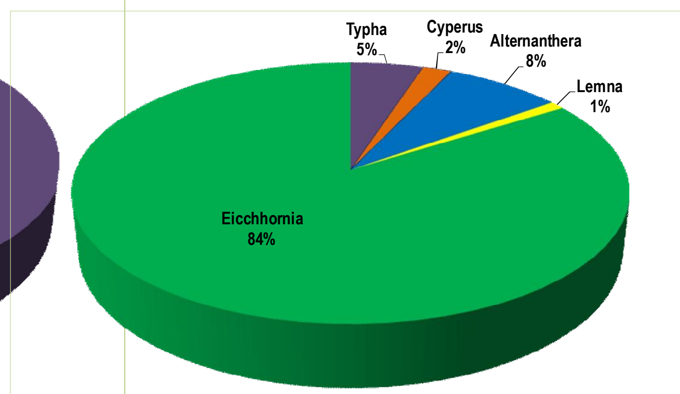


Figure 8: Composition of Macrophytes in Jakkur Lake

Table 5: Macrophytes of Wetlands at Jakkur

Name: *Alternanthera philoxeroides* **Common name:** Alligator weed **Habitat:** grow in a variety of habitats, including dry land but usually found in water(Shallow water or wet soils, ditches, marshes, edges of ponds and slow-moving watercourses) These grow best under high-nutrient (eutrophic) conditions **Stems** are pinkish, long, branched, and hollow. Fleshy, succulent stems can grow horizontally and float on the surface of the water, forming rafts, or form matted clumps which grow onto banks **Leaves** are simple, elliptic, and have smooth margins. They are opposite in pairs or whorls, with a distinctive midrib, and range in size from 5-10 cm. **Flowers:** Whitish, papery ball-shaped flowers that grows on stalks. Fibrous roots arising at the stem nodes may hang free in water or penetrate into the sediment/soil. **Flowering:** December-April **Harvesting period:** May **Impact:** Alligator weed disrupts the aquatic environment by blanketing the surface and impeding the penetration of light. Such blanketing can also prevent gaseous exchange (sometimes leading to anaerobic conditions) which adversely affects aquatic flora and fauna. It also competes with and displaces native flora along river and in wetlands	 
Name: *Typha* **Common name:** Cattail **Description:** It is a common perennial marsh, Aquatic or wetland plant in temperate, tropical, and subtropical climates. Plants are rhizomatous monoecious herb, grow upto 1.5-3m high, **Leaves** radical, sheath white. Flowering stem length is typically equal to or somewhat longer than leaf length. Numerous tiny, dense, flowers occur in a terminal spike that is 0.7 to 2 inches, Male flowers make up the upper, narrower half of the spike and female flowers the lower, slightly wider half **Flowering:** June- August **Harvesting period:** September **Habitat:** It grows in shallow water of lakes, rivers, ponds, marshes, and ditches. These species grow vigorously under eutrophic conditions and in low nutrient wetlands, they grow sparsely. **Significance:** Phytoremediation, wastewater treatment, Used as medicine, fodder	

<table>
<tr>
<td>
Name: Lemna
Common name: Common duckweed
Lemna minor: free-floating aquatic plants, with one, two or three leaves each with a single root hanging in the water; as more leaves grow, the plants divide and become separate individuals. The root is 1-2 cm long. The leaves are oval, 1-8 mm long and 0.6-5 mm broad, light green, with three (rarely five) veins, and small air spaces to assist flotation. It propagates mainly by division, and flowers rarely produced.
Habitat: Grows in water with high nutrient levels and a pH of between 5 and 9, optimally between 6.5 and 7.5, and temperatures between 6 and 33 °C.
Significance: Important food resource for fish and birds(ducks)
</td>
<td>

Lemna minor

Lemna gibba
</td>
</tr>
<tr>
<td>
Name: Cyperus
It is a perennial plant, which may reach a height of up to 40 cm.
Common name: nut grass, nut sedge
Habitat: Cyperus is found in cultivated fields, farmlands, neglected areas, wastelands, grasslands, at the edges of forests, and on roadsides, sandy or gravelly shores, riverbanks and irrigation canal banks. Grow profusely in nutrient rich environment.
Leaves: Leaves sprout in ranks of three from the base of the plant. The flower stems have a triangular cross-section. The flower is bisexual and has 3 stamina and a three-stigma carpel. The fruit is a three-angled achene.
Rhizome: The root system of a young plant initially forms white, fleshy rhizomes. Some rhizomes grow upward in the soil, then form a bulb-like structure from which new shoots and roots grow, and from the new roots, new rhizomes grow. Other rhizomes grow horizontally or downward, and form dark reddish-brown tubers or chains of tubers.
Harvesting period: November/December
Impacts/significance: It is a weed and the world's worst invasive weed based on its distribution and effect on crops. It contains several chemical compounds and used in medicines.
</td>
<td>


</td>
</tr>
</table>

Name: *Ludwigia* **Common name:** Water Primrose, Water Dragon, marshy jasmine **Habitat:** Still or slow flowing freshwater habitats, occurring in marshes, swamps, ditches, ponds, and around lake margins, where they form dense floating mat. Shallow, nutrient-rich ponds, lakes, and drainage ditches provide ideal conditions for abundant growth of this weed. Aquatic floating herb, floats crowded at nodes, white **Leaves** alternate simple, ovate, obtuse entire **Flowers:** Axillary, solitary, peduncle 2.5 cm long, corolla 5, yellow, inserted on the rim of the disc, base narrow. **Flowering:** February-July **Harvesting period:** August **Impacts:** Once established, however, it forms dense, monotypic stands along shorelines and banks and then begins to sprawl out into the water and can form floating islands of vegetation. At this point, Ludwigia can clog waterways, damage structures and dominate native vegetation. Large accumulations of this species can lead to a depletion of oxygen levels in the water while also competing with native species for space and resources.	 
Name: *Colocasia* **Common name:** Green Taro, cocoyam **Habitat:** This species usually grows in wet fields and near the banks of ponds and streams. **Description:** plant is a perennial herb with clusters of long heart- or arrowhead-shaped leaves It produces heart shaped leaves 2-3 ft long and 1-2 ft across on 3 ft long stalks that all emerge from an upright tuberous rootstock, corm. The stems are usually several feet high. Plant bears a short underground stem called a corm, where the plant stores starch produced by the leaves. The inflorescence is a pale green spathe and spadix Flowers tiny, densely crowded on upper part of fleshy stalk, with female flowers below and male flowers above. Fruit a small berry, in clusters on the fleshy stalk. **Significance:** the plant is used for several purposes across the worlds such as fodder, medicine or as an ornamental plant	 

Name: *Eichhornia crassipes* **Common Name:** Water hyacinth **Description:** Water hyacinth is a free-floating perennial aquatic plant, with broad, thick, glossy, ovate leaves; leaves are 30-40 cm long with spongy petiole. Roots are fibrous and featherlike. **Flowering:** March-July **Harvesting period:** August **Habitat:** Water hyacinth grows in still or slow-flowing fresh water in tropical and temperate climates. Optimum growth occurs at temperatures of between 28°C and 30°C, and requires abundant nitrogen, phosphorus and potassium. **Impact:** Its wide spread occurrence in the fresh water lakes and riverbeds is harmful to fishing (depleting DO), rowing, and depleting water content from the water bodies and interfering in water utilization and other activities. Water hyacinth by its abundance of leaves, dense vegetation and innumerable rootlets in tertiary manner obstruct water flow in irrigation channels and displaces many aquatic grasses, which were useful as fodder for cattle, and suppresses the phytoplankton growth. Water hyacinth provides suitable breeding places for mosquitoes and other disease-carrying insects by stagnating the water in ditches and shallow areas. **Uses**: Phytoremediation, wastewater treatment	 

7.0 Land use (LU) Dynamics in Wetlands Catchment

Land use changes in the wetland catchments are the direct and indirect consequence of human actions to secure essential resources. These changes encompass the greatest environmental concerns of human populations today, including loss of biodiversity, pollution of water and soil, and changes in the climate. Monitoring and mitigating the negative consequences of LU changes, while sustaining the production of essential wetlands resources has therefore become a major priority today.

Land use change analyses is done using Landsat MSS (1973), IRS P6 data (2013) and Google Earth (http://earth.google.com). The Landsat data is cost effective, with high spatial resolution and freely downloadable from public domains like GLCF (http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp) and USGS (http://glovis.usgs.gov/). IRS P6 LISS-IV (Indian Remote Sensing Satellite, part of the Indian Space Programme) data was procured from the National Remote Sensing Centre, Hyderabad (http://www.nrsc.gov.in).

Remote sensing data obtained were geo-referenced, rectified and cropped corresponding to the study area. Geo-registration of remote sensing data (Landsat data) has been done using ground control points collected from the field using pre calibrated GPS (Global Positioning System) and also from known points (such as road intersections, etc.) collected from geo-referenced topographic maps published by the Survey of India. In the correction process numerous GCP's are located in terms of their two image coordinates; on the distorted image and in terms of their ground coordinates typically measured from a map or located in the field, in terms of UTM coordinates as well as latitude and longitude. The Landsat data of 1973 are with a spatial resolution of 57.5 m x 57.5 m (nominal resolution), while IRS P6 are of 5.8 m.

Land use analyses involved (i) generation of False Color Composite (FCC) of remote sensing data (bands–green, red and NIR). This composite image helps in locating heterogeneous patches in the landscape, (ii) selection of training polygons by covering 15% of the study area (polygons are uniformly distributed over the entire study area) (iii) loading these training polygons co-ordinates into pre-calibrated GPS, (vi) collection of the corresponding attribute data (land use types) for these polygons from the field. GPS helped in locating respective training polygons in the field, (iv) supplementing this information with Google Earth and (v) 60% of the training data has been used for classification, while the balance is used for validation or accuracy assessment. The land use analysis was done using supervised classification technique based on Gaussian maximum likelihood algorithm with training data (collected from field using GPS).

Classifier based on Gaussian Maximum Likelihood algorithm has been widely applied as an appropriate and efficient classifier to extract information from remote sensing data. This approach quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel of remote sensing data, assuming the distribution of data points to be Gaussian. After evaluating the probability in each category, the pixel is assigned to the most likely class (highest probability value). **GRASS GIS *(Geographical Resources Analysis Support System***, http://ces.iisc.ernet.in/grass***)*** a free and open source software with the robust support for processing both vector and raster data has been used for analyzing RS data. Temporal remote sensing data have been classified through supervised classification techniques by using available multi-temporal "ground truth" information. Earlier time data were classified using the training polygon along with attribute details compiled from the historical published topographic maps, vegetation maps, revenue maps, land records available from local administrative authorities.

Figure 9: Land use dynamics in Jakkur lake catchment

1973 (57M) 2013 (2.7M)

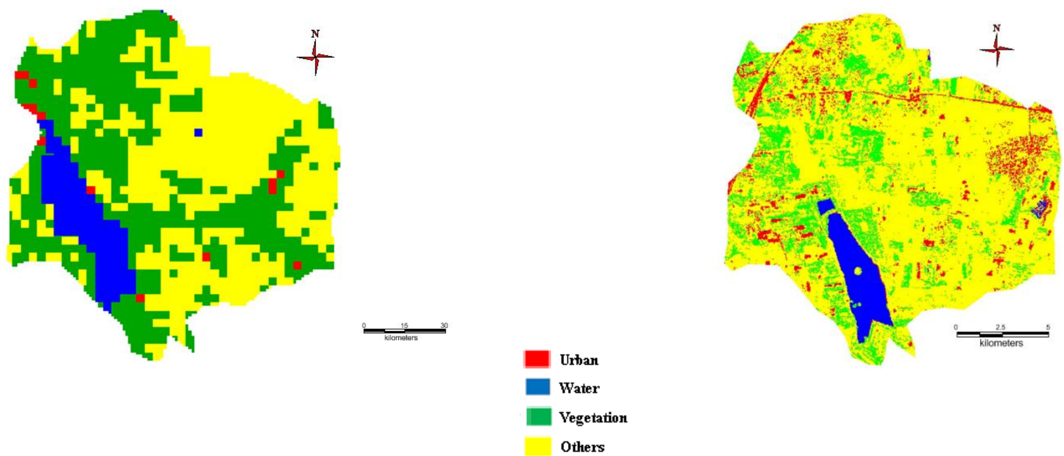


Table 6: Land use changes in Jakkur lake catchment (1973 -2013)				
Land Use categories (%)				
Years	**Urban**	**Vegetation**	**Water**	**Others**
1973	1.19	44.06	5.63	49.1
2013	6.56	22.38	4.79	65.81
% Change	5.37	-21.68	-0.84	18.71

Temporal remote sensing data of Landsat (1973) and IRS data (2013) were classified into four land use categories (**Figure 9**): tree vegetation, built-up, water-bodies and others (agriculture, open area, etc.). The analyses show decline of tree vegetation by 50% from 44.06% (1973) to 22.38% (2013), with an increase in built-up from 1.19 (1973) to 6.56% (2013). Details of land use analyses are listed in Table 6.

8.0 Integrated Wetlands Ecosystem: Sustainable Model to Mitigate Water Shortage in Bangalore

Performance assessment of an integrated wetland ecosystem at Jakkur provides vital insights towards mitigating water crisis in Bangalore. An integrated system as outlined in Figure 10. The integration of sewage treatment plant with wetlands (consisting of reed bed and algal pond) has helped in sustained treatment of water for reuse.

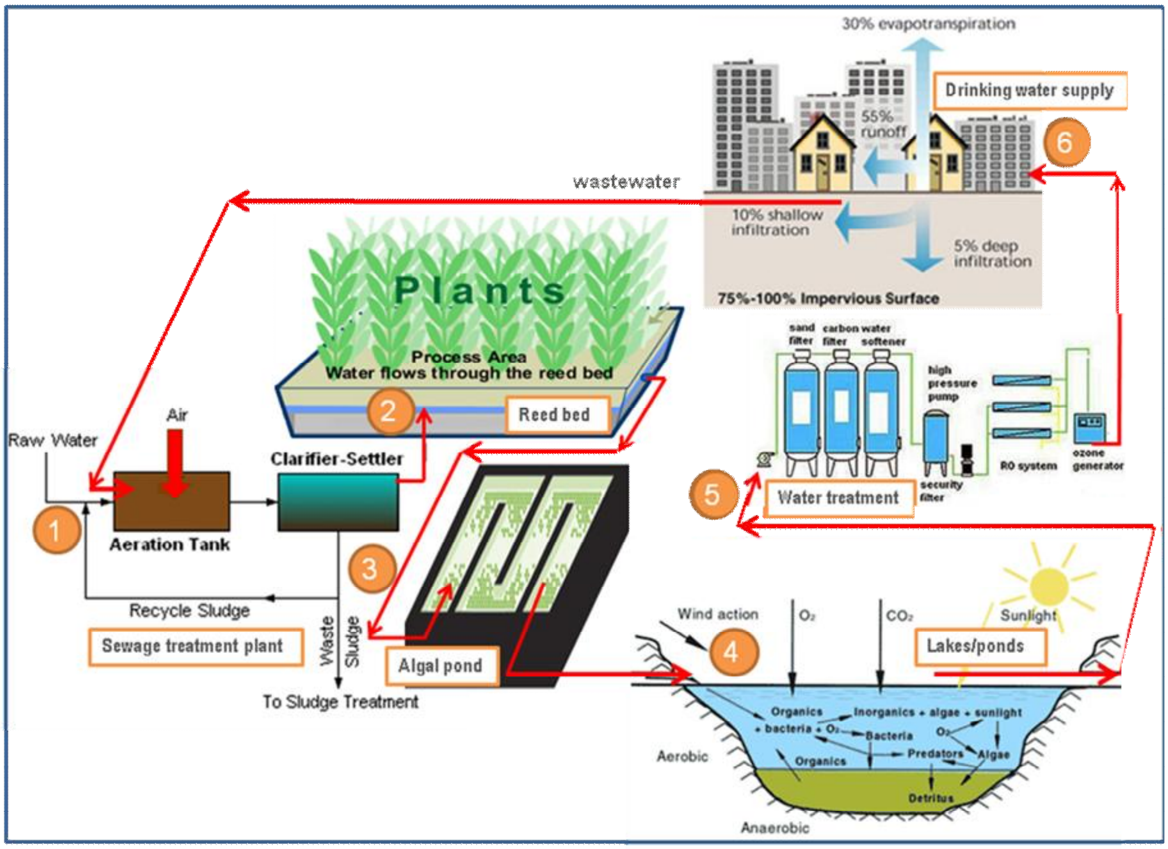


Figure 10: Integrated wetlands system for managing water and wastewater

8.1 Functional aspects of the integrated wetlands systems are:

- Sewage Treatment Plant (STP): The purpose of sewage treatment is to remove contaminants (Carbon and solids) from sewage to produce an environmentally safe water. The treatment based on physical, chemical, and biological processes include three stages – primary, secondary and tertiary. Primary treatment entails holding the sewage temporarily in a settling basin to separate solids and floatables. The settled and floating materials are filtered before discharging the remaining liquid for secondary treatment to remove dissolved and suspended biological matter. STP's effluents were still nutrient rich requiring further treatment (for nutrient removal) and stabilization for further water utilities in the vicinity.

- Integration with wetlands [consisting of reed (typha etc.) beds and algal pond] would help in the complete removal of nutrients in the cost effective way. A nominal residence time (~5 days) would help in the removal of pathogen apart from nutrients. However, this requires regular maintenance of harvesting macrophytes and algae (from algal ponds). Harvested algae would have energy value, which could be used for biofuel production. The wetland systems helps in the removal of ~77 % COD, ~90% BOD, ~33% NO_3-N and ~75% PO_4^{3}-P (Figure 11).

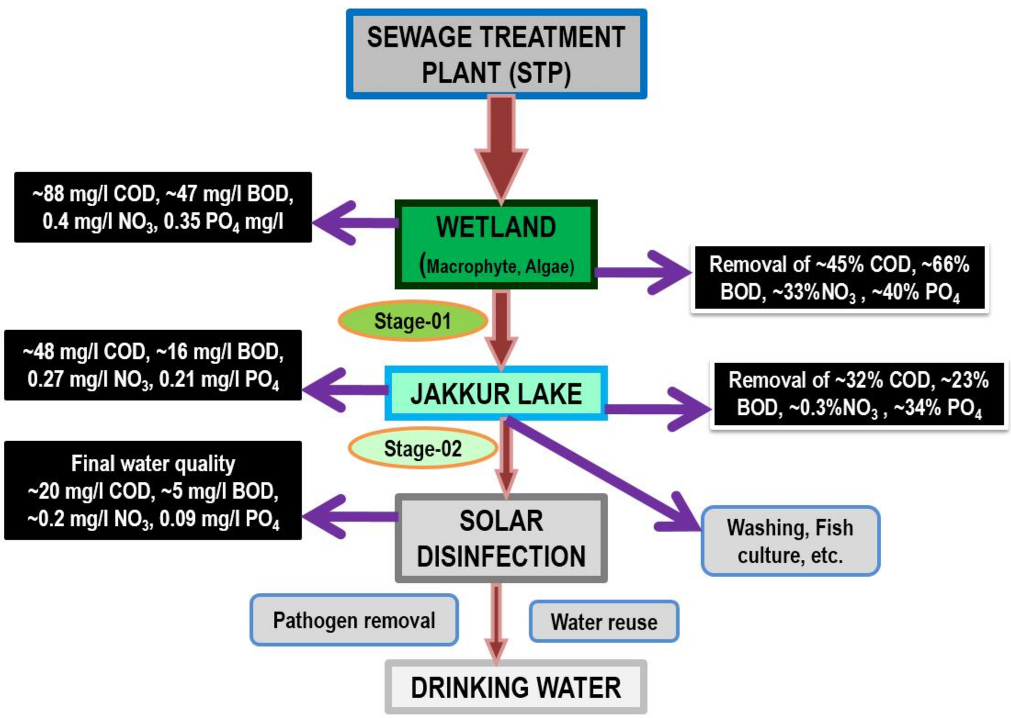


Figure 11: Level of treatment at various stages of integrated wetlands system

Pilot scale experiment in the laboratory has revealed nutrient removal of algae are 86%, 90%, 89%, 70% and 76% for TOC, TN, Amm.-N, TP and OP respectively (Figure 11) and lipid content varied from 18-28.5 % of dry algal biomass. Biomass productivity is of ~122 mg/l/d and lipid productivity of ~32 mg/l/d. Gas chromatography and mass spectrometry (GC-MS) analysis of the fatty acid methyl esters (FAME) showed a higher content of desirable fatty acids (biofuel properties) with major contributions from saturates such as palmitic acid

[C16:0; ~40%], stearic acid [C18:0; ~34%] followed by unsaturates as oleic acid [C18:1(9); ~10%] and linoleic acid [C18:2(9,12); ~5%]. The decomposition of algal biomass and reactor residues with calorific exothermic heat content of 123.4 J/g provides the scope for further energy derivation (Mahapatra et al., 2014). Water that comes out of the wetlands is portable with minimal efforts for pathogen removal via solar disinfection.

Our earlier experiments have shown the vital role of wetlands in recharging the groundwater resources, evident from the decline of groundwater table to 200-300 m from 30 to 50 m with the removal of wetlands. This means, Jakkur lake system is helping in recharging the groundwater sources. There need to be regulation on the exploitation of groundwater in Bangalore. Over exploitation of groundwater through borewells by commercial private agencies would harm the sustainability, depriving the local residents in the vicinity who are dependent on borewells in the absence of piped water supply from the government agency.

Measures required to mitigate water crisis in burgeoning Bangalore are:

1. Rainwater harvesting at decentralized levels through wetlands (lakes) is the most efficient and cost effective mechanism to address the water crisis in the region than technically infeasible, ecologically unsound and economically unviable river diversion or inter linking of river schemes being proposed by vested interests in various parts of the country.
2. Rejuvenation, restoration of existing lakes. This is necessary to decontaminate water bodies due to the unabated inflow of effluents and sewage.
3. Removal of deposited silt would enhance the storage capacity as well as bioremediation capability of lakes.
4. Integrated wetlands ecosystem (consisting of reed bed (typha, etc.), algal pond) with lake helps in the treatment of water entering the lake through bioremediation. Replicating Jakkur wetland ecosystem would help in the treatment of water and reuse. This also has an added advantage of maintaining groundwater quality in the vicinity. Studies have shown that groundwater sources in the vicinity of sewage fed lakes are contaminated, evident from the nutrient enrichment, presence of coliform, etc.
5. Sustainable management of integrated wetlands ecosystem includes
   i). Letting only treated sewage to wetlands.

ii). Maintaining at-least 33% vegetation cover in the lake catchment. This is necessary to ensure sufficient infiltration of rainwater to ensure water in the lake throughout the year.

iii). Ban on number of borewells (or extraction of groundwater) in the lake catchment and command area

iv). Restriction on overexploitation of groundwater in the lake catchment to ensure sustained water availability to the local residents

v). Regular harvesting of macrophytes

vi). Mechanism to harvest algae at regular interval and manufacture of biofuel and other beneficial biochemical products. These would enhance the employment opportunity in the region.

vii). Provision of appropriate infrastructure for washer men who depend on the lake for livelihood through washing clothes.

viii). Restriction on the introduction of exotic species of fish by commercial vendors

ix). Permission to scientific fish culturing through strict regulations (on fish species introduction, type of nets, frequency of harvesting, restrictions during breeding season and locations)

9.0 Conclusion

Surface water-bodies (lakes, ponds, tanks, etc.) in Bangalore are subjected to high nutrient loads due to the sustained inflow of untreated or partially treated sewage, altering physico-chemical and biological integrity of water bodies. The treated water from sewage treatment plant in Jakkur still contains nutrients as primary and secondary treatment does not completely remove nutrients. However, passage of STP effluents through wetlands (consisting of emergent macrophytes and algal pond) ensures removal of nutrients to an extent ensuring portability of water. This study investigates the water quality at different stages in the integrated wetland system. Physico-chemical and biological parameters were monitored as water enters the algal pond (wetland) from the STP (sewage treatment plant), outlet of wetlands and at the inlet, middle and outlets of Jakkur Lake. The nutrient analysis highlights of nutrient removal by wetlands due to macrophytes and algae, which removes 77 % COD, ~90 % BOD, ~33 % NO_3-N and ~75 % PO_4^{3-}-P. The first stage comprising of emmergent vegetataion and algal pond removes ~45% COD, ~66 % BOD, ~33 % NO_3-N and ~40 %

PO_4^{3-}P. Jakkur lake as a seconf stage treats the water and acts as the final level of treatment and removes ~ 32 % COD, ~23% BOD, ~ 0.3 % NO_3-N and ~34 % PO_4^{3-}P.The combination of all the stages leads to a complete removal of nutrients to acceptable levels according to CPCB norms. This study provided vital insights towards environmentally sound option of managing wastewater, while addressing water crisis due to unscientific and chaotic urbanisation in Bangalore.

Acknowledgement:

We are grateful to the NRDMS Division, the Ministry of Science and Technology (DST), Government of India, The Ministry of environment and Forests (MoEF), Government of India and Indian institute of Science for the financial and infrastructure support. We thank Vishwantah S, Rainwater Club (*http://*www.rainwaterclub.org) for suggestions during the discussion, which helped in initiating this study.

10.0 References

1. Amengual-Morro, C., Moya-Niell, G., & Martinez-Taberner, A.(2012). Phytoplankton as bioindicator for waste stabilization ponds. Journal of Environmental Management,95: 71 – 76.
2. APHA (1998): Standard Methods (20 Ed.) for the examination of water and waste water, APHA, AWWA, WPCE, Washington DC.
3. Benjamin R, Chakrapani BK, Devashish K, Nagarathna AV, Ramachandra TV (1996) Fish mortality in Bangalore Lakes, India. Electronic Green Journal 1(6).
4. Durga Madhab Mahapatra, Chanakya H N and Ramachandra T V, 2014. Bioremediation and lipid synthesis through Myxotrophic Algal Consortia in Municipal Wastewater, Bioresource Technology, http://dx.doi.org/10.1016/j.biortech.2014.03.130
5. Durga Madhab Mahapatra, Chanakya H.N. and Ramachandra. T.V, 2013(a). Treatment efficacy of algae-based sewage treatment plants. Environmental Monitoring and Assessment, pp. 1-20.
6. Durga Madhab Mahapatra, Chanakya H.N. and Ramachandra. T.V, 2013(b). Euglena sp. as a suitable source of lipids for potential use as biofuel and sustainable wastewater treatment., Journal of Applied Phycology, pp. 1-11.
7. Durga Madhab Mahapatra, Chanakya H. N and T. V. Ramachandra, 2011a, Assessment of Treatment capabilities of Varthur Lake, Bangalore. International Journal for Environment, Technology and Management. UNESCO. 14, 1-4:84-102
8. Durga Madhab Mahapatra, Chanakya H.N., Ramachandra. T.V., 2011b. Role of macrophytes in a sewage fed urban lake. Institute of Integrative Omics and Applied Biotechnology Journal (IIOABJ), Vol. 2, Issue 8, pp.
9. Department of mines and Geology (2011). Groundwater hydrology and groundwater quality in and around Bangalore city.

10. Ganapati S, Amin P (1972) Studies on algal-bacterial symbiosis in low cost waste treatment systems. In Desikachary TV (ed.) Taxonomy and Biology of Blue-green Algae. University of Madras, Madras: 483–493.
11. Garcia J, Mujeriego R, & Hernandez-Marin M., (2001) High rate algal pond operating strategies for urban wastewater nitrogen removal, Journal of Applied Phycology 12: 331-339.
12. Garcia J, Rousseau D P L, Morato J, Lesage E, Matamoros V and Bayona J M. 2010. Contaminant Removal Processes in Subsurface-Flow Constructed Wetlands: A Review. Critical Reviews in Environmental Science and Technology. 40(7):561-661.
13. Government of India, 2008. Groundwater Information Booklet, Bangalore Urban District, Karnataka. http://cgwb.gov.in/district_profile/karnataka/bangalore_urban_brochure.pdf.
14. Karin Larsdotter (2006). Wastewater treatment with Microalgae- A literature review, Vatten 62: 31-38.
15. Kiran. R. and Ramachandra. T.V., 1999. Status of Wetlands in Bangalore and its Conservation aspects. ENVIS Journal of Human Settlements, March 1999: 16-24
16. Oswald WJ (1988) The role of microalgae in liquid waste treatment and reclamation. In Borowitzka MA, Borowitzka LJ (eds), Micro-algal Biotechnology. Cambridge U.P., Cambridge: 255–282.
17. Prescott, G.W. (1973). The Freshwater Algae: The Pictured Key Nature series. William C. Brown and Co., Dubuque, IA.
18. Prescott, G.W. (1982). Algae of the Western Great Lakes Area. Second Edition. Otto Koeltz Science Publishers, Koenigstein.
19. Ramachandra T V, Mahapatra D M, Shilpi Samantray and Joshi N V, 2013a. Algal biofuel from urban wastewater in India: Scope and challenges, renewable and Sustainable Energy review, 21 (2013): 767–777, http://dx.doi.org/10.1016/j.rser.2012.12.029
20. Ramachandra T V, Bharath H. Aithal, Vinay S and Aamir Amin Lone, 2013b, Conservation of Bellandur Wetlands: Obligation of Decision Makers to ensure Intergenrational Equity, ENVIS Technical Report: 55, ENVIS- Environmental Information System, Centre for Ecological Sciences, Indian Institute of Science, Bangalore
21. Ramachandra. T.V., Bharath H. Aithal and Durgappa D. Sanna, 2012a. Insights to Urban Dynamics through Landscape Spatial Pattern Analysis., International Journal of Applied Earth Observation and Geoinformation, Vol. 18, Pp. 329-343.
22. Ramachandra T V, Bharath H. Aithal and Uttam Kumar, 2012b. Conservation of wetlands to mitigate urban floods, Resources, Energy, and Development 9(1): 1–22
23. Ramachandra T V, Alakananda B, Ali Rani and Khan M A, 2011. Ecological and socio-economic assessment of Varthur wetland, Bangalore, Journal of Environmental Science and Engineering, 53(1): 101-108
24. Ramachandra T V, 2010. Wetlands: Need for appropriate stratergies for conservation and sustainable management, Journal of Basic and Applied Biology, 4(3):1-17.
25. Ramachandra T V and Uttam Kumar, 2010. Greater Bangalore: Emerging Heat Island, GIS for Development, 14(1): 86-104 http://www.gisdevelopment.net/application/urban/sprawl/Greater-Bangalore-Emerging-Urban-Heat-Island.htm
26. Ramachandra T V, 2009a, Conservation and management of urban wetlands: Strategies and challenges, ENVIS Technical Report: 32, Environmental Information System, Centre for Ecological Sciences, Bangalore
27. Ramachandra T V, 2009b. Essentials in urban lake monitoring and management, CiSTUP Technical report 1, Urban Ecology, Environment and Policy Research, Centre for Infrastructure, Sustainable Transportation and Urban Planning, IISc, Bangalore

28. Ramachandra T.V. and Uttam Kumar.(2008). Wetlands of Greater Bangalore, India: Automatic Delineation through Pattern Classifiers, Electronic Green Journal Issue 26 Spring 2008.
29. Ramachandra T.V., Sudhira H.S., Karthick B. and Avinash K.G., 2007. Environmental Impact of Developmental Activities in the Bellandur Lake Catchment, ENVIS Technical Report: 27, Environmental Information System, Centre for Ecological Sciences, Bangalore
30. Ramachandra T.V. and Sudhira H.S. 2007. Present Status of Gottigere Tank: Indiactor of Decision Maker's Apathy, ENVIS Technical Report: 26, Environmental Information System, Centre for Ecological Sciences, Bangalore
31. Ramachandra T V and Malvikaa Solanki, 2007. Ecological assessment of Lentic Waterbodies of Bangalore, ENVIS Technical Report 25, Environmental Information System, Centre for Ecological Sciences, Bangalore
32. Ramachandra T.V., Ahalya N. and Mandy Payne, 2003. Status of Varthur lake: Opportunities for Restoration and Sustainable management, CES Technical report No 102, Centre for Ecological Sciences, Bangalore.
33. Ramachandra T.V. and Rajinikanth R. 2003. Economic valuation of wetlands, , CES Technical report No 101, Centre for Ecological Sciences, Bangalore.
34. Ramachandra, T.V. 2002. Restoration and Management Strategies of Wetlands in Developing Countries, *The Greendisk Environmental Journal*. (International Electronic Jour. URL: http://egj.lib.uidho.edu/egj15/ramacha1.html)
35. Raj, K. (2013). Sustainable Urban Habitats and Urban Water Supply: Accounting for Unaccounted for Water in Bangalore City, India. Scientific Research - Current Urban Studies, Vol.: 1 (4), pp. 156-165.
36. Sharachchandra Lele, Srinivasan, V., Jamwal P., Thomas B. K., Eswar M. and Zuhail T. Md. (2013). Water management in ARKAVATHY basin a situation analysis. Environment and Development Discussion Paper No. 1.
37. Sawkar, R. H. (2012). Evaluation of Surface, Ground and Sewage Water for Sustainable Supply of Potable Water to Bengaluru. NEWS AND NOTES, Journal Geological Society of India. Vol: 80.
38. Sawyer CN, McCarty PL (1978) Chemistry for environmental engineering, 3rd edn. McGraw-Hill Book Company, New York.

Macrophytes of Wetlands at Jakkur	
	
	
	
	






Outlet of the lake - people washing clothes (S1)

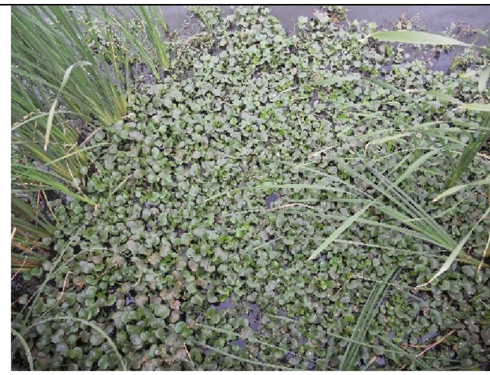

Second Outlet (S2)


Macrophyte cover before outlet


Inlet from treatment plant(treated water in channel and untreated beside)


Inlet to the lake after algae pond(with macrophytes)


Algae and macrophyte in the algae pond(wetland)



ENERGY AND WETLANDS RESEARCH GROUP, CES TE15
CENTRE FOR ECOLOGICAL SCIENCES,
New Bioscience Building, Third Floor, E Wing
Near D Gate, INDIAN INSTITUTE OF SCIENCE, BANGALORE 560 012

Telephone: 91-80-22933099/22933503 extn 107
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