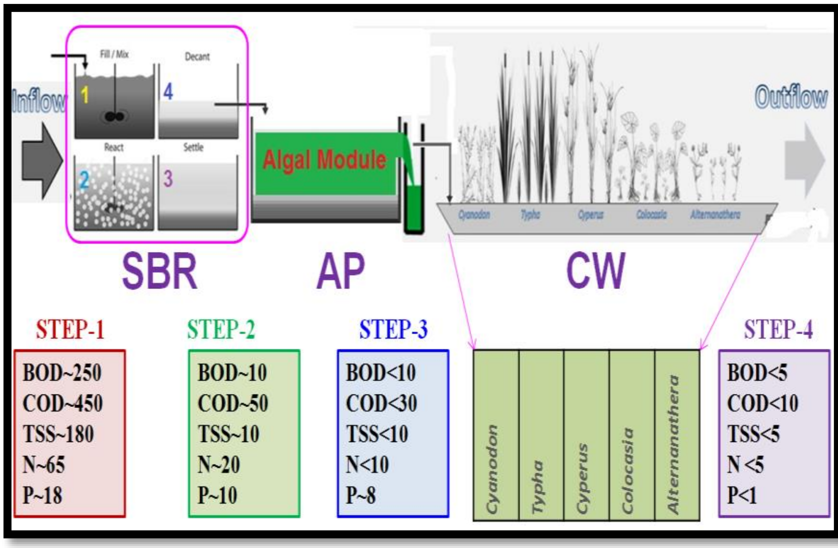
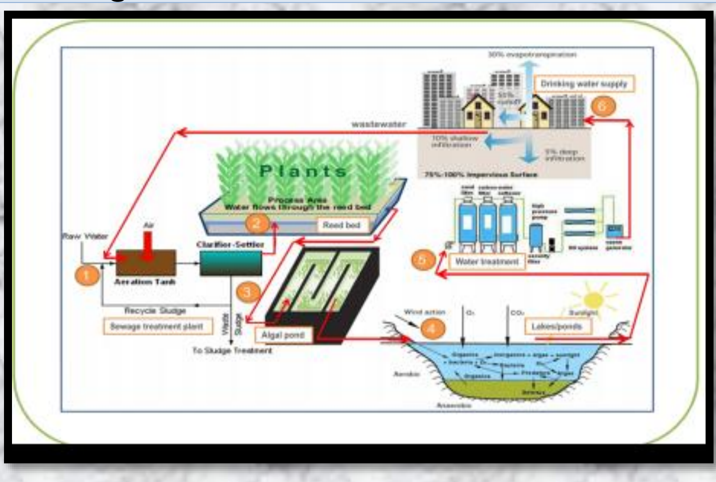
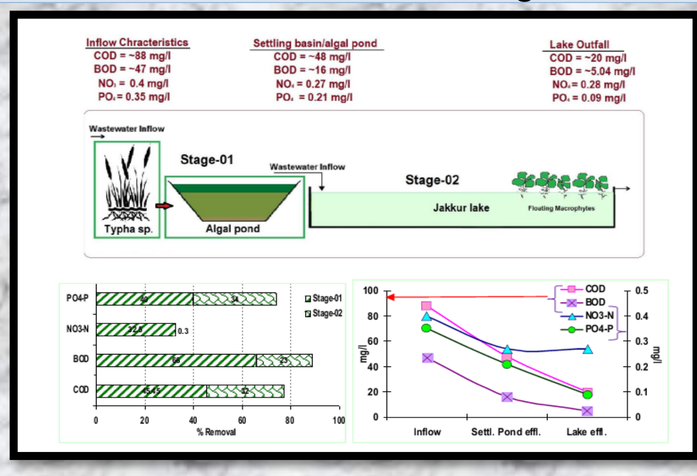
Bellandur and Varthur Lakes Rejuvenation Blueprint

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



Integrated Constructed Wetlands - Wastewater Treatment for Bellandur Sewage influx





Gautam and Vasantha Jagadisan Endowment– Lake Rejuvenation

The Ministry of Science and Technology, Government of India
The Ministry of Environment, Forests & Climate Change, Government of India
Indian Institute of Science, Bangalore 560012

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Energy & Wetlands Research Group
Centre for Ecological Sciences, CES TE 15
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

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T V Ramachandra **Durga Madhab Mahapatra** **Vinay S**
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22nd April 2017 – *International Mother Earth Day*
Dedicated to the Residents of Varthur and Bellandur Lakes catchment

Gautam and Vasantha Jagadisan Endowment– Lake Rejuvenation
The Ministry of Science and Technology, Government of India
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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
https://www.researchgate.net/profile/T_V_Ramachandra/publications

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Bellandur and Varthur Lakes Rejuvenation Blueprint

- Rejuvenate Bellandur and Varthur Lakes together;
- **Stop Pollution** – only treated sewage shall enter the lake. Sewage treatment through integrated constructed wetlands (similar to Jakkur Model – Secondary Treatment Plant (STP) + Constructed Wetlands + Algae ponds, will remove nutrients, etc.);
- **No diversion of sewage** from upstream to downstream regions and de-centralized treatment and reuse of treated sewage;
- **Remove all blockades** at outlets as well as inlets– so that water will not stagnate, which will enhance aeration in the water body;
- **Remove all encroachments** without any considerations or political interventions (lake bed, storm water drains, buffer zone);
- **Recover the area identified for setting up STP (40 acres as per RMP 2015) in the region between Agaram and Bellandur lakes**
- **De-siltation** to enhance storage capacity and also to remove contaminated sediments; Adopt latest state of the art technology - wet dredging to remove deposited sediments;
- Implementation of '**polluter pays' principle** as per the water act 1974; Zero discharge from industries;
- Stop dumping of solid waste and construction & Demolition wastes in the lake bed, storm water drain;
- Remove macrophytes (covered on the water surface) regularly;
- Regular surveillance through vigilant resident groups and network of education institutions;
- Regular monitoring of treatment plant and lake water quality (physical, chemical and biological) and the availability of information to the public through internet;
- Install fountains (with music and LED) to enhance surface aeration and recreation value of the ecosystem;
- No introduction of exotic species of fauna (fish, etc.);
- Identify Local NGO for regular maintenance and Management;
- Public Participation: Decentralised management of lakes through local lake committees involving all stakeholders - Involve local stakeholders in the regular maintenance and management;
- **Ban on use of phosphates** in the manufacture of detergents; will minimise frothing and eutrophication of water bodies;
- **Digitation of land records** (especially common lands – lakes, open spaces, parks, etc.) and availability of this geo-referenced data with query based information system to public;
- **Implementation of 'polluter pays'** principle as per water act 1974;
- Planting native species of macrophytes in the buffer zone (riparian vegetation) as well as in select open spaces of lake catchment area;
- Restrictions on the diversion of lake for any other purposes;
- NO construction activities in the valley zones;
- Good Governance - Single agency with the statutory and financial autonomy to be the custodian of natural resources [ownership, regular maintenance and action against polluters (encroachers as well as those contaminate through untreated sewage and effluents, dumping of solid wastes)]. Effective judicial system for speedy disposal of conflicts related to encroachment.
- Efficient Local administration through elimination of Land, water and Waste Mafia.
- **Stop Unplanned Irresponsible Urbanisation – DECONGEST BANGALORE**

Bellandur and Varthur Lakes Rejuvenation Blueprint

EXECUTIVE SUMMARY

Lakes and water bodies also referred to as wetlands are one of the most productive ecosystems contributing to ecological sustainability thereby providing necessary linkages between land and water resources. The quality and hydrologic regime of these lakes and wetlands is directly dependent on the integrity of its watershed. In last couple of decades, rapid urbanization coupled with the unplanned anthropogenic activities has altered the wetland ecosystem severely across globe. Changes in land use and land cover (LULC) in the wetland catchments influence the water yield and water quality for the lakes. Apart from LULC changes, the inflow of untreated domestic wastewater, industrial effluents, dumping of solid wastes and rampant encroachments of catchment has threatened the sustenance of urban wetlands. This is evident from the nutrient enrichment and consequent profuse growth of macrophytes, impairing the functional abilities of the wetlands. Reduced treatment capabilities of the wetlands have led to the decline of native biodiversity, prevailing unhygienic conditions with mosquito menace, contamination of groundwater levels, affecting the livelihood of wetland dependent population. Decline in the services and goods of wetland ecosystems have influenced the social, cultural and ecological spaces as well as of water management. This necessitates a systematic lake rejuvenation paradigm and associated monitoring of wetlands to mitigate the impacts through appropriate management strategies. A combination of LULC analysis in the catchment using remote sensing data acquired through the space-borne sensors facilitates identification of valley zones and wetland area. This in turn aids in maintaining records for encroachment and consequent action. Factor like nature of the catchment, wastewater quality and quantity influx, garbage dumping etc. related to water quality are the most important pressure driving the productivity of these rapidly disappearing wetland systems and are reasons for today's dominance of exotic organisms with increasing heterogeneity of biotic components at an intermediate spatial and temporal scale. Nutrient (C, N and P) influx being the most significant reason for the present deterioration of these wetland and water bodies. Suitable catchment management practices with strategic control of untreated industrial and domestic effluents getting into these water bodies will be key for a sustainable city management plan. Recommended de-silting and de-weeding the water bodies, complete treatment of municipal and industrial wastewater, a ban in P use in detergents, removal of encroachments, fencing and green belt around the water bodies, and growth of essential N-rich aquatic vegetation for the livelihood of nearby dependent communities and provision to retain the natural floating islands for in-situ bioremediation. Further strategic planning needs to be adopted at the higher level for increase in consensus for optimal water usage, provisions for rain water harvesting, ground water recharge etc. for fostering sustainable city management.

Recommendations:

Short term / Immediate Action	
Current Status	Recommendations
1.Poor water quality	1. Regular harvesting of macrophytes – helps in curtailing nutrients accumulation (**ANNEXURE I,** spatial extent of macrophytes and productivity in Bellandur lake). 2. Improve aeration – (i) installing fountains, removing all blockages, (ii) widening and increasing number of channels / removal of blockades at outlets (**ANNEXURE II** – comparative assessment of aerators), 3. Stop dumping of municipal solid waste 4. Evict all waste processing units (in the vicinity of lakes and lake bed) 5. Stop dumping of construction and demolition (C & D) wastes in Rajakaluve, Valley zones and Lake beds 6. Strengthen legal cell (at BBMP, BDA, Forest Department, KLCDA) to address all illegalities and evolve fast track mechanism to speedy disposal and eviction of encroachers and for penalising polluters 7. No diversion of sewage from one locality to another. Decentralised treatment plants to handle sewage in the city (**Annexure III – sewage generated in the locality**). 8. Ensure that all apartments let only treated water to the lake. Implement mechanisms such as separate electric meters (net metering) and updating of details at respective resident association websites (including a copy at BWSSB web site) 9. Providing water quality details (each apartment discharge) – inflow to the lake at respective resident association websites (including a copy at BWSSB web site) 10. Functional ETP's to ensure zero untreated effluent discharges by industries. KSPCB to ensure zero untreated effluent discharges. 11. Evolving surprise environment audit mechanisms to ensure zero untreated effluent discharges to storm water drains (and lakes). Vetting of inspection report by the respective resident lake association. 12. Installation of surveillance cameras at the outlet of BWSSB STP (inlet of the lakes) and availability of electricity consumption details and surveillance camera streaming details to the public (through cloud sourcing or any other efficient and optimal mechanisms) 13. Formation of local residents association for each lake involving of all stakeholders to aid in regular monitoring and management. 14. Evolve mechanisms to make respective elected members (councillors, MLA and MP) and local ward engineers and bureaucrats accountable for lakes and open area status in their respective jurisdiction.
2. Physical integrity of lakes and storm water drains	1. Surveying and mapping of water body (including flood plains) and buffer zones (30 m as per BDA; 75 m as per NGT)

	2. Surveying and mapping valley zones (eco-sensitive zone as per RMP 2015, and green belt as per CDP 2005). Remove all encroachments without any consideration.
	3. Recover the area identified for setting up STP (40 acres as per RMP 2015) in the region between Agaram and Bellandur lakes
	4. Remove all encroachments (lake bed, Raja kaluves, storm water drains) to prevent calamities related to floods
	5. Identify the common lands, kharab lands, streams, drains, tracks and paths (as per cadastral / revenue maps) in K and C Valley and on priority between the Agara, Bellandur and Varthur Lakes. This land would be useful to setup waste water treatment plants (STP's) and constructed wetlands.
	6. Identify the areas required for setting up decentralised treatment plants (and if required mechanisms to acquire these lands for public utility)
3. Alteration in topography and unplanned concretisation	1. Refrain from granting any consent for establishment for large scale projects in these catchments with immediate effect (Bangalore is undergoing unplanned, un-realistic urbanisation)
4. Fragmented, un-co-ordinated lake Governance	1. Strengthen KLDCA – single agency / custodian to address all issues related to lakes (including maintenance, monitoring, management and removal of all illegalities) and interconnected drains. This helps in minimising fragmented governance. 2. Scientifically competent committee to address the lake issues.

Short and Long Term Measures

Current Status	Recommendations	Benefits
1. Untreated Sewage	1. No more untreated sewage diversions in the city. 2. Decentralised treatment of sewage (city sewage as well as local sewage in the vicinity of the lake). Model similar to Jakkur Lake – STP with constructed wetlands and algal ponds.	1. Removal of nutrients; 2. Helps in reuse of water; 3. Removal of contaminants; 4. Regulates nutrient enrichment; 5. Recharge of groundwater without any contaminants
2. Untreated Industrial Effluents	Enforcement of 'Polluter pays principle'. Ensure zero discharge through efficient effluent treatment plants.	1. Heavy metal will not get into food chain. Currently vegetables grown with the lake water has higher heavy metals 2. Less kidney failures and instances of cancer in the city
3. Nutrient enriched sediments	De-silting of lake (wet dredging / excavation).	1. Efficient mechanism of rainwater harvesting. Water yield in the catchment is 5.3 TMC and storage capacity of lakes is about 7.5TMC. 2. Increase the storage capacity 3. Enhances the groundwater recharging potential
4. Encroachment of lakebeds, valley zone and rajakaluves	Evict all encroachments.	1. Common lands would be available for setting up STP, wetlands 2. Removal of encroachments of Rajakaluves and drains would re-establish interconnectivity among

		lakes so that water would move from one lake to another, enabling treatment of water (through aeration)
5. Regular maintenance of macrophytes	Macrophytes harvesting at regular interval	1. Helps in further treatment of water as macrophytes uptake nutrients and regular harvesting would prevent accumulations 2. Supports livelihood of local people 3. Scope for generating energy (biogas)
6. Frothing and fire	i. Ban Phosphorus use in detergents or regulate detergent with Phosphorous in market ii. Decentralised treatment of sewage (city sewage as well as local sewage in the vicinity of the lake). Model similar to Jakkur Lake – STP with constructed wetlands and algal ponds.	1. Reduces eutrophication of lakes(nutrient enrichment 2. Minimises the instance of frothing 3. Minimises health issues (skin, respiratory, etc.) related to contaminated air; 4. Reduces accident instances

STOP UNPLANNED & IRRESPONSIBLE URBANISATION – DECONGEST BANGALORE

Cities' origin can be traced back to the river valley civilizations of Mesopotamia, Egypt, Indus Valley and China. Initially these settlements were largely dependent upon agriculture; however, with the growth of population the city size increased and the economic activity transformed to trading[1]. The process of urbanisation gained impetus with industrial revolution 200 years ago and accelerated in 1990's with globalization and consequent relaxations in market economy[2].

Urbanisation refers to the growth of the towns and cities due to large proportion of the population living in urban areas and its suburbs at the expense of rural areas[2]. In most of the countries the total population living in the urban regions has extensively accelerated since the Second World War. Rapid urbanisation during the 20th century is evident from the dramatic increase in global urban population from 13% (220 million, in 1900), to 29% (732 million, in 1950), to 49% (3.2 billion, in 2005) and is expected to increase to 60% (4.9 billion) by 2030 and 9.6 billion in 2050[2]. Current global population is 7.4 billion and urban population has been increasing three times faster than the rural population, mainly due to migration in most parts of the world. People migrate to urban areas with the hope of a better living, considering relatively better infrastructural facilities (education, recreation, health centres, banking, transport and communication), and higher per capita income. Unplanned urbanisation leads to the large scale land use changes affecting the sustenance of local natural resources. Rapid unplanned urbanisation in most cities in India has led to serious problems in urban areas due to higher pollution[3] (air, water, land, noise), inequitable distribution of natural resources, traffic congestion, spread of slums, unemployment, increased reliance on fossil fuels, and uncontrolled outgrowth or sprawl in the periphery. Urbanisation is one of the demographic issues being investigated in the 21st century, understanding spatial patterns of changes in the land and visualization in advance of growth is imperative for sustainable management of natural resources and to mitigate changes in climate[3]. This would help the city planners in planning to mitigate the problems associated with the increased urban area and population, and ultimately build sustainable cities.

Bangalore is experiencing unprecedented rapid urbanisation and sprawl in recent times due to unrealistic concentrated developmental activities with impetus on industrialisation for the economic development of the region[2]. This **has led to large scale land cover changes with serious environmental degradation,** posing serious challenges to the decision makers in the city planning and management process involving a plethora of serious challenges such as climate change, enhanced emissions of greenhouse gases (GHG)[3], lack of appropriate infrastructure, traffic congestion, and lack of basic amenities (electricity, water, and sanitation) in many localities, etc. Apart from these, major implications of urbanisation are:

- **Urbanisation and loss of natural resources (wetlands and green spaces):** Urbanisation during 1973 to 2016 (1005% concretization or increase of paved surface) has telling influence on the natural resources such as decline in green spaces (88% decline in vegetation), wetlands (79% decline), higher air pollutants and sharp decline in groundwater table. Figure 1 depicts the unrealistic urban growth during the last two decades. Quantification of number of trees in the region using remote sensing data with field census reveals that there are only 1.5 million trees to support Bangalore's population of 9.5 million, indicating one tree for every seven persons in the city[4]. This is insufficient even to sequester respiratory carbon (ranges from 540-900 g per person per day). Geo-visualisation of likely land uses in 2020 through multi-criteria decision making techniques (Fuzzy-AHP: Analytical Hierarchal Process) reveals calamitous picture of 93% of Bangalore landscape filled with paved surfaces (urban cover) and drastic reduction in open spaces and green cover. This would make the region GHG rich, water scarce, non-resilient and unlivable, depriving the city dwellers of clean air, water and environment.

  Field investigations (during 2015-16) of 105 lakes reveals that 98% lakes have been encroached for illegal buildings (high raise apartment, commercial building, slums, etc.) and 90% of lakes are sewage fed. Also, lake catchments are being used as dumping yards for either municipal solid waste or building debris. Indiscriminate disposal of solid and liquid waste (rich in organic nutrient) has enriched nitrate levels in the surrounding groundwater resources, threatening the residents' health (such as kidney failure, cancer, etc.). Washing, household activities, vegetable cultivation and even fishing was observed in few contaminated lakes. Unauthorised construction in valley zones, lakebeds and storm water drains highlight the apathy of decision makers while mirroring weak and fragmented governance. This is correlated with the increase in unauthorized constructions violating town planning norms (city development plan) which has affected severely open spaces and in particular water bodies.

Large-scale fish mortality in recent months further highlights the level of contamination and irresponsible management of water bodies. Sustained inflow of untreated sewage has increased the organic content beyond the threshold of remediation capability of respective water bodies. Increasing temperature (of 34 to 35 °C) with the onset of summer, enhanced the biological activities (evident from higher Ammonia and BOD -Biochemical Oxygen Demand) that lowered dissolved oxygen levels leading to fish death due to asphyxiation.

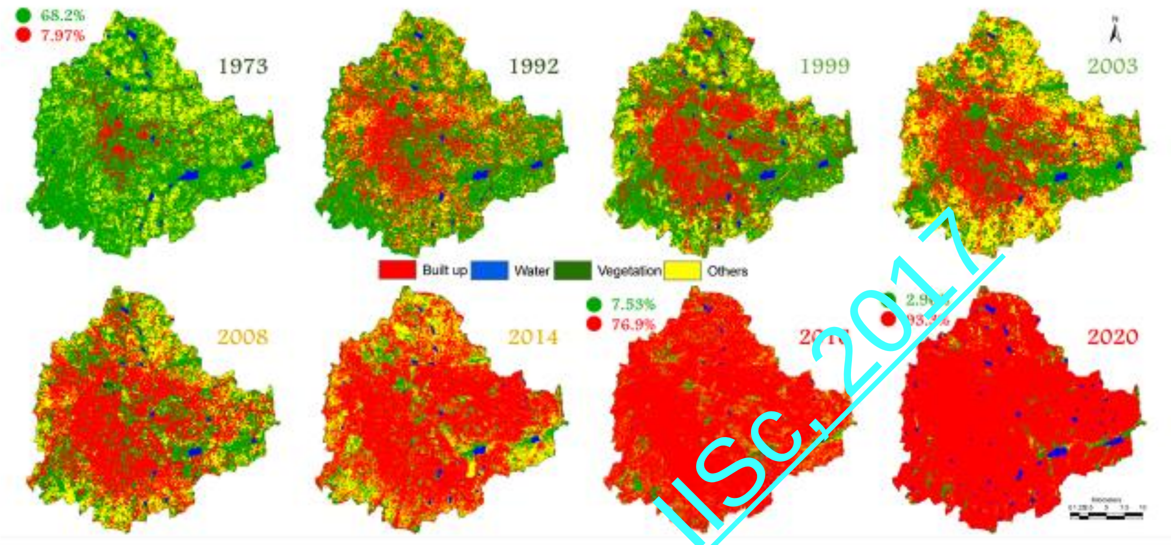

Figure 1: Urban growth in Bangalore (based on temporal data acquired through space borne sensors)

- **Floods:** Conversion of wetlands to residential and commercial layouts has compounded the problem by removing the interconnectivities in an undulating terrain. Encroachment of natural drains, alteration of topography involving the construction of high-raise buildings, removal of vegetation cover, reclamation of wetlands are the prime reasons for frequent flooding even during normal rainfall post 2000.

- **Decline in groundwater table:** Water table has declined to 300 m from 28 m and 400 to 500 m in intensely urbanised area such as Whitefield, etc. over a period of 20 years.

- **Heat island:** Surface and atmospheric temperatures have increased by anthropogenic heat discharge due to energy consumption, increased land surface coverage by artificial materials having high heat capacities and conductivities, and the associated decreases in vegetation and water pervious surfaces, which reduce surface temperature through evapotranspiration. An increase of ~2 to 2.5 ºC during the past three decades highlights implication of explosive urban growth on local climate, necessitating appropriate strategies for the sustainable management of natural resources.

- **Increased carbon footprint**: Drastic increase in electricity consumption was observed in certain corporation wards due to the adoption of inappropriate building architecture in tropical climate. Per capita electricity consumption in the zones dominated by high raise building with glass facades ranges from 14000-17000 units (kWh) per year compared to the zones with eco-friendly buildings (1300-1500 units/person/year)[3].

Emissions from transport sector is about 43.83% (in Greater Bangalore) on account of large scale usage of private vehicles, and mobility related to job accounts for 60 % of total emissions due to lack of appropriate public transport system and haphazard growth with unplanned urbanisation. Higher fuel consumption, enhanced pollution levels due to the increase of private vehicles, traffic bottlenecks have significantly contributed to carbon emissions. Majority commute longer distances due to lack of integrated land use and mobility planning, thus contributing to emissions. Apart from these, mismanagement of solid and liquid wastes has aggravated the situation. Dumping of solid and liquid waste in water bodies has increased the anaerobic condition leading to emissions of greenhouse gases (methane, CO_2, etc.).

Unplanned cities thus not only contribute to global climate change by emitting the majority of anthropogenic greenhouse gases but also are particularly vulnerable to the effects of climate change and extreme weather. This emphaises the need to improve urban sustainability through innovations while addressing technical, ecological, economic, behavioral, and political challenges to create cities that are low-carbon, resilient, and livable.

The smart cities mission launched by the Government of India recently (in June 2015) envisages developing physical, institutional, social infrastructure in select cities with central assistance targeted at improving the quality of life as well as economic visibility of the respective urban centres[5]. Four strategic components are (i) green field development through smart townships by adopting holistic land management, (ii) pan-city development through adoption of smart applications like transport, reuse and recycle of wastewater, smart metering, recovering energy from solid waste, etc., (iii) retrofitting to make existing area more efficient and livable by reducing greenhouse gas (GHG) footprint, improving power and treated water supply[3], improving communication and infrastructure connectivity and security, (iv) re-development of existing built-up area, creation of new layout through mixed land use, adoption of appropriate floor area index (FAI) considering the level of existing and scope for improvement of infrastructure and basic amenities, which helps in keeping the city's growth within the region's carrying capacity[4] and urban infrastructure becomes inclusive. This entails efficient decision making through (i) integrated land use planning as per the city's requirements considering mobility, etc., to minimize mobility related to jobs; (ii) enhancement of the functional capacity through user friendly and economic public transport support; (iii) development of mass rapid-transport systems for easy mobility in inter and intra cities; and (iv) effective use of ICT's as enabling technologies to improve the level of services. These measures have to be implemented quickly as most cities are in a civic and financial disarray because of senseless unplanned rapid urbanisation.

Environmentally sound urban centres with essential basic amenities and advanced infrastructures (such as sensors, electronic devices and networks) would stimulate sustainable economic growth and improvements in citizen services. The deployment of information and communication technology infrastructures for effective governance support social and urban growth through improved economy and active participation of citizens. Indian cities while exhibiting technological innovations and connectedness, should also focus on increased living comfort through adequate infrastructure, green spaces and essential basic amenities to every citizen.

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Bellandur and Varthur Lakes Rejuvenation Blueprint

1.0 INTRODUCTION

Rapid urbanisation coupled with industrialisation in urban areas has greatly stressed the available water resources qualitatively and quantitatively in India. This has also resulted in the generation of enormous sewage and wastewater after independence. Unplanned urbanisation and ad-hoc approaches in planning are evident everywhere, from settlements to sanitary systems and networks. Urban areas in India lack adequate infrastructure for sanitation, leading to inappropriate management of the wastewater and sewage generated in the locality. Most of the sewage and wastewater generated is discharged directly into storm water drains that ultimately link to water bodies. Bangalore is located on a ridge with natural water courses along the three directions of the Vrishabhavaty, Koramangala–Challaghatta (KC) and Hebbal–Nagavara valley systems along the foothills of the terrian, and these water courses are today being misused for the transport and disposal of the city's untreated sewage. The shortfall or lack of sewage treatment facilities has contaminated the majority of surface and ground waters. These aquatic resources are now unfit for current as well as future use and consequently pose critical health problems.

Bangalore is the principal administrative, cultural, commercial, industrial and knowledge capital of the state of Karnataka. Greater Bangalore, an area of 741 km^2 including the city, neighbouring municipal councils and outgrowths. Bangalore is one of the fastest growing cities in India, and is also known as the 'Silicon Valley of India' for heralding and spearheading the growth of Information Technology (IT) based industries in the country. With the advent and growth of the IT industry, as well as numerous industries in other sectors and the onset of economic liberalisation since the early 1990s, Bangalore has taken the lead in service- based industries, which have fuelled the growth of the city both economically and spatially. Bangalore has become a cosmopolitan city attracting people and business alike, within and across nations (Sudhira et al., 2007; Ramachandra and 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. This led to Bangalore having hundreds of such water bodies through the centuries. In 1961, the number of lakes and tanks in the city stood at 262. A large number of water bodies (locally called lakes or tanks) in the city had ameliorated the local climate, and maintained a good water balance in the neighbourhood. A current temporal analysis of wetlands, however, indicates a decline of 79% in Greater Bangalore during 1970- 2016, which can be attributed to unplanned intense urbanisation processes. The undulating topography, featured by a series of valleys radiating from a ridge, forms three major watersheds, namely the Hebbal Valley, Vrishabhavathi Valley and the Koramangala and Challaghatta Valleys. These form important drainage courses for the interconnected lake system which carries storm water beyond the city limits. Bangalore, being a part of peninsular India, had the tradition of storing this water in these man-made water bodies which were used in dry periods. Today, untreated sewage is also let into these storm water streams which progressively converge into these waterbodies and results in a) algal bloom b) proliferation of exotic aquatic weeds and macrophytes c) large scale fish kill due to asphyxia (zero dissolved oxygen levels) and d) frothing due to P enrichment (Fig. 1.1)

Fig. 1.1: Consequences of nutrient enrichment (algal bloom, macrophytes infestations, fish mortality, frothing..)

Of the three major catchments, the Koramangala–Challaghatta (KC) valley houses the largest of the water to dowsteam and finally takes the water out of the city limits with the drainage channels. Bellandur and Varthur lakes are historic that were originally built to store water for drinking and irrigation purposes (Government of Karnataka, 1990). Today, large-scale developmental activities in recent times due to unplanned urbanisation in the lake catchment has resulted in reduced catchment yield and higher evaporation losses. Inefficient primary feeder channels feeding the lake have also contributed to water shortage and reduced catchment flow. However, this shortage has been supplemented by an increased quantum of sewage inflow. Due to the sustained influx of fresh sewage over several decades, nutrients in the lake are now well over safe limits. Bellandur and Varthur lakes being the end of the lakes series in the KC valley Varthur Lake has been receiving about ~45% of the city sewage for over last 60 years resulting in eutrophication. There are substantial algal blooms, Dissolved Oxygen (DO) depletion and malodour generation, and an extensive growth of water hyacinth that covers about 70–80% of the lake in the dry season. Sewage brings in large quantities of C, N and P which are trapped within the system. A similar situation prevails in most of the other lakes and water bodies in Bangalore due sewage influx and associated increase in productivity. Such instances have been recurring despite the fact that a certain part of the sewage undergoes at least primary treatment in most cities of India. Thus, any solution to this problem can go a long way in restoring thousands of such water bodies in India.

The various forms of nitrogen influent in sewage are organic N (protein N), urea, ammonia, nitrites and nitrates through processes like nitrification, de-nitrification and ammonification. Autotrophic nitrification consists of two consecutive aerobic reactions, the conversion of ammonia to nitrite by nitrosomonas and then from nitrite to nitrate by nitrobacter (Koops and Pommerening-Roser, 2001). Nitrite-Oxidising Bacteria (NOB) use CO_2 and bicarbonate for cell synthesis and ammonium or nitrite as the energy source (Hooper et al., 1997). Ammonia-Oxidising Bacteria (AOB) a β-Proteobacteria comprises of two genera, nitrosospira and nitrosomonas (Purkhold et al., 2003). The availability of any oxygen in the system helps in nitrification chemistry. Complete nitrification stoichiometry requires 4.6 kg oxygen per kg NH^{4+} (ammonia N). Dissolved oxygen concentrations of 1 mg/l are sufficient for the oxidation of ammonium (Hammer and Hammer, 2001). However, at DO concentrations lower than approximately 2.5 mg/l, nitrite oxidation is inhibited, leading to its accumulation (Paredes et al., 2007). In such conditions, the oxygen transfer rate may be as important as the actual O_2 concentration. In natural shallow aquatic vegetation set up, the plant species as *Typha* and *Phragmites* provides as oxygenated zone around the roots which enhances nitrification (Munch et al., 2005). In less-aerated systems, however, the transfer rate varies according to the plant species and other environmental and operational factors (Faulwetter et al., 2009). Higher concentrations of nitrates and phosphates primarily contribute to the nutrient enrichment of these urban water bodies resulting in higher productivity and consequent ecological instability. Though there are large number of studies on nutrient enrichment in urban water setup but studies on various forms of nitrogen and its partitioning into protein, urea, ammoniacal-N, nitrate, nitrite and nitrate denitrified into di-nitrogen are scarce. More importantly N flux and the conversion rates, uptake/release rates by various biological agents and their quantification are often not carried out.

Carbon and nutrient (N and P) recycling are very important for sustainable development (Janzen, 2004) and there has been significant accumulation of these nutrients into urban water bodies, lakes and tanks, thus causing phenomenal alteration to the aquatic integrity of the system resulting in deterioration of these systems at the same time resulting in degradation of water quality and higher GHG emissions. This has not only rendered these systems useless but also has impacted the microclimate of the regions and the ground water resources and is certainly a potential threat to existence. Bangalore has been witnessing a manifold increase in its population, due to IT and BT boom in the city for the last 3 decades. This has resulted in a serious change in both the land cover consequent to the land use and alteration to existing use of water resources and the local hydro-geology of the region. Due to a large population in the city there has been a unprecedented demand for resources and basic amenities but incidentally the city has been witnessing a huge deterioration of the vital landscape elements as vegetation (7.53 %) and water bodies (0.98 %), air (RSPM: 190-347 μg/m^3; 39-83 μg/m^3 NO_x; 8-20 μg/m^3 SO_2; KSPCB under NAAQM at Graphite) and water resources (90 % surface water (Ramachandra et al., 2015) and 60 % ground water (CG), noise (>100 db; permissible 60-70 db, KSPCB). Rampant urbanisation without any fundamental understanding of the assimilative capacity of the city region and the hydro-geological and climatic variability's, have lead to an unsustainable city profile. This has not only resulted in a disturbance in the water balance of the region but also has affected the micro-climate of the region immensely.

Historically the lakes, tanks and water bodies were created basically for maintaining a hydro-geologic regime in water flows for checking floods, recharging, and maintaining the ground water table. They also act as sediment traps, prevent clogging up of natural valleys and reduce erosion by regulating run off. Lakes and Tanks belong to wetland ecosystem and have a larger biological and ecological role that acts as natural filters to myriads of pollutants and maintains a balance between the biota and the aquatic environment. Due to unplanned urbanization most of the tanks/lakes/water bodies in the districts have been transformed to built-up area wrecking the drainage patterns and the hydrologic regime in the city. Therefore, measures for rejuvenation of tanks and lakes in the city will definitely build up ground water resources and safeguard our future water availability for domestic use. In requires an integrated effort made by State authorities (BBMP) in consultation with various stakeholders to conserve and rejuvenate major tanks in Bangalore city.

2.0 **STUDY AREA**: Bangalore

Bangalore city and Greater Bangalore: Bangalore is located in the Deccan plateau, toward the south east of Karnataka state extending from 12°49'5"N to 13°8'32"N in latitude and 77°27'29" E to 77°47'2"E in longitude (Figure 1). Spatially Bangalore urban area has spatially increased from 69 sq.km (1901), 161 sq.km (1981), 221 sq.km (2001) to 741 sq.km (2006, Greater Bangalore). The decadal (2001 to 2011) population increase in urban India is 31.8% and in Karnataka is 31.5%. However, Bangalore witnessed dramatic decadal increase of 44%. The population has increased from 4.3 Million (Bangalore city in 2001) to 8.4 Million (in 2011, Greater Bangalore) and the population density has increased from 7880 persons per square kilometre to over 11330 persons per square kilometre. Bangalore receives an annual average rainfall of 750-850 mm. Bangalore located on the ridge with the topography undulating from 700 m to about 962 m AMSL. Taking the advantage of undulating terrain, earlier administrators of the region constructed interconnected water bodies (lakes/tanks) to meet the domestic and irrigation demand in the region. This is evident from historical records, Ganga rulers (870 AD) had constructed Agara, Bellandur and Varthur lake systems to facilitate irrigation, agriculture and other needs (District Gazetteer of Bangalore, *Chapter 4, 214-215,http://gazetteer.kar.nic.in/gazetteer/distGazetteer*). Similarly earlier sensible rulers had constructed and managed many lakes [Mayisandra (1245 AD), Ramasandra (1340), Allalasandra (1544 AD), Tippasandra (Anekal taluk- 1614 AD), Tirumalapura (1766), Mattikere (1834)] to sustain irrigation, domestic and other anthropogenic needs. Integrated lake management through regular desilting activities were also reported at Ramasandra Lake (1515 AD). The interconnected lake system in Bangalore also aided in transporting storm water from the city centre to outskirts. Bangalore City (spatial extent in 1980's is 161 sq.km) had about 274 lakes and was aptly known as city of lakes, which helped in recharging groundwater resources, moderating micro climate, supported local livelihood (fish, fodder, etc.), irrigation and domestic water demand apart from recreation facilities.

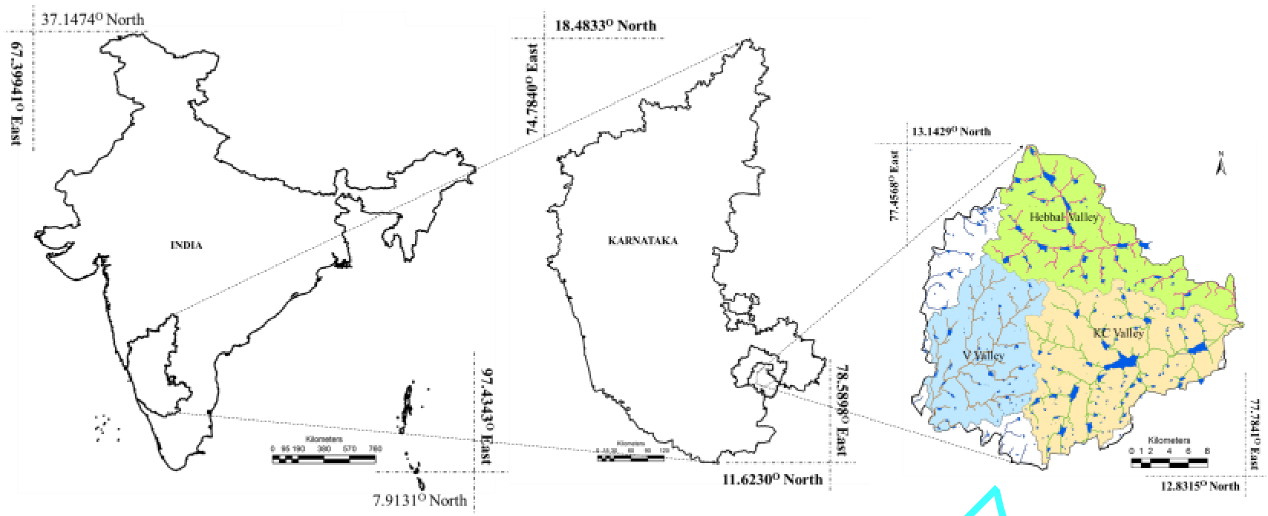


Figure 1: Location of KC-Valley (source: http://ces.iisc.ernet.in/energy)

Bangalore landscape with undulating terrain forms three major watersheds (Figure 1) namely Koramangala and Challaghatta valley (K C Valley), Hebbal Valley and the Vrishabhavati Valley (V Valley). K&C valley is the largest catchment (255 sq. km.) in Bruhat Bengaluru (with spatial extent of 741 sq.km), followed by Hebbal valley (207 sq. km.) and Vrishabhavati valley (165 sq. km.). Interconnected lakes in KC and Hebbal valleys' join at Nagondanahalli village (BBMP Ward 94 – Hagadur) and finally joins Dakshina Pinakin River. Interconnected lake systems in Vrishabhavathi valley joins Arkavathi River which is a tributary of the river Cauvery.

Bangalore is experiencing unprecedented rapid urbanisation and sprawl in recent times due to unplanned unrealistic concentrated developmental activities. This has led to large scale land cover changes with the serious environmental degradation, posing serious challenges to the decision makers in the city planning and management process involving a plethora of serious challenges such as loss of green cover and water bodies, climate change, enhanced greenhouse gases (GHG) emissions, lack of appropriate infrastructure, traffic congestion, and lack of basic amenities (electricity, water, and sanitation) in many localities, etc.

Urbanisation and loss of natural resources (wetlands and green spaces): Urbanisation is one of the demographic issues being investigated in the 21st century, understanding spatial patterns of changes in the land and advance visualization of growth is imperative for sustainable management of natural resources and to mitigate changes in climate. This would help the city planners in planning to mitigate the problems associated with the increased urban area and population, and ultimately build sustainable cities. Urbanisation during 1973 to 2016 (1005% concretization or paved surface increase) has telling influences on the natural resources such as decline in green spaces (88% decline in vegetation), wetlands (79% decline), higher air pollutants and sharp decline in groundwater table. Geo-visualisation of likely land uses in 2020 through multi-criteria decision making techniques (Fuzzy-AHP: Analytical Hierarchal Process) reveals calamitous picture of 93% of Bangalore landscape filled with paved surfaces (urban cover) and drastic reduction in open spaces and green cover. This would make the region

GHG rich, water scarce, non-resilient and unliveable, depriving the city dwellers of clean air, water and environment (Source: Ramachandra T V and Bharath H. Aithal, 2016. Bangalore's Reality: Towards unlivable status with unplanned urbanisation trajectory, Current Science (Guest Editorial)), 110 (12): 2207-2208, 25 June 2016)

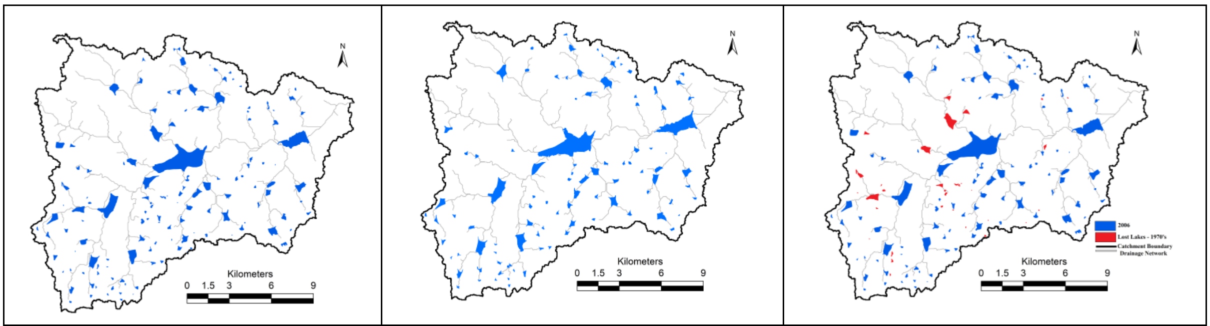
2.1 K&C Valley and its importance: Upstream lake series description.

Koramangala Challaghatta Valley (KC Valley): Koramangala Challaghatta Valley (KC Valley) is located to the south eastern portion of Bangalore city (Figure 2.1), with a catchment of 290.44 sq. km. and drains to Dakshina Pinakini River. This region witnessed disappearance of 37.5% lakes during 1970 to 2016 due to various anthropogenic pressure. Figure 2 depicts the lake dynamics during 1970 (the Survey of India 1:50000 topographic sheets) to 2016 (remote sensing data- Google Earth, http://earth.google.com, Bhuvan, http://bhuvan.nrsc.gov.in). The catchment earlier consisted of 132 interconnected lakes (Survey of India Topographical sheet - 1970's) and now (24th May 2016– Google earth) has about 96 lakes *(*46 in Bellandur lake catchment and 50 lakes connect to Varthur lake*)*. Interconnected lake system consists of lake series of Hulimavu, Puttenalli, Halasuru, Kaikondralli, Kaggadasapura, Gunjuru-Chikka Bellandur, Kundalalli, Nalluralli. KC valley catchment has a population of 39.6 lakhs (Census of India, 2011) with a population density of 9600 persons per sq. km. The feeder to Bellandur lakes are a) Ulsoor lake series (north-west); b) Hulimavu lake series C) Sarakki lake series d) Beguru lake series e) Ambilipura lake series f) kaikondarahalli lake series and g) Doddanekundu lake series.

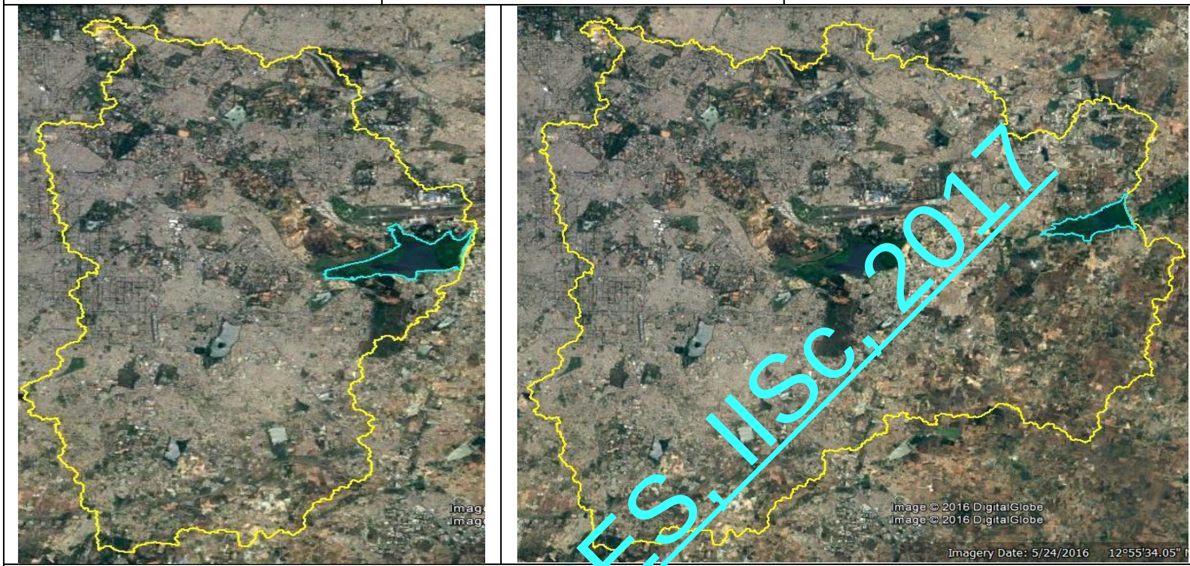
As per the Survey of India, topographic maps (based on contours), the potential storage capacity of lakes in Bangalore (in 1800 with 1452 water bodies in 741 sq.km spatial extent) was ~ 35 TMC or 981 Mm^3 (of which ~7.3 TMC in Bellandur (~18.67 Mm^3) and Varthur (~6.10 Mm^3). However, due to siltation, etc. the current storage volume is about ~5.5 (Bellandur) and ~1.61 Mm^3 (Varthur). This necessitates de-silting of lakes that would help in enhancing the storage capacity as well as removal of accumulated nutrients (especially P, Phosphorous, lake sediment has high quantity) apart from enhancing recharging potential of groundwater resources.

Suggestion: De-silting of lakes has to be done on priority to enhance the storage capacity as well as to remove nutrient (N and higher amounts of P) enriched sediments.

Benefits: (i) Efficient harvesting of rainwater, (ii) recharging of groundwater resources, (iii) improvements in micro climate, (iv) removal of nutrient rich silt – could be used in agriculture.



1970's (SOI Toposheet)	2016	Lost Lakes 1970's to 2016



Remote sensing data (Google Earth, 24th May 2016) Source: EWRG, CES, IISc,

Figure 2.1: Lake dynamics in K C Valley between 1970's and 2016

2.1.1 Bellandur Lake (at 12.9464° to 12.9277° N and 77.6420° to 77.6807° E) located in Agaram and Bellandur ward is the largest lake (366.89 hectares; 906 acres 25 guntas) in Bangalore city (BBMP) and spread across six villages (Table 1.1). Bellandur Lake has a catchment area of nearly 279 square kilometers with 46 cascading interlinked lakes. Bellandur lake catchment has a population of 34.8 lakhs (2011) with population density of 138 persons per square kilometre (Figure 2.2).

Table 1.1: Bellandur lake, break up and extent in each village

Taluk	Hobli	Village	Survey number	Area	
				Acre	Gunta
Bangalore East	Varthur	Ammanikere Bellandur khane	1	284	2
Bangalore South	Begur	Ibbaluru	12	399	14
Bangalore South	Begur	Agara	43 (A)	166	15
Bangalore East	Varthur	Kempapura	6	13	15
Bangalore East	Varthur	Belur	2	40	15
Bangalore East	Varthur	Yamalur	62	3	4
			Total Area	906	25
As per the RTC, www.bhoomi-karnataka.gov.in					
Spatial analysis using remote sensing data with geo-informatics (367.34 hectares)				907	28.4

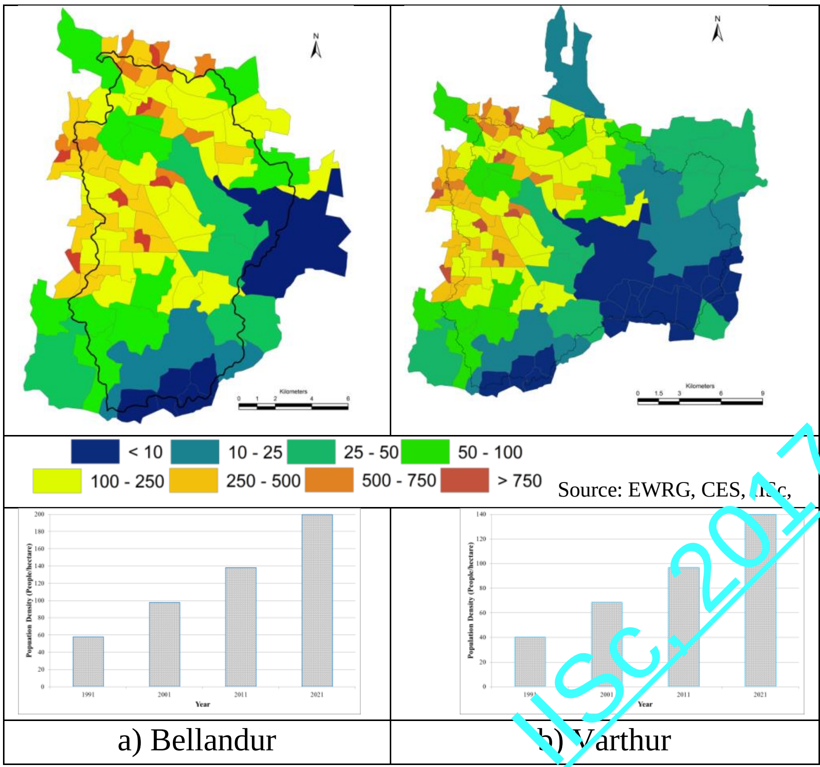
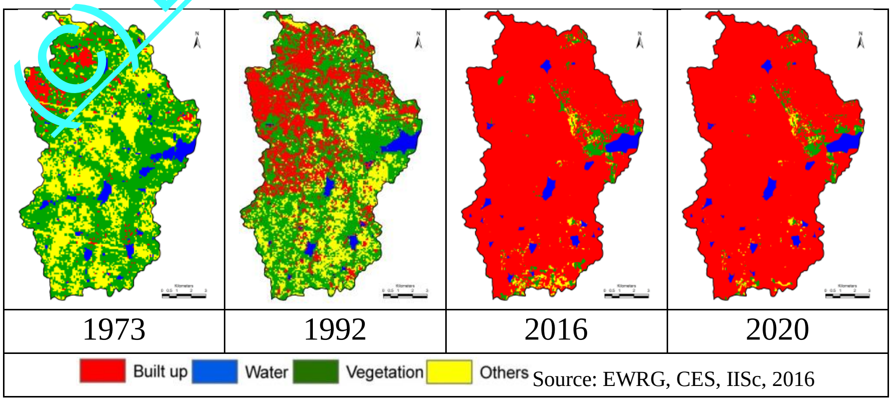


Figure 2.2: Population density (persons/hectare) as per 2011 Census

Land use: Land use analyses carried using temporal (1970's to 2016) remote sensing data shows an increase in built-up (paved surfaces; buildings, roads) from 5.4% (1973) to 92.3% (2016) with the decline in vegetation cover (58.0% to 4.1%), water bodies (4.3% to 1.4%) and other (open lands, agriculture) land uses (32.3% to 2.1%). Predication of likely land uses reveals that 94% of the catchment would be concretised by 2020.



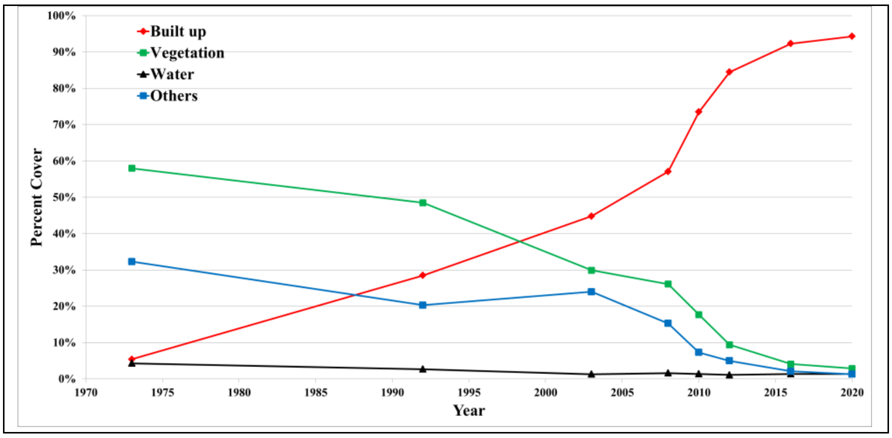


Figure 2.3: Land use dynamics in Bellandur Catchment

2.1.2 Varthur Lake (at 12.9407° to 12.9566° N and 77.67189° to 77.7476°E) is the second largest lake in Bangalore city (BBMP). The lake located in Varthur ward with a spatial extent of 180.8 hectares (447 acres 14 guntas) and spreads across Ammanikere Bellandur Khane village (Table 1.2). Varthur Lake has a catchment area of nearly 279 square kilometers with 96 cascading interlinked lakes. Varthur catchment has a population of 39.5 lakhs (2011) with population density of 97 persons per square kilometre (figure 2.2).

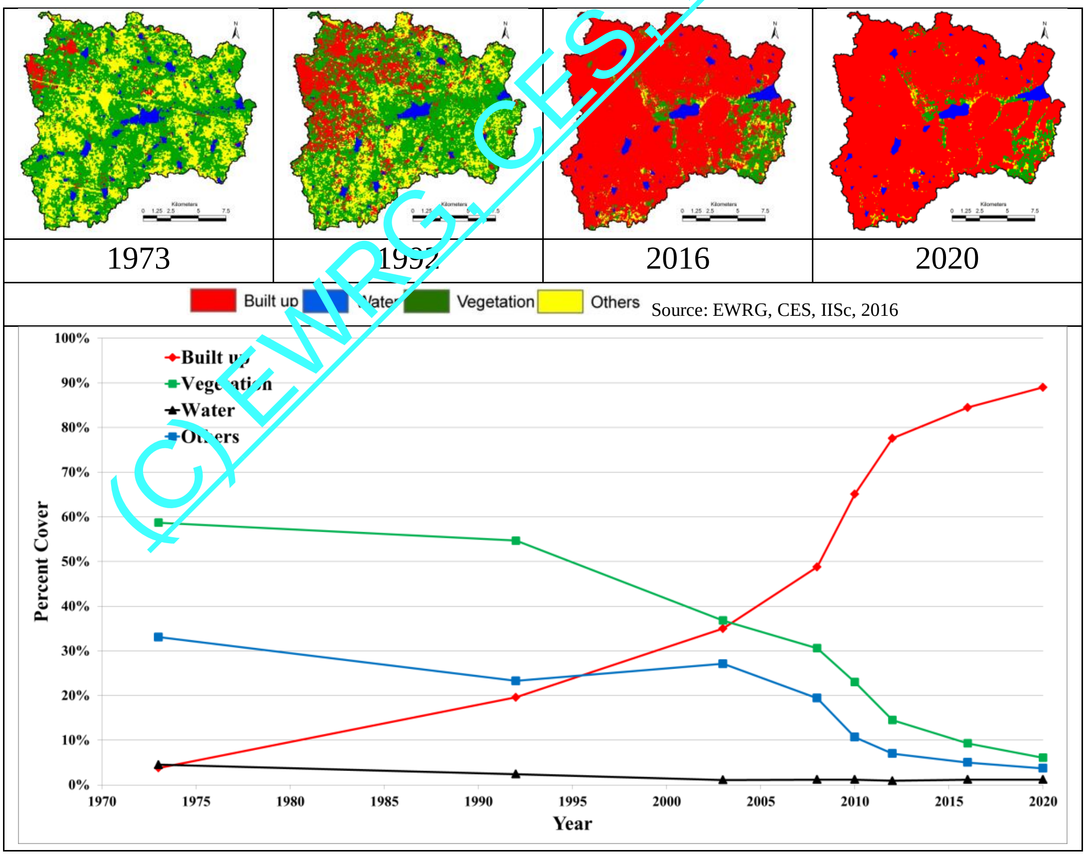


Figure 2.4: Land use dynamics in Varthur Catchment

Table 1.2: Varthur lake, break up and extent in each village

Taluk	Hobli	Village	Survey number	Area	
				Acre	Gunta
Bangalore East	Varthuru	Ammanikere Bellandur khane	319	447	34
As per the Akarabhandu, RTC, www.bhoomi-karnataka.gov.in; and recent survey by the revenue department					
As per spatial analysis - remote sensing data with geo-informatics (188.9 hectares)				467	00

Land use analyses in Varthur Catchment using temporal (1970 to 2016) remote sensing data (Figure 2.4) shows an increase in built-up (paved surfaces: buildings, roads, etc.) from 3.8% (1973) to 89% (2016) with a sharp decline in vegetation (58.7% to 6.1%), water bodies (4.5% to 1.2%) and other (open lands, agriculture) land uses (33.1% to 5.0%).

3.0 LAKES: CONTEMPORARY RELEVANCE

Lakes (wetlands) have been aiding in recharging groundwater resources, moderating micro climate, supported local livelihood (fish, fodder, etc.), irrigation and domestic water demand apart from recreation facilities. Washing, household activities, vegetable cultivation and fishing are the regular activities in the lake for livelihood. Multi-storied buildings have come up on some lake beds intervening the natural catchment flow leading to sharp decline and deteriorating quality of water bodies. Unauthorised construction in valley zones, lakebeds and storm water drains highlight the weak and fragmented governance. This is correlated with the increase in unauthorized constructions violating town planning norms (city development plan) which has affected severely open spaces and in particular water bodies. Problems encountered by Bangaloreans due to mismanagement of water bodies in Bangalore are:

- **Decline in groundwater table:** Water table has declined to 300 m from 28 m and 400 to 500 m in intensely urbanised area such as Whitefield, etc. over a period of 20 years with the decline in wetlands and green spaces.

- **Recurring episodes of fish mortality**: Large-scale fish mortality in recent months further highlights the level of contamination and irresponsible management of water bodies. Sustained inflow of untreated sewage has increased the organic content beyond the threshold of remediation capability of respective water bodies. Increasing temperature (of 34 to 35 °C) with the onset of summer, enhanced the biological activities (evident from higher BOD and Ammonia) that lowered dissolved oxygen levels leading to fish death due to asphyxiation.

- **Floods:** Conversion of wetlands to residential and commercial layouts has compounded the problem by removing the interconnectivities in an undulating terrain. Encroachment of natural drains, alteration of topography involving the construction of high-rise buildings, removal of vegetative cover, reclamation of wetlands are the prime reasons for frequent flooding even during normal rainfall post 2000.

- **Heat island:** Surface and atmospheric temperatures are increased by anthropogenic heat discharge due to energy consumption, increased land surface coverage by artificial materials having high heat capacities and conductivities, and the associated decreases in vegetation and water pervious surfaces, which reduce surface temperature through evapotranspiration. An increase of ~2 to 2.5 ºC during the last decade highlights implication of explosive urban growth on local climate, necessitating appropriate strategies for the sustainable management of natural resources.

- **Ecosystem goods and services:** Valuation of tangible benefits (fish, fodder, drinking water, etc.) reveal that wetlands provides goods worth Rs. 10500 per hectare per day (compared to Rs 20 in polluted lake), and sustains the local livelihood. This also emphasises the need for rejuvenation and sustainable management of water bodies.

3.1 Present status of Bellandur Lake

Bellandur Lake is being subjected to increased anthropogenic stress due to sustained inflow of untreated domestic sewage and industrial effluents, dumping of solid waste, encroachment of wetlands and connecting drains (figure 3.1).

In order to understand the pollution status of Bellandur lake, sampling (water, slush, sediment, biota - phytoplankton, zooplankton, macrophytes) was carried out at 70 locations (Figure 3.2 and Figure 3.3) during 8-14th April 2016 with the help of MEG (Madras Engineering Group), Indian Army. The analyses of samples include physico-chemical (water temperature, pH, electrical conductivity, TDS, turbidity, DO, nitrate, orthophosphate, turbidity, total alkalinity, calcium and magnesium hardness, total hardness, chlorides, COD, BOD, sodium and potassium) as well as biological characterisation (phytoplankton, zooplankton, nacrophytes). The physico-chemical characteristics of Bellandur Lake revealed that the lake has higher amounts of nutrients and ionic components with the dissolved oxygen levels were equal to zero which, indicate pollution/sewage entry into the lake. Thus, Bellandur lake falls under Class E as per CPCB's Classification of Inland Surface Water. Pollution tolerant phytoplankton and zooplankton population were present in the Bellandur lake water, which indicates pollution as well as eutrophic conditions. Development activities consequent to urbanization around Bellandur Lake had degraded its water quality and enhanced frothing which has become a threat to public health and its water is completely unfit for human use. Also, there is a decline in the biodiversity in the lake.

Dumping of liquid waste and solid waste, unabated encroachments…….

Figure 3.1: Bellandur Lake's Tragedy – Encraochments, sustained inflow of untreated sewage (BWSSB, local apartments, slums, etc.) and industrial effluents, dumping of solid waste, construction and demolition wastes, biomedical waste

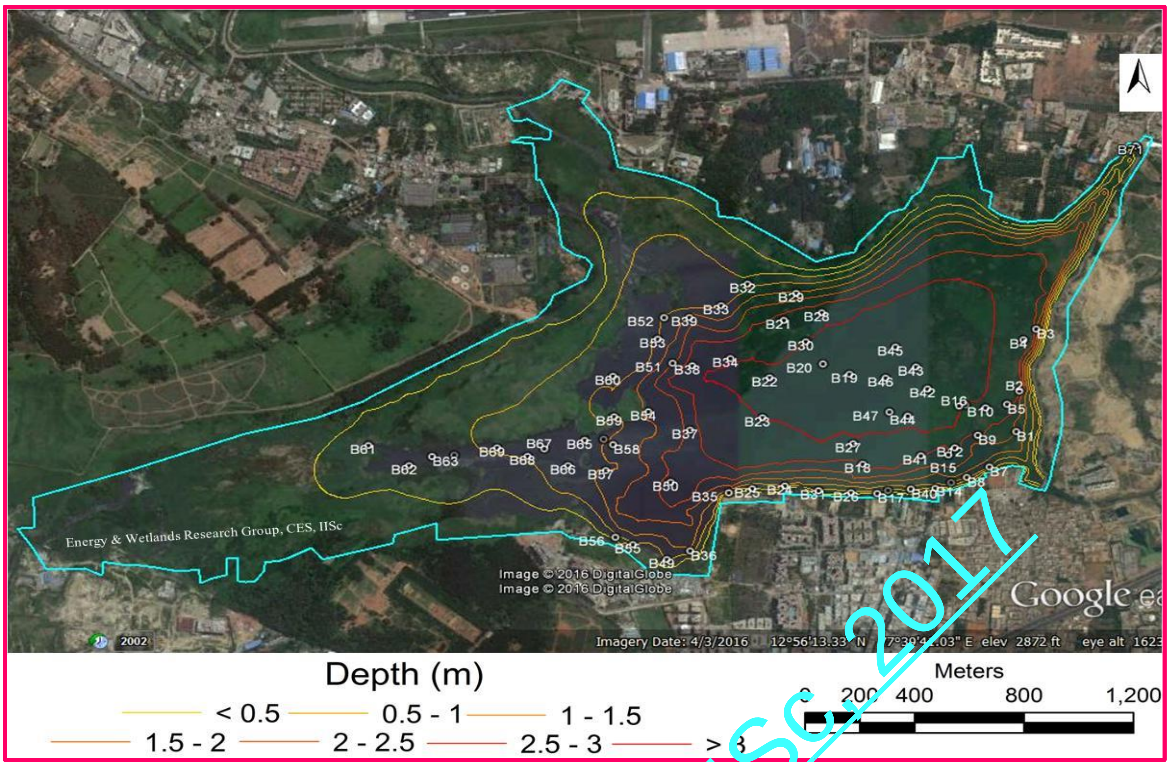


Figure 3.2: sampling points in Bellandur lake

The analysis of physico- chemical parameters like water temperature; pH; total dissolved solids; electrical conductivity; turbidity; dissolved oxygen; chemical oxygen demand; biochemical oxygen demand; total alkalinity; chloride; total hardness; calcium; magnesium; nitrate; orthophosphate; sodium and potassium of lake samples collected from Bellandur lake were done according to the standard protocol.

The analysis of physical and chemical variables in the water of Bellandur lake (based on PCA: Principal Component Analysis and Cluster analysis) reveals the existence of three groups (figure 3.4).

- **Cluster 1** (highly polluted sites) includes sampling sites like 49, 51, 54, 59, 61, 63, 64, 65, 66, 67, 68, 69 and 70. This group include sites that have slightly alkaline conditions with low depth and DO levels (= 0 mg/l). It is found that other parameters like water temperature, TDS, EC, turbidity, BOD, COD, chloride, total hardness, calcium, magnesium, nitrate, ortho-phosphate, sodium and potassium are very high as these sites have direct waste water sewage inlets.

- **Cluster 2** (moderately polluted sites) includes 1, 2, 3, 4, 5, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 27, 30, 55 and 56. In the case of group 2, pH, DO and total alkalinity are higher.

- **Cluster 3** (less polluted sites) has sites such as 7, 26, 28, 29, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 50, 52, 53, 57, 58, 60 and 71. Here, depth is high and all the other parameters like water temperature, TDS, EC, turbidity, BOD, COD, chloride, total hardness, calcium, magnesium, nitrate, sodium and potassium are very low.

Field Inspection and Sample collection

Figure 3.3: Sample collection at various points in Bellandur lake

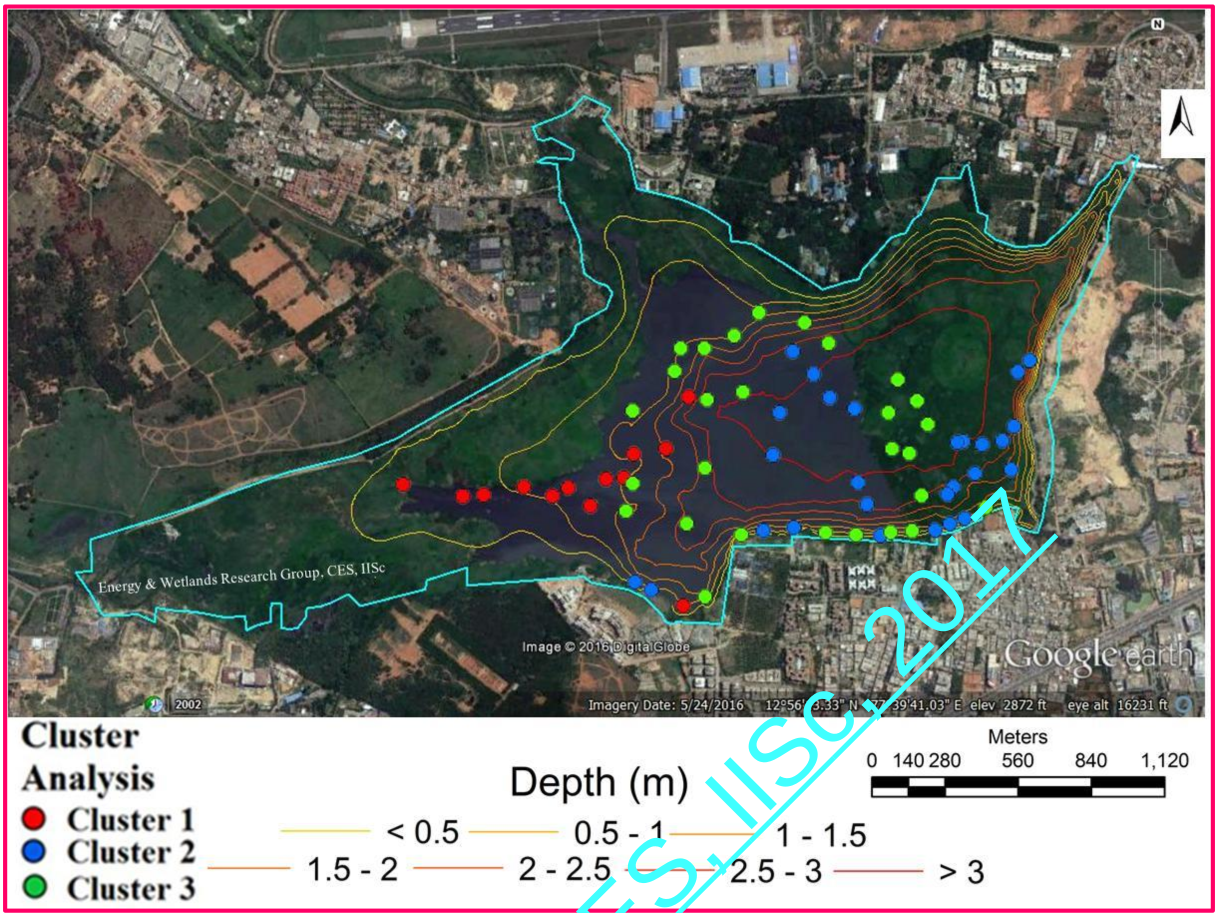


Figure 3.4: Bellandur lake water quality status - based on multivariate analysis

3.2 Present status of Varthur Lake

Sampling was carried out during $4-7^{th}$ April (2016) in Varthur lake (Figure 3.5) along with MEG, Indian Army. The water samples were collected from 47 different sites and analyzed its water quality as well as planktons (Biomonitoring). Figure 3.6.1 depicts various anthropgenic stress in the Lake, while Figure 3.6.2 portrays the consequences of mismanagement. The physico-chemical analysis revealed that Varthur Lake receives nutrients, organic and ionic components which indicated pollution of the lake. This led to organic matter accumulation at the lake bottom, finally, leading to hypoxic/anoxic conditions. Thus, Varthur Lake falls under Class E as per CPCB's Classification of Inland Surface Water. Chlorophyceae were found to be dominant in Varthur Lake among phytoplanktons whereas Protozoa and Rotifera were dominant among zooplanktons. Many pollution tolerant phytoplankton and zooplankton population were present in the Varthur lake water, indicating eutrophic conditions.

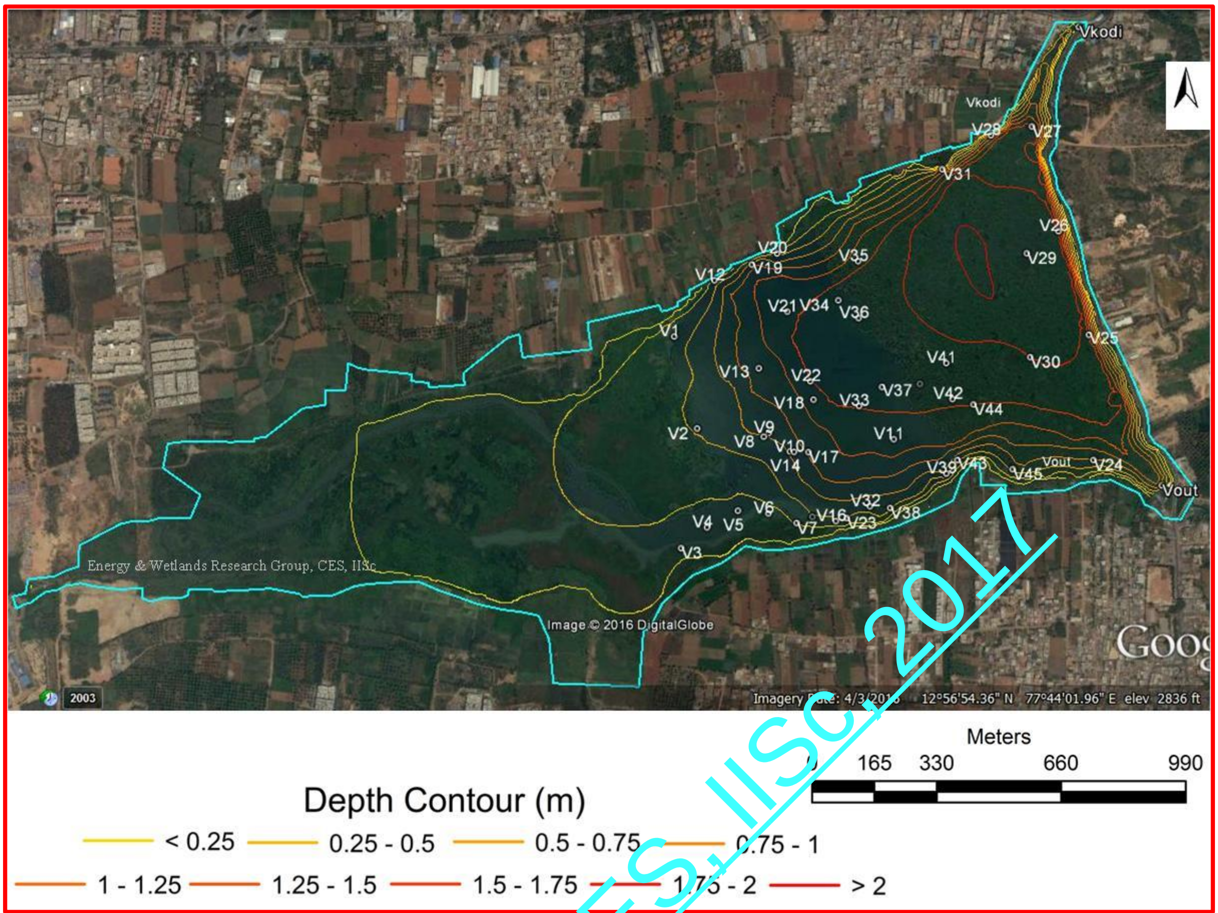


Figure 3.5: sampling locations in Varthur lake

Figure 3.6.1: Varthur Lake –outcome of fragmented governance of common lands

Figure 3.6.2: Frothing in Varthur and Bellandur lake

The analysis of physical and chemical variables in the water of Varthur lake based on sampling at 47 sampling sites in Bangalore and subsequent multi-varaiate analysis (PCA and cluster) reveal of two clusters (figure 3.7).

- Cluster **1** includes sampling sites like 24, 25, 27, 28, 29, 30, 32, 33, 36, 40, 41, 44, 26, 31, 34, 35, 37, 38, 39, 42, 43, 46 and 47 influenced by parameters like water temperature, TDS, EC, COD, total alkalinity, total hardness, magnesium, sodium and depth. These points are near to middle and outlet of the lake but are highly stressed due to anthropogenic activities with solid waste dumping, untreated sewage entry, dumping of building debris etc. Cluster 1 includes moderately polluted points.
- Cluster **2** has sites such as 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23 and 45 with high turbidity, pH, DO, BOD, calcium, chlorides, potassium, nitrate and ortho-phosphate, These points receive untreated sewage water daily thus, lot of suspended particles float at the lake surface. Suspended particles along with high algal and bacterial population contribute to high turbidity values. DO levels are high due to increased photosynthetic activities by algae. High DO levels help in increased rate of nitrification process as a result of which, nitrates in large amounts releases to lake water. With increased amount of ortho-phosphate and nitrate, macrophytes and algae grow well. Cluster 2 includes highly polluted points.

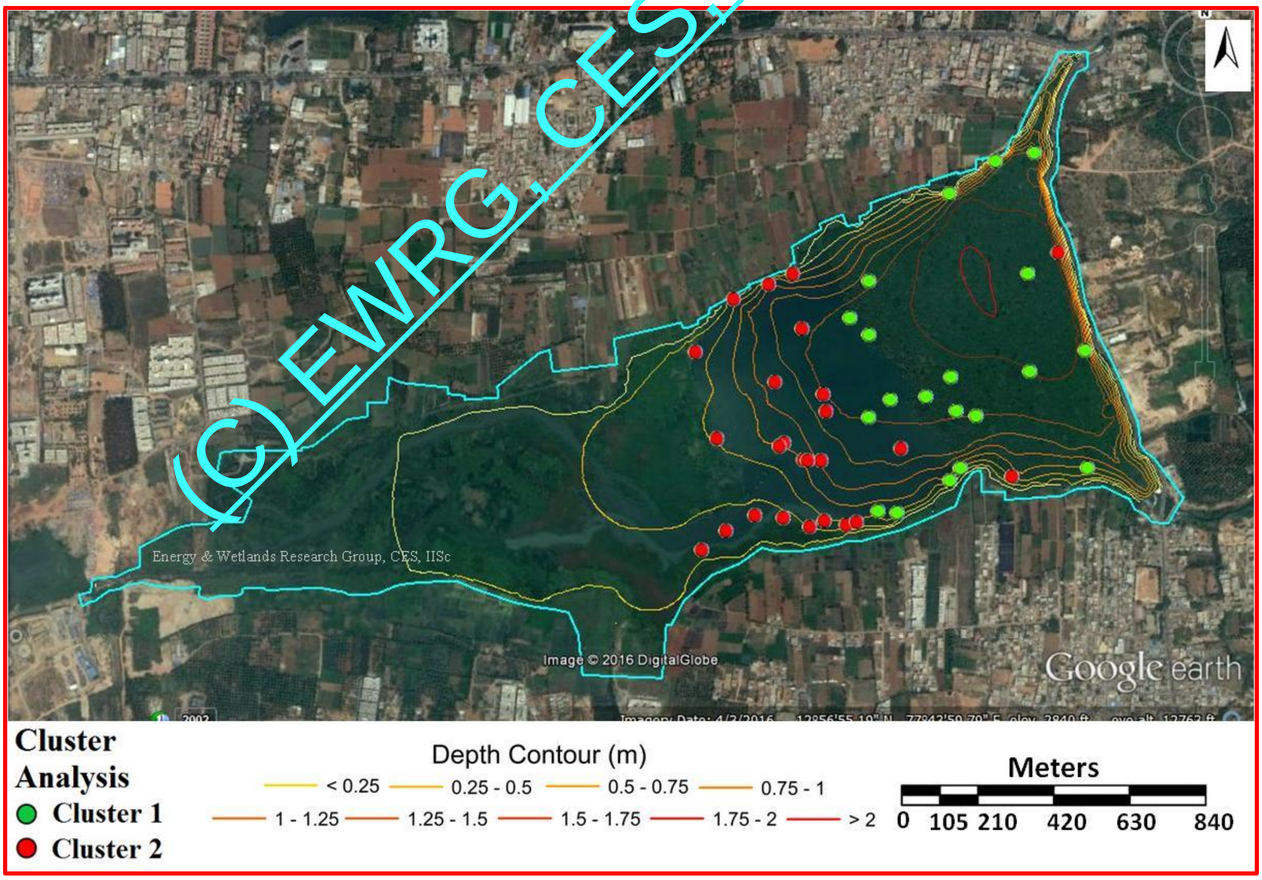


Figure 3.7: the status of Varthur lake based on multi-variate analysis

Table 3.1 highlights the level of contamination – nutrient enrichment, heavy metal contamination, etc.

Table 3.1: key water quality parameters observed in the two lakes over past several years

Parameter	Bellandur Lake	Varthur Lake	Studies referred to
pH	6.8-8.4	6.9-8.2	(Ramachandra et al., 2008, 2009, 2013; 2015, Mahapatra et al., 2011, 2010; 2014; Mahapatra, 2015; Ramachandra et al., 2015).
Total Bacterial Count (cells/ml)	10^4-10^7	10^5-10^7	
Dissolved Oxygen (mg/L)	0 to 3	0-5	
BOD (5-day 20degC) (mg/L)	25 to 180	32-175	
COD (mg/L)	44-330	51-280	
Cadmium (mg/L)	0.03-0.76	0.04-0.25	
Lead (mg/L)	0.01-1.77	0.04-2.84	
Chromium (+6) (mg/L)	0.02-0.67	0.014-1.66	
Nickel (mg/L)	0.002-0.41	0.026-1.89	
Copper (mg/L)	0.01-0.461	0.02-0.46	

From the above, it is clear that both the lakes are severely polluted, and have been in this condition for several years

3.3Heavy Metals in Bellandur and Varthur Lakes:

The presence of heavy metals in the Bellandur and Varthur lakes are indicative of contamination of industrial and untreated municipal wastewater. Heavy metals in the sediment materials are well within the metal levels found in cultivable lands in India and within the critical limits as per Awasthi et al., 2000 (Cd: 3- 6 mg/kg; Pb 250-500 mg/kg; Cu 135-270 mg/kg and Ni 75-150 mg/kg). Values are Cd 7 mg/kg; Co 8 mg/kg; Cu 68 mg/kg; Fe 20 g/kg; Mn 140 mg/kg; Ni 26 mg/kg, Pb 7 mg/kg and Zn 106 mg/kg (table 3.2).

Table 3.2: Elemental and nutrient analysis (heavy metals and essential trace elements)

Sl no.	Description	Measuring units	SLUSH	SEDIMENT
1	Bulk Density	kg/cum	500	1700
2	Organic Carbon	%	18	8
3	Nitrogen	%	3	0.35
4	Phosphorous	%	2.5	0.28
5	Cadmium	mg/kg	7	2.4
6	Cobalt	mg/kg	8	5
7	Copper	mg/kg	68	30
8	Iron	mg/kg	20935	13580
9	Manganese	mg/kg	140	98
10	Nickle	mg/kg	26	20
11	Lead	mg/kg	7	6.5
12	Zinc	mg/kg	106	45
13	Sodium	mg/kg	2175	2075
14	Potassium	mg/kg	7750	6025
15	Calcium	mg/kg	581	608
16	Magnesium	mg/kg	433	1452

The lake water samples were found to have a slightly high values of heavy metals (Cd: 0.55 mg/L; Cr: 0.4 mg/l; Pb 1.35 mg/l; Cu 0.21 mg/l and Ni 0.27 mg/l) value than the permissible levels (Cd : 0.01 mg/L; Cr: 0.1 mg/l; Pb 0.5 mg/l; Cu 0.2 mg/l and Ni 0.2 mg/l). The vegetable samples grown on these wastewater towards the lower reaches of the Varthur lake also showed high heavy metal content (Cd: 8.5 -11 mg/kg; Cr: 51-131 mg/kg; Pb 24-147 mg/kg; Cu 89-323 mg/ka and Ni from 0.5-91 mg/kg) compared to the Indian safe limits (Cd: 1.5 mg/kg; Cr: 20 mg/kg; Pb 2.5 mg/kg; Cu 30 mg/kg and Ni 1.5 mg/kg) that is alarming.

3.4 SEDIMENTS: Nutrient analyses and valuation of the quantum of Nutrients

The elemental analysis of the lake systems reveal high nutrient potential of the sedimentary material with organic matter (14 – 31%); C (8-18%) N (0.35 – 35%); P (0.28 – 2.5 %) and K (0.6 -0.7%). This concentration of nutrients in the sedimentary material with other trace and essential mineral nutrients are of superior quality and can be used directly as organic manures or as bio-fertilisers in the agricultural fields. In terms of mass percentage of the nutrients and from the available market values of the chemical fertilisers sold in the country, the priced for NPK have been derived and is provided in table 3.2. The worth of the total sedimentary material as nutrient laden supplementary dose to the agricultural land amounts to Rs 15, 000 crores that can fertilise millions of acres of land.

Table 3.3: Estimation of sedimentary materials and economics

Sl no	Description	Unit of measurement	BELLANDUR LAKE		VARTHURU LAKE	
1	Surface Area	hectares	367.34		190.78	
2	Water storage capacity (historical)	M.cum	18.67		6.10	
3	Current water storage volume	M.cum	5.50		1.61	
			SLUSH	SEDIMENT	SLUSH	SEDIMENT
4	Volume	M.cum	6.56	6.60	0.62	3.87
5	Weight	M.Ton	3.28	11.22	0.31	6.58
6	Bricks	Numbers	820045125	2806038275	77750000	1644325000
7	Gross Income from Bricks	Crore Rupee	410	1403	39	822
8	Number of Truck Loads	Number	131207.22	448966.12	12440.00	263092.00
9	Gross Income as Sand	Crore Rupee	328.02	1122.42	31.10	657.73
10	Organic Carbon	Ton	590432	897932	55980	526184
11	Nitrogen	Ton	98405	39285	9330	23021
12	Phosphorous	Ton	82005	31428	7775	18416
13	Cadmium	Ton	23	27	2	16
14	Cobalt	Ton	26	56	2	33
15	Copper	Ton	223	337	21	197
16	Iron	Ton	68671	152424	6511	89320
17	Manganese	Ton	459	1100	44	645

18	Nickel	Ton	85	224	8	132
19	Lead	Ton	23	73	2	43
20	Zinc	Ton	348	505	33	296
21	Sodium	Ton	7134	23290	676	13648
22	Potassium	Ton	25421	67626	2410	39628
23	Calcium	Ton	1906	6824	181	3999
24	Magnesium	Ton	1420	16297	135	9550
25	Organic Matter	Ton	1015544	1544443	96286	905036
26	Gross Income from Nitrogen	Crore Rupee	59.0	23.6	5.6	13.8
27	Gross Income from Phosphorous	Crore Rupee	287.0	110.0	27.2	64.5
28	Gross Income from Potassium	Crore Rupee	43.2	115.0	4.1	67.4
	Gross Income from Organic Carbon	Crore Rupee	4569.9	6950.0	433.3	4072.7
			16846.2			
33	Cost per kg	Rupee	30.24	12.83	30.24	12.83
35	Rebated Amount per kg	Rupee	25	12	25	12
34	Gross Amount @ 50% yeild	Crore Rupee	4100	6734	389	3946
	Gross Amount @ 50% yeild		10835		4335	
	Gross Amount @ 50% yeild		15170			

3.5 Depth: Bathymetric Survey

Bellandur Lake: Bathymetric study involves measuring relative lake depth / sounding at certain intervals using various techniques and instruments. In Bellandur Lake, depth measurements were carried out using graduated staff associated with GPS for position of measurement. At every position of sounding, dual measurements were made i.e., depth of water and depth of slush. Figure 3.8 depicts the position of depth measurements in Bellandur Lake. In order to quantify the sediment deposits in the lake, historical depths need to be known. The Survey of India topographic sheets of 1:50000 scale were used for understand earlier depth supplemented with the field interviews with the local fishermen (elderly). Depth of water varies from as low as 10 cm near the inlets to over 350 cm near the outlet, and depth of slush varies between 50 cm to 225 cm. Water storage capacity of Belladuru lake now is 5.5 Million cubic meters, and volume of silt deposit is nearly 6.56 Million cubic meters. Table 3.4 lists describes the quantity of silt, sediment, water *etc.* in the lake. Value of silt deposited in the lake ranges from 1122 crores (as sand) to 1403 crores (moulded to bricks).

© Ramachandra T V, Durga Madhab Mahapatra, Vinay S, Sincy V, Asulabha K S, Sudarshan Bhat, Bharath H. Aithal, 2017. Bellandur and Varthur Lakes Rejuvenation Blueprint, ENVIS Technical Report 116, Environmental Information System, CES, Indian Institute of Science, Bangalore 560012

Figure 3.8: Depth measurement locations (Bellandur Lake)
(Lake Boundary: Cyan, Current Water level: Yellow, depth measurements: Points)

Contours were used in order to develop historical bathymetric map of Bellandur lake. The analysis of contours shows that Bellandur Lake had a capacity of 18.67 Million cubic meters. Based on the bathymetric survey through sounding and depth profile from the topographic sheets, sediment volume in the lake was quantified (Figure 3.9 and 3.10). Volume of sediment present in the lake is about 6.60 Million cubic meters (Table 3.4). If the available sediment is used to mold burnt bricks, it would yield in gross income of rupees 1403 crores in Bellandur lake, and if the sediment is used as sand, gross income of rupees 1122 crores can be obtained.

Table 3.4: Summary of Bathymetric results

Slno	Description	Quantity
1	Surface area of Lake (hectares)	367.3
2	Storage Volume (Million cubic meters)	18.67
3	Current Storage Volume of Water (Million cubic meters)	5.50
4	Volume of Slush deposit (Million cubic meters)	6.56
5	Volume of Sediment deposits (Million cubic meters)	6.60
6	Bulk Density of Sediment (kilograms per cubic meter)	1700
7	Weight of Sediment present in the lake (Million Tonne)	11.22
	Using Sediment for moulding Burnt Brick	
8	Average Weight of Burnt Brick (kilograms)	4
9	Number of Bricks that can be manufactured using the sediment (Million)	2806
10	Cost of one Brick (Rupee)	5.00
11	Revenue generated by manufacturing Burnt Bricks (Crore Rupee)	**1403**
	Using Sediment For Construction	
12	Capacity of One truck (Tonne)	25
13	Number of Truck loads (thousands)	449
14	Cost of Low grade Sand for each truck load (Rupee)	25000
15	Revenue Generated from Sediment as sand (Crore Rupee)	**1122**

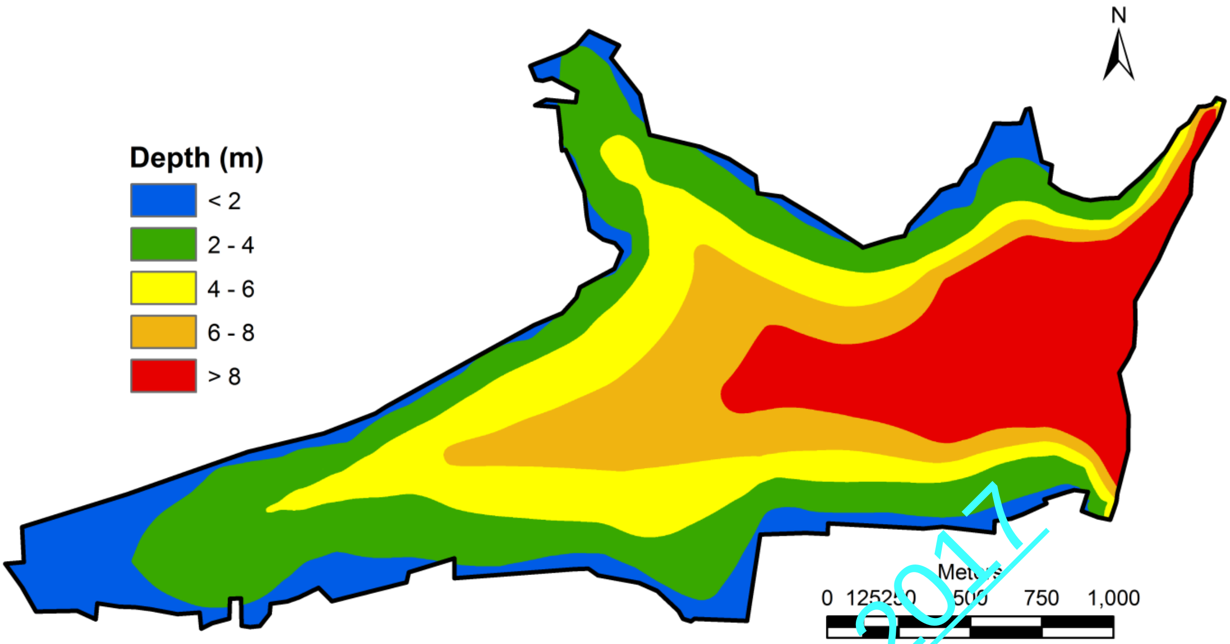


Figure 3.9: Historical Bathymetric Map of Bellandur Lake

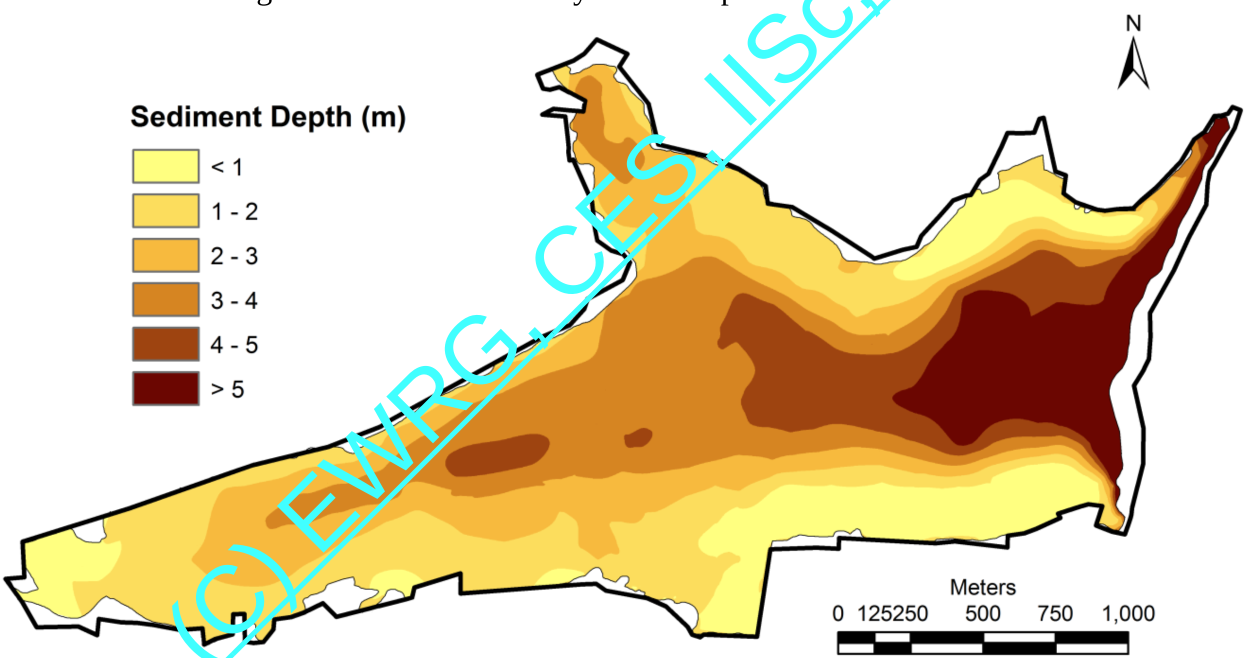


Figure 3.10: Sediment Accumulation in Bellandur Lake

Varthur Lake: Figure 3.11 depicts the position of depth measurements in Varthur Lake. Based on the bathymetric survey through sounding and depth profile from the topographic sheets, sediment volume in the lake was quantified (Figure 3.12 and 3.13). Depth of water varies from as low as 10 cm near the inlets to over 220 cm near the outlet, and depth of slush varies between 50 cm to 150 cm. Current water storage capacity of Varthur lake is 1.61 Million cubic meters, and volume of silt deposit is nearly 0.62 Million cubic meters. Volume of sediment present in the lake is about 3.87 Million cubic meters. Table 3.5 lists the quantity of silt, sediment, water *etc*. in the lake. Value of the accumulated silt ranges from 658 crores (sand) to 822 crore rupees moulded to bricks).

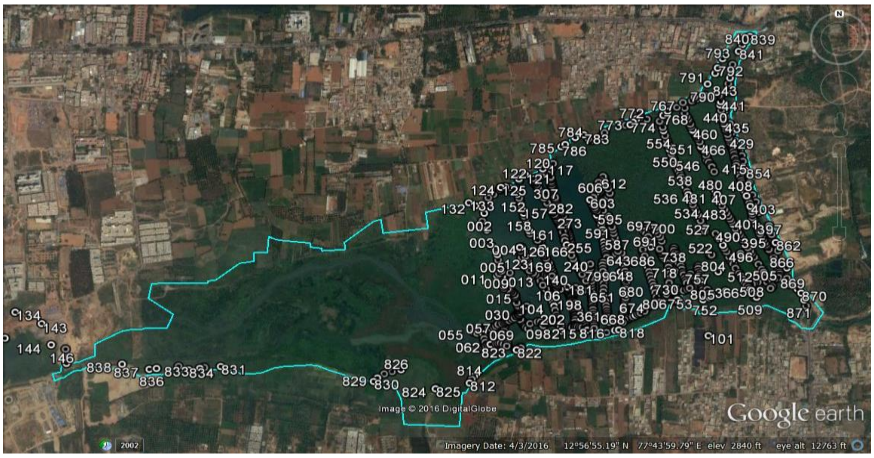


Figure 3.11: Depth measurement locations (Varthur Lake Boundary: Cyan, Sounding: Points)

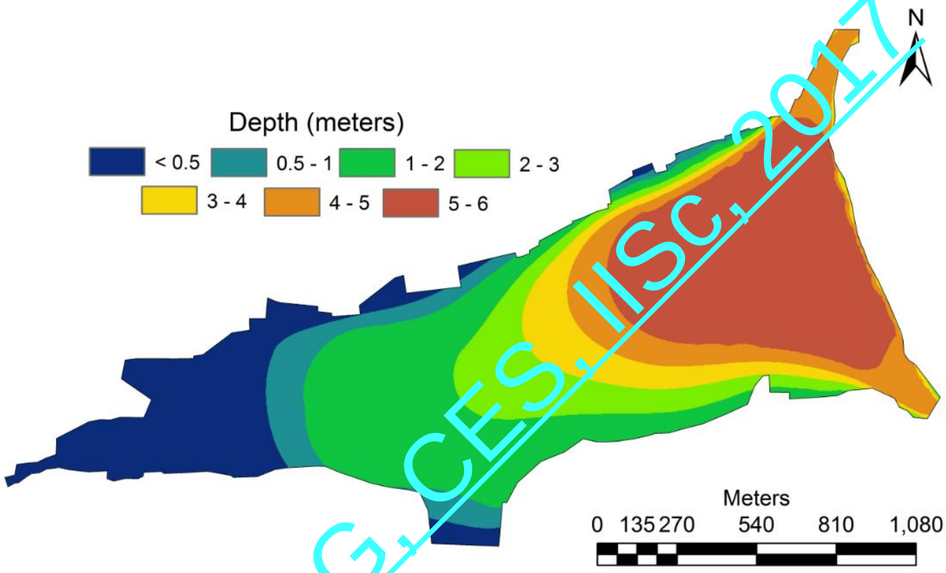


Figure 3.12: Historical Bathymetric Map of Varthur Lake

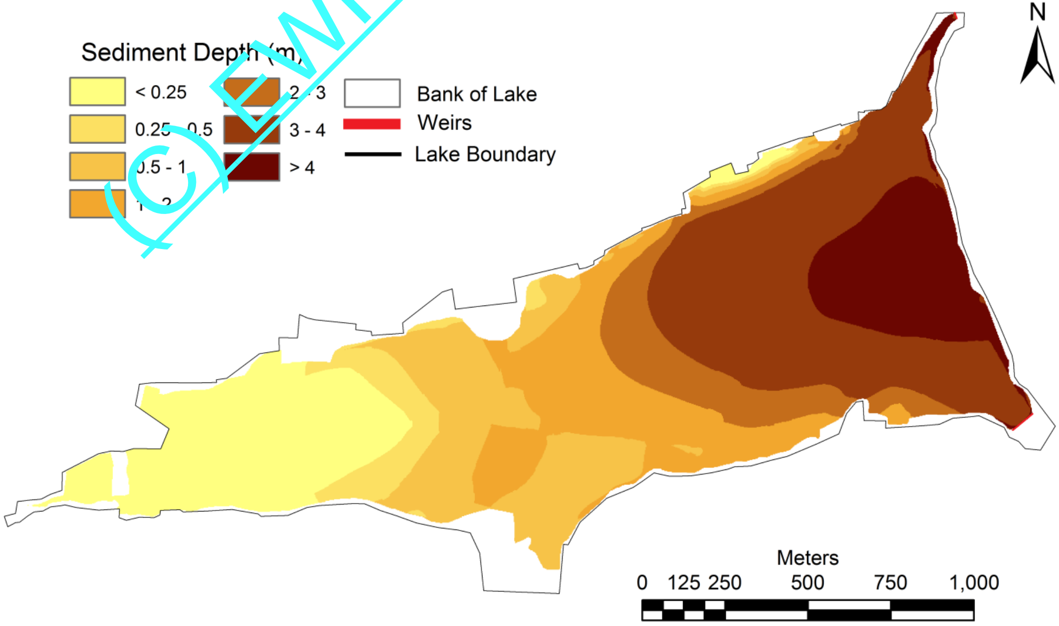


Figure 3.13: Sediment Accumulation in Varthur Lake

Table 3.5: Summary of Bathymetric results

Slno	Description	Quantity
1	Surface area of Lake (hectares)	190.75
2	Storage Volume (Million cubic meters)	6.10
3	Current Storage Volume of Water (Million cubic meters)	1.61
4	Volume of Slush deposit (Million cubic meters)	0.62
5	Volume of Sediment deposits (Million cubic meters)	3.87
6	Bulk Density of Sediment (kilograms per cubic meter)	1700
7	Weight of Sediment present in the lake (Million Tonne)	6.58
	Using Sediment for moulding Burnt Brick	
8	Average Weight of Burnt Brick (kilograms)	4
9	Number of Bricks that can be manufactured using the sediment (Million)	1644
10	Cost of one Brick (Rupee)	5.00
11	Revenue generated by manufacturing Burnt Bricks (Crore Rupee)	**822**
	Using Sediment For Construction	
12	Capacity of One truck (Tonne)	25
13	Number of Truck loads (thousands)	263
14	Cost of Low grade Sand for each truck load (Rupee)	25000
15	Revenue Generated from Sediment as sand (Crore Rupee)	**658**

3.6 Consequences of Lake Pollution:

- **Fish mortality**: Large-scale fish mortality in recent months further highlights the level of contamination and irresponsible management of water bodies. Sustained inflow of untreated sewage has increased the organic content beyond the threshold of remediation capability of respective water bodies. Increasing temperature (of 34 to 35 °C) with the onset of summer, enhanced the biological activities (evident from higher BOD and Ammonia) that lowered dissolved oxygen levels leading to fish death due to asphyxiation.

- **Decline in groundwater table and quality:** Water table has declined to 300 m from 28 m and 400 to 500 m in intensely urbanised area such as Whitefield, etc. over a period of 20 years with the decline in wetlands and green spaces. The analysis of groundwater samples in 1 km buffer region reveals (i) higher levels of nitrate, (ii) traces of heavy metal and (iii) biological contamination.

- **Increased GHG (Greenhouse gas) footprint**: Mismanagement of solid and liquid wastes has increased the anaerobic condition leading to emissions of greenhouse gases (methane, CO_2, etc.).

- **Frothing**: Foams are formed in lakes due to sustained inflow of sewage (rich in phosphates). Decomposition of algae, fish and macrophytes, releasing a variety of organic compounds into the water body. These organic compounds act as surfactants (foaming agents) that has a hydrophilic (water attracting) end and hydrophobic hydrocarbon chain (water repelling) at the other end. Also, surface-active agents in wastewater include synthetic detergents, fats, oils, greases and bio-surfactants. These agents rise to the surface of lakes and interact with water molecules thus, reducing the attraction of water molecules to each other (i.e. surface tension of the water). When the surface tension decreases, air mixes with the water molecules and foaming agents resulting in bubbles formation. These bubbles aggregate together and forms foam in lakes. The surface-active agents or surfactants reduce the surface tension of water, allowing air bubbles to persist at the water's surface. Natural surfactants include carboxylic fatty acids derived from lipids from macrophytes/weeds etc. These are released into water and contribute to a large variety of soluble organic material known as dissolved organic carbon (DOC). Though DOC is produced within lake waters, the major source is the sustained inflow of sewage from the vicinity of the lakes and the watershed. Higher DOC concentrations in lakes, generally impart a brown colour to the water. However, white colour of the lake foam (Figure 3.10.1) indicates that is caused by synthetically produced surfactants released through sewage to surface waters. Synthetic surfactants are widely used in household cleaning products (detergents/soaps), cosmetics and personal care products (shampoo, toothpaste etc.). Common detergents also contains branch-chained alkyl benzene sulfonate surfactants, which are non-biodegradable and results in extremely persistent foam accumulating below the fall levels in the lake and other wastewater outfalls.

Detergents and soaps mostly contain phosphate (P, ~30 % STPP) softeners to enhance the effectiveness of surfactants through the reduction of water hardness. P loading in lakes has contributed to nutrient enrichment with the proliferation of cyano-bacterial blooms and macrophytes (aquatic plants). There are set of advanced detergents that exclude phosphates but contain biodegradable linear alkyl benzene sulfonate surfactants, such as sodium or ammonium lauret or lauryl sulfate. Surfactants are also used by many industries as wetting agents, dispersants, defoamers, de-inkers, antistatic agents, and in paint and protective coatings, pesticides, leather processing, plastics and elastomer manufacturing, and oil extraction and production. A portion of phosphates is up-taken by aquatic plants while the balance gets trapped in the sediments. Pre-monsoon showers coupled with gusty winds leads to the churning of lake water with upwelling of sediments. Vigorous mixing of surface water coupled with high flow across narrow channels, leading to bubble formation that persist and build up as foam (Figure 3.10.1). The foams formed in large quantities moves to shorelines by wind and water currents. Natural foams are usually linked to humic and fulvic acid substances, fine colloidal particles, lipids and proteins released from aquatic or terrestrial plants, saponins (plant glycosides), the decomposition products of phytoplankton containing carbohydrates and proteins and the organic matter in sediments. In these lakes, foam /froth gets accumulated along windward shores. Continuous sewage fed in Bellandur and Varthur lakes, has been witnessing foam at downstream in chocked channels or below fall/discharge point since one decade (this is witnessed since 2000 and the quantum of foam has gone up by manifolds in recent times – post 2012).

Sampling and water quality analysis (subsequent to frothing in May 2015) reveals the presence of higher amount of different physico-chemical parameters like total dissolved solids (332-1246 mg/l); electrical conductivity (460-1470 µS); dissolved oxygen (0-8.16 mg/l); chemical oxygen demand (40-325.33 mg/l); biochemical oxygen demand (24.39-140.8 mg/l); alkalinity (56-520 mg/l); chloride (88.04-191.7 mg/l); total hardness (198-436 mg/l); calcium hardness (56.11-344.27 mg/l); magnesium hardness (18.08-124 mg/l); sodium (9-1046 mg/l) and potassium (0-130 mg/l), indicate pollution/sewage entry into the lake.

- **Fire:** Foam caught fire (figure 3.10.2) due to compounds with high flammability i.e. hydrocarbons and organic polymers that came from nearby industries in the vicinity of Bellandur lake. Discharge of untreated effluents (rich in hydrocarbon) with accidental fire (like throwing cigarettes, beedi) has led to the fire in the lake on 16th May 2015 (Source: Ramachandra, T. V., Asulabha, K. S., Sincy, V., Vinay, S., Aithal, B. H., Bhat, S. P., and Mahapatra, D. M., 2015. Pathetic status of wetlands in Bangalore: Epitome of inefficient and uncoordinated Governance. ENVIS Technical Report 93, CES, Indian Institute of Science, Bangalore).

Figure 3.10.1: Froth in Bellandur and crossing over mesh (failed short term arrogant measure!)

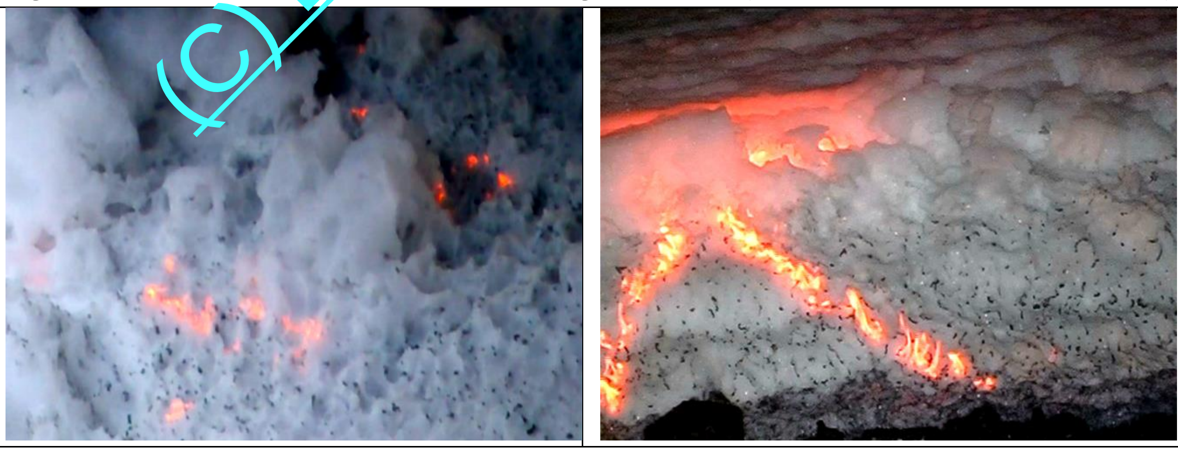


Figure 3.10.2: Fire at Yamlur outlet of Bellandur Lake

3.7 Overall Observation and Recommendations**:**

Due to the sustained influx of fresh sewage over the last several decades, nutrients in the lake are now well over safe limits. Bellandur and Varthur lakes being the end of the lakes series in the KC valley Varthur Lake has been receiving about ~45% of the city sewage for over last 60 years resulting in eutrophication. There are substantial algal blooms, Dissolved Oxygen (DO) depletion and malodour generation, and an extensive growth of water hyacinth that covers about 70–80% of the lake in the dry season. Sewage brings in large quantities of C, N and P which are responsible for eutrophication, profuse growth of macrophytes and algal bloom.

Recommendations: The restoration and conservation strategies has to be implemented for maintaining the ecological health of aquatic ecosystems, aquatic biodiversity in the region, inter-connectivity among lakes, preserve its physical integrity (shorelines, banks and bottom configurations) and water quality to support healthy riparian, aquatic and wetland ecosystems. The regular monitoring of water bodies and public awareness will help in developing appropriate conservation and management strategies.

The success of rejuvenation depends on:

- **Good governance** (too many para-state agencies and lack of co-ordination). Single agency with the statutory and financial autonomy to be the custodian of natural resources (ownership, regular maintenance and action against polluters (encroachers as well as those contaminate through untreated sewage and effluents, dumping of solid wastes). Effective judicial system for speedy disposal of conflicts related to encroachment.
- **Digitation of land records** (especially common lands – lakes, open spaces, parks, etc.) and availability of this geo-referenced data with query based information system to public;
- **Removal of encroachment of lakes / wetlands, lake beds and storm water drains** (connecting feeders) after the survey based on reliable cadastral maps; Ensure proper fencing of lakes and to make land grabbing cognizable non-bail offence;
- **Restriction of the entry of untreated sewage and industrial effluents into lakes;** Decentralised treatment of sewage (preferably at ward levels). Letting only treated sewage into the lake (as in **Jakkur lake model**); Ensure that sewage generated in a locality /ward is treated locally;
- **Removal of nutrient rich sediments** – to enhance the storage capacity, improve groundwater recharge, to minimise further contamination of treated water, etc.;
- **Ban on use of phosphates in the manufacture of detergents**; will minimise frothing
- Regular removal of macrophytes (*Eichhornia* sp., *Alternanthera* sp. etc.) in the lakes;
- Implementation of 'polluter pays' principle as per water act 1974;
- Plant native species of macrophytes in open spaces of lake catchment area;
- Stop solid wastes dumping into lakes / in the lake bed; Banning of filling of a portion of lake with building debris.
- Restrictions on the diversion of lake for any other purposes;
- Complete ban on construction activities in the valley zones.
- Decentralised management of lakes through local lake committees involving all stakeholders

4.0 SEWAGE TREATMENT PLANTS:

Koramangala Challaghatta valley

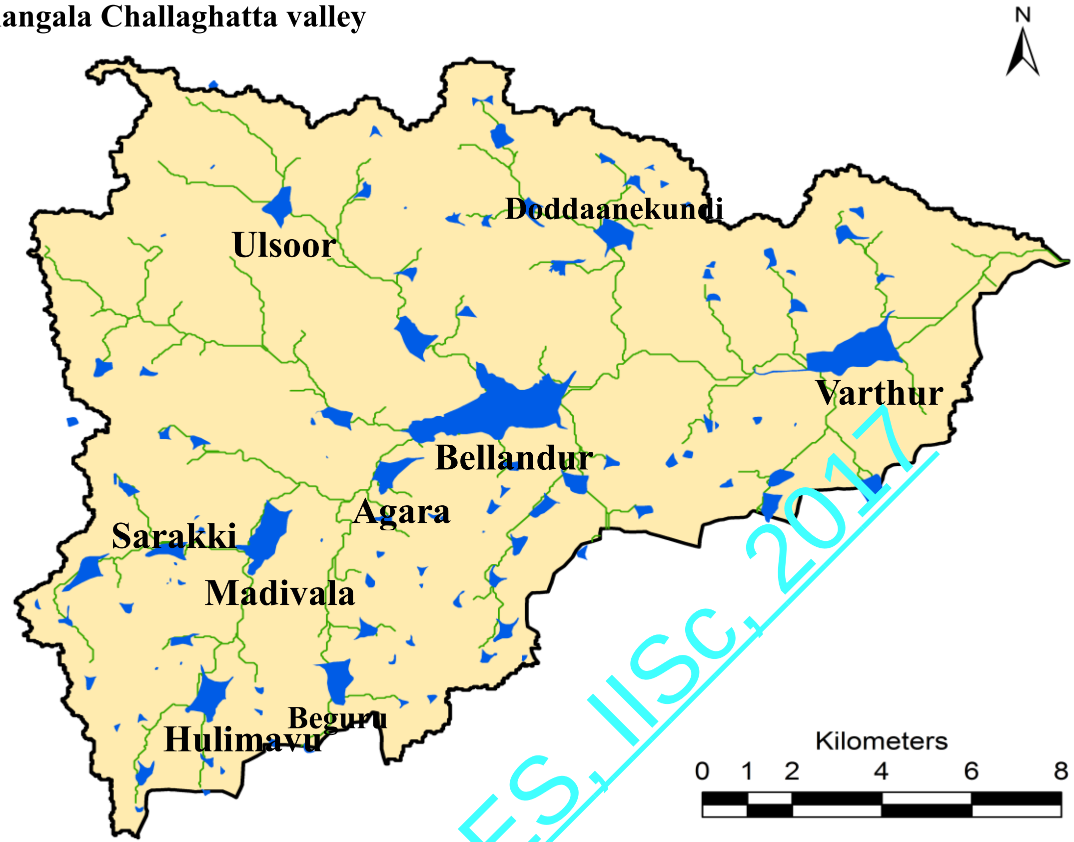


Fig. 4.1: The KC Valley catchment area

Presently there is a meagre understanding on the nutrient dynamics of urban systems in relation to the size of nutrient pool and type of losses across the transport process that can be understood with a mass-balance approach (Rodriguez and Macias, 2005). Considering the Nutrient inputs from the urban population (organised/un-organised) where we have high nutrient flux due to open sewers, soak pits, septic tanks and to a lesser extent practices like open urination and defecation, the nutrient flux as infiltrations would result in high leaching losses and reason for accumulation of nutrients in groundwater causing contamination. The present population in the city depends on ~30% on groundwater, with potentially high N enrichment due to the above mentioned causes. This requires immediate interventions in regulating and checking this enrichment in ground water sources that requires a proactive action with interdisciplinary knowledge driven decisions and identifying possible accountability on extent of damage already made to the ground water resources and the anticipated costs for the remediation/mitigation. Of the three catchments, the KC valley (Fig. 4.1) spanning over 255 km^2 forms the major lake cluster and collects bulk of the overland surface flows of the Bangalore city (~45 %) across the drainage channels mediated by historic storm water drains (Rajukaluves). Bellandur and then Varthur lakes (apparently the largest water bodies of the city i.e. 367 and 190 hectares respectively) form the end of the chain lakes in KC valley catchment before it drains to Kalaveripalli reservoir and Krsihnagiri dam in Tamil nadu and becomes a main feeder to Dakshina Pinakini River. These water bodies are of utmost importance in relation to water storage, and as an indicator of water quality, quantity and the nature of the catchment.

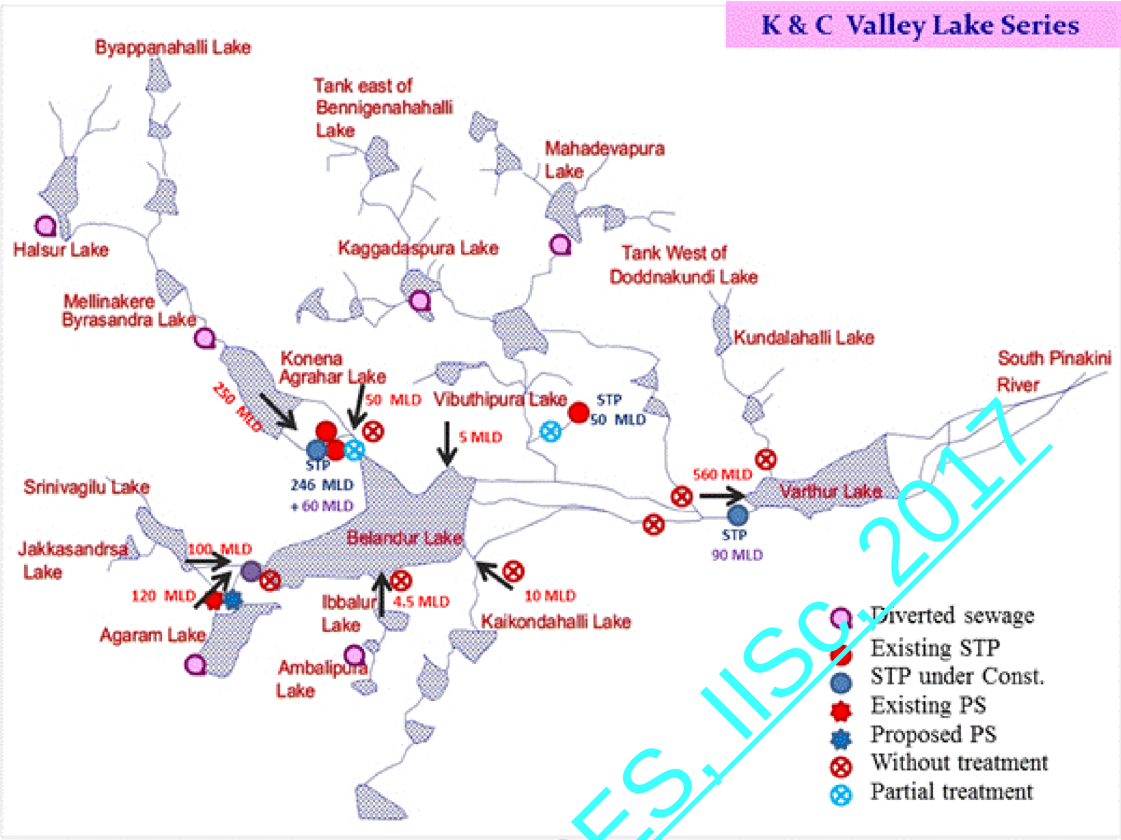


Fig. 4.2: Various lake series joining Bellandur and Varthur lakes

The KC valley catchment harbours about 56 lakes with a potential storage volume of ~200 million m^3 (~7.3 TMC), where the both Bellandur and Varthur at present have water storage capacities of ~5.5 and ~1.61 Mm^3 that is very small compared to the total catchment yields and the storage capacity of the lake system. However on the basis of historical data in terms of surface area and depth according to the Survey of India, topographic maps (based on contours) the potential storage capacity 18.67 Mm3 and ~6.10 Mm3 for Bellandur and Varthur respectively. This put together accounts to ~25 Mm^3 i.e. only one eighth of the potential water storage capacity of the catchment. On account of water balance of the region, the region receives >750 mm rainfall in ~40 % of the catchment area, from 750-850 mm rainfall in >50 % of the area and >850 mm rainfall in <10 % of the total catchment area. The runoff based on the natural topology of the region ranges from 500 to 700 mm. Based on this inputs the total overland flow in the KC valley catchment is around 5.3 TMC i.e. ~35 % of the total run off of Bangalore region. The feeder to Bellandur lakes are a) Ulsoor lake series (north-west); b) Hulimavu lake series C) Sarakki lake series d) Beguru lake series e) Ambilipura lake series f) kaikondarahalli lake series and g) Doddaanekundu lake series According to the studies conducted earlier considering the net water supply to the city. An estimated ~500 MLD of total wastewater flows in the catchment that are partially treated by the STP's. The existing treatment facility running in the KC valley is the K & C valley STP 248 MLD (163+55+30); Madivala STP (4 MLD) and Kadabesena halli STP (50 MLD) (provided in Fig. 4.2). These treatment units running at ~50 5 of its installed capacity and highly inadequate to treat the wastewater of the region. Though there are new provisions for many new STP's at crucial important sewerage drawing location proposed by BWSSB under SWD Plan a strategic know how of the drainage basin and the sewerage load is still missing in the conceptual plan. Some of the STP's in the KC valley have been already commissioned and are projected to work from march, 2017 as an extension of the K and C valley STP for another 60 MLD, Bellandur Ammanikere STP (90 MLD). These systems still needs a huge quantity of electricity to pump sewage from the pumping units located at Agaram lake (additional pumping unit being built) to the STP's i.e 60 MLD to additional treatment unit to K & C valley and 90 MLD to Bellandur ammanikere STP upstream of Varthur. To save the cost of laying UGD to these centralised STP's, and capital and OM cost of the present pumping station and the additional pumping requirement a potential option is to treat the wastewater right at the collection node near the mouth of the trunk sewers, by setting up an STP in the land earmarked for public utilities like waste management in this area (Fig. 4.3).

Fig. 4.3: Inlets to Bellandur lake - total wastewater influx and the area earmarked for public utility as per CDP

The flow calculations shows a sewage influx of >500 MLD, considering ~5% as evaporation losses around ~25 MLD is lost to atmosphere. Sewage from the residential sector is about 420 MLD (Annexure III). An additional 40 MLD is contributed by the immediate peripheral wastewater influx apart from major inlets from KC valley and Agaram inflow points. These are contributed by the sewerage from HAL, Challaghatta, Ibblur lake etc. Large influx of sewer water into the lakes despite treatment efforts by BWSSB are due to diversions of sewage from major lake inlets directly into Bellandur lake. Similarly the flow estimation of Varthur lake shows 560 MLD of wastewater entering through the major inlet from Ammanikere and additional 30 MLD from the peripheral water influx regions adding up to a total of ~590 MLD into the lake (Fig. 4.4).

In the city considering an average population density of 10,000 person/sq. km i.e. ~100 person/ha with a use of ~20 gN/capita/day, the anthropogenic N flux is ~0.73 tons/ha/yr. As the cost of nutrients have been exceedingly high, this is the right time where the principles of re-use and recycle can be adopted to augment out nutrient requirements where we have huge resource constraint in the state. In case of the K and C valley and other lake series draining into the Bellandur and Varthur lake series assuming that ~50 % of N inflows into sewers. The balance N fraction can losses due to leaching, on land decomposition, decomposition along the flow path of ~15 km through decomposition in water and bacterial and algal uptake during the flow. Even then ~45 tons of N enters into this system every day (TN entering the system ~60-90 mg/l). The total loading rate of N in Bellandur lake ~8.18 gN/m^3/day. Where the Bellandur lake traps and transforms ~60 % of the TN and there is a loss of ~40 % (~20-40 mg/l) and around ~60 % of then is cellular N. This N escaping from the system becomes a huge load to adjoining lake systems as Varthur. Provisions for a complete capture of this appreciable N pool will lead to complete resource recovery that is presently undervalued and inadequately and unsuitably used. Similarly considering ~5 gP/capita/day, the anthropogenic P flux is ~0.18 tons/ha/yr and the lading rate is around 3.63 gP/m^3/day. ~20 tons of P enters the Bellandur lake system (TP entering the system 15-30 mg/l). Here the net P accumulated in the system is ~70 % and the balalnce flows out through the outlets. The major sources of P are human excrements and extensive use of sodium tri-poly phosphate (STPP) based detergents and to a smaller extent industries in the catchment. These huge urban nutrient pool sizes can be estimated with help of steady state mass balance approach.

The urban sewerage system transports a massive quantity of carbonaceous compounds mainly in the organic form to the downstream regions with the help of the lake systems in Bangalore. The Bellandur lake series comprise of few lake systems that joins at the Bellandur segment. Earlier reports from as per LDA, 2006 show ~ 400-500 MLD of sewage entering the Bellandur Lake. With a water spread area of 380 ha and an average depth of 2 m, the total wastewater influx into the Bellandur lake ~500 MLD, the HRT of the system ~16 days during high flow conditions and ~20 days during low flow conditions considering the flow as ~400 MLD. During monsoon the lateral run-off and the additional storm water further pulls down the average HRT of the lakes ~7-10 days. Considering TOC variation of 120 to 390 mg/l with a flow of ~500 MLD. The total C input into the lake on an average 125 tons/day. Due to stagnation and various stationary zones on the surface of the lake the contents of the lake do not mix completely like a continuously stirred tank reactor (CSTR) and acts as a mixed flow reactor (MFR). For the calculated input of ~125 tC and the present volume of the lake ~5.5 Mm^3, the C loading rate is 22.73 $gC/m^3/d$ into Bellandur lake. Compared to the loading rates observed in a sewage treatment lagoon and detention ponds these vales are nominal and can be easily managed by mere detention by virtue of the bio-physical and chemical transformations. But, these systems act as incompletely mixed reactors with a negligible surface flow and higher detention resulting in uneven oxic/anoxic zones with varying treatment abilities.

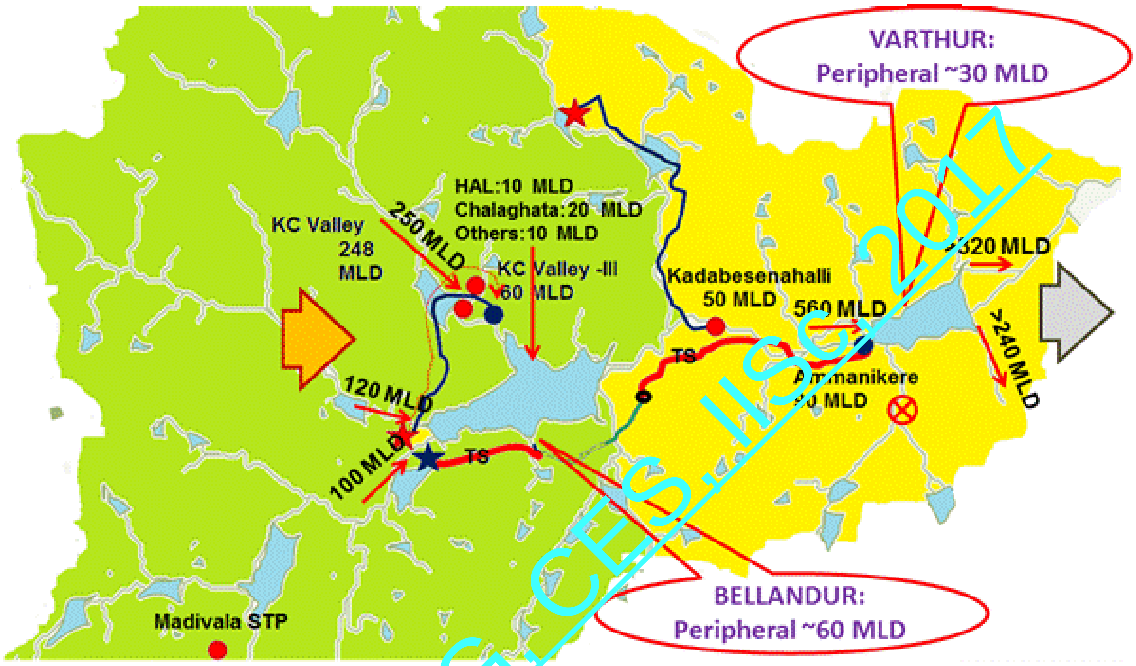


Fig. 4.4: Present sewerage system and proposed sewer lines with pumping stations

4.1 Waste-Water Treatment Unit Operations and Processes

The wastewater treatment bioprocesses transform minute solids and dissolved organic matter present in wastewaters into organic and inorganic solids that can be settled by application of flocculants.

Process analysis:

1. Microbes as bacteria – transforms particulate carbonaceous colloidal matter and dissolved organics present in wastewater into bulkier cellular lumps/tissues and into gases as a metabolic by product.
2. The gases escape into the environment
3. The cellular masses are removed with the help of sedimentation tanks or clarifiers.
4. The main objectives of Bio-treatments are to reduce organic matter in wastewaters mainly measured in the form of BOD, COD and TOC.
5. Bio-treatments also remove nutrients (N and P) from wastewaters.
6. These bioprocesses are used in tandem with other physico-chemical processes for attaining optimal effluent quality.
7. Bio-processes technologies used in wastewater treatment can be broadly divided into three categories – Aerobic, Anaerobic and Anoxic
8. These processes can be run either as suspended growth system or attached growth system or as a combination of both.

Working of Conventional Wastewater Treatment Systems: The conventional treatment set up for wastewaters comprise of primary, secondary and tertiary treatments (Table 4.1) that involves various steps

Screening is essentially to remove larger floating solids that take a very long tome for breakdown and decomposition. The screen comprises of an ordered array of flat metal plates that are welded to the horizontal bars at ~ 4 cm – 2 cm spacing. During the course of the water flow, the screens are juxtaposed perpendicular to the flow direction. The large amount of floating materials, sand debris, polymers etc stuck to the screen is removed manually or through other mechanical means. These floatable materials are then carried out as solid waste for proper disposal.

The grit removal process mainly intends to remove heavy and inert inorganic matter. Grit, dense coarse materials, sand, shells, gravel and other heavy inorganic matter tend to settle bt sedimentation in the settling basin within a minute. The materials are then send to proper disposal sites.

The primary clarification happens in a settling basin that is intended for settling of heavier inorganic matter. These clarifiers have detention period of ~ 120 minutes and are mostly circular in shape. The settled materials on various parts of the clarifiers are scraped and pushed towards the centre with the help of rakers and the settled material mostly known as primary sludge are then transported to the through the primary sludge pump to the sludge digesters. Importantly in this exercise ~40 % of BOD and ~70 % of suspended solids are removed.

Secondary treatment involving suspended aerobic processes in carried out with the help of aerobic microbes. At this stage, the wastewater are mostly devoid of particulate inorganic and organic matter and comprise of decomposed or semi-decomposed organic matter i.e. carbohydrates, proteins, lipids, fibres etc., in the presence of oxygen and aerobic bacteria these compounds are broken down into simpler forms as carbon dioxide, ammonia, water etc. The microbial activity transforms these dissolved forms into flocculating biomass and the finer organic matter into settleable mass. The oxygen is provisioned through the help of surface aerators that helps in the growth of aerobic bacteria that are required for the decomposition of organic matter. The powerful surface aerators droves the wastewater through a mechanical churning process from the bottom of the aeration tank units and splatters it over the surface thus ensuring oxygenation mobilisation.

Secondary treatment involving attached growth processes involves of wastewater over a combination of media that acts as substrates for attachment and growth of microbes over the surfaces. In this biological process the surface grown biological microbial assembly absorbs the organic matter the wastewaters and starts multiplying of the surface of the substrates. When the weight of the surface biomass becomes critical is swept away by the trickling waters that captured in the subsequent settling units and are often recycled back. Various types of media can be used for development of the attached microbial communities as gravel, pebbles; granite of ~10-15 cm is often used in trickling filters.

The final round of settling the solids is performed by the secondary clarifiers where the microbial flocks comprising of cellular biomass and organic aggregates are made to settle. Usually these settling clarifiers are circular in shape and with a retention time of ~90-120 min. The same rakers are used to draw the settled sludge to the centre which is then carried for recirculation to the aerobic tanks or the trickling filters. The excess amount of the solid/sludge is transferred to the sludge thickeners that separate the excess water content in the sludge. This biological process ensures ~90% of BOD removal and ~90% of SS removal of the influent wastewater.

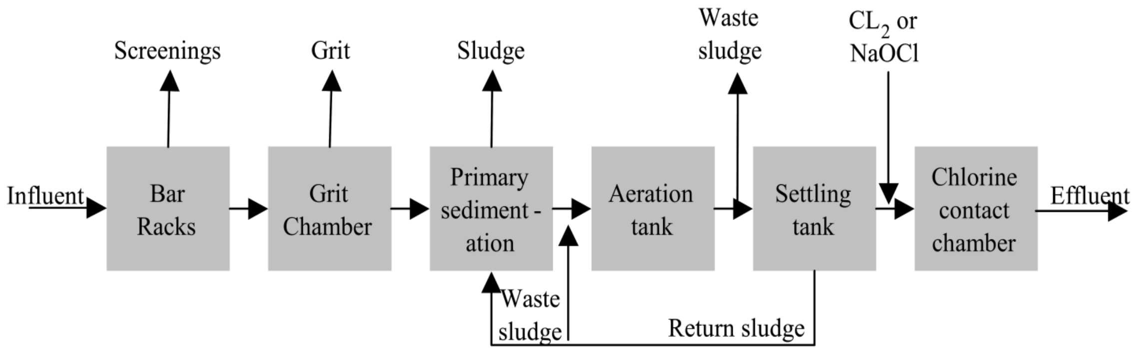
Table 4.1: Various wastewater treatment and process parameters

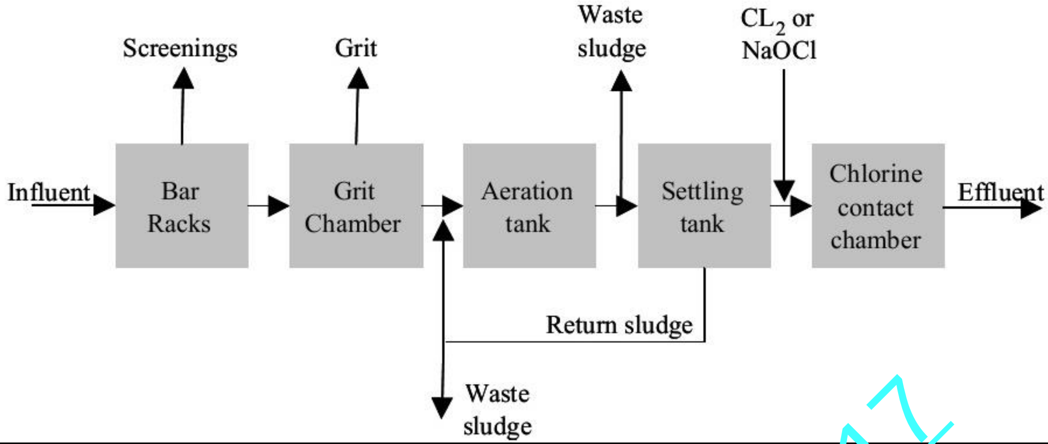
Physical	Chemical	Biological
• **Screening** • **Comminute** • **Flow equalization** • **Sedimentation** • **Flotation** • **Granular-medium filtration**	• Chemical precipitation • Adsorption • Disinfection • Dechlorination • Other chemical applications	• Activated sludge process • Aerated lagoon • Trickling filters • Rotating biological contactors • Pond stabilization • Anaerobic digestion • Biological nutrient removal

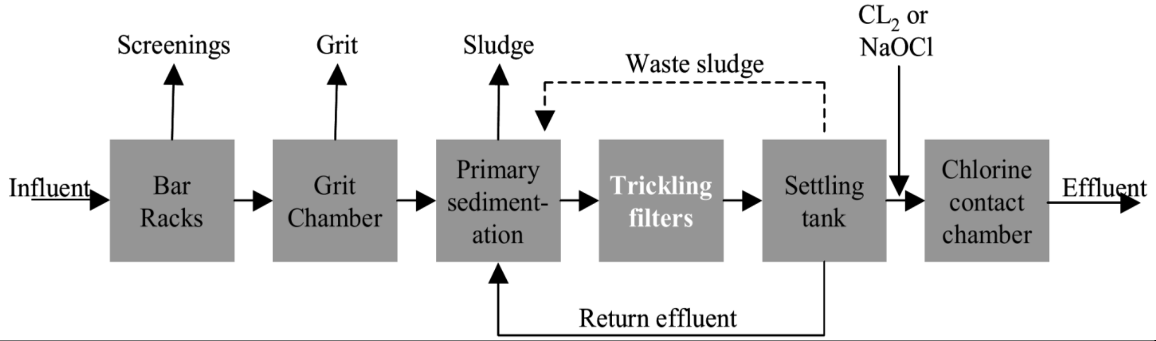
WWT Technologies working at Bangalore are

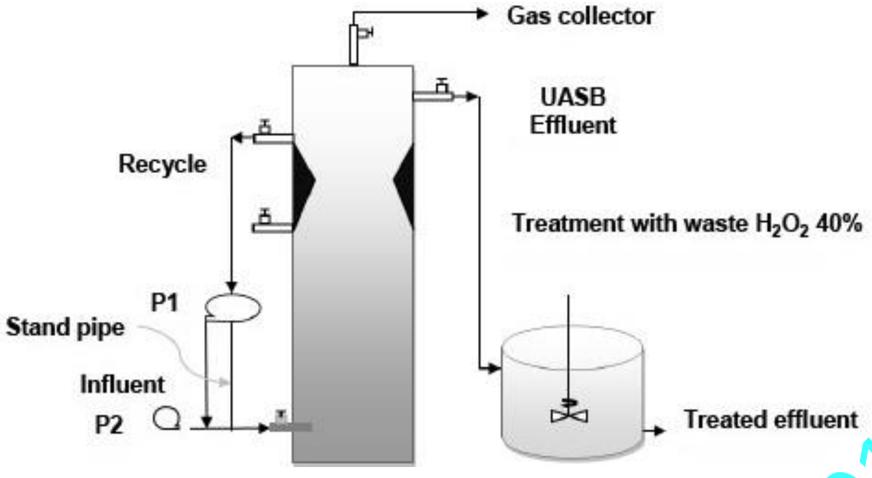
1. ASP (Activated Sludge Process)
2. EA (Extended Aeration)
3. TF (Trickling Filters)
4. UASB (Up-flow Anaerobic Sludge Blanket Reactor)
5. SBR (Sequential Batch Reactor)
6. MBR (Membrane Bio-Reactor)
7. MBBR (Moving Bed Biofilm Reactor)
8. CAB (Cascading Algal Bioreactor)

Table: 4.2: Comparative assessment of wastewater treatment process

I	**Treatment Process: Activated-sludge process (ASP/EA)**
2	**Sketch** 
3	**Technical details and Operation** ASP is microbial assisted wastewater stabilisation technique that runs continuously in an aerobic environment with the help of activated i.e. force suspended bacterial mass. In this process the clarified wastewater after preliminary treatment including primary settling in let into an aeration basin in which activated biomass mostly comprising of bacteria and protozoans aerobically degrade the wastewater organics into CO_2, sludge mass (new cells) and other end products. The microbes that forms the activated biomass in ASP mainly comprise of gram negative bacteria, C and N oxidisers, floc/non-floc forming members, aerobic and facultative anaerobic bacteria. The other group of organisms are the protozoans that are flagellates, ciliates and amoeba. To maintain the aerobic environment for the growth and development of the above mentioned microbial communities aerobic conditions are maintained either with the help of mechanical or diffused aeration in the treatment basin. This also serves to maintain a completely mixed system essential to keep the contents in the reactor usually known as the mixed liquor distributed in the basin. With in a short retention time the organics are converted essentially into larger sludge masses and CO_2, and then the mixed liquor is transferred to the secondary clarifier where the sludge/biomass is allowed to settle and the clarified effluent is all set for disposal and reuse. During this operation, a substantial part of the sludge from the secondary clarifier is recycled back to the aeration unit to maintain the activated biomass concentrations. **Land Area requirement:** 0.09 Ha/MLD (0.1 Ha/MLD-Tertiary Treatment included) **Power requirement:** 186 kWh/d/MLD
4	**Feasibility** This is the most widely used option for treatment of domestic wastewater for medium to large towns where land is scarce. ASP is only appropriate for a centralized treatment facility with the construction of long distance sewage channels, a well-trained staff, constant electricity, technical equipment (monitoring appliances), appropriate funding and a highly developed management system that ensures that the facility is correctly operated and maintained. Because of economies of scale and less fluctuating influent characteristics, this technology is more effective for the treatment of large volumes of flows of municipal wastewater from medium to large towns of 10000 - 1 million population equivalent. ASP works in almost every climate for the removal of both settable (physical primary treatment) and dissolved, colloidal and particulate organic matter and nutrients (biological removal in the activated sludge). The treatment capacity is low in colder environments.
5	**Economics:** Infrastructure/Capital Cost: Rs. 68 lakhs/MLD OM Cost: Rs. 12 lakhs/MLD/Y Running cost: 0.32 paisa/litre
6	Suitability in the present context: Unsuitable

II	**Extended aeration (EA)**
1	**Treatment Process: Extended aeration (EA)**
2	**Sketch** 
3	**Technical details and Operation** This aerobic bioprocess can be considered as a small modification to the ASP where the untreated raw wastewater is directed straight away to the aeration basin without any primary clarification for treatment. Such simplifications tend to provide longer aeration time (thus called extended aeration) with retention and thus reduce the need for additional mechanisation. A high BOD removal through extended aeration makes it highly desirable that needs a tertiary treatment for a high effluent quality. It is mostly preferred over ASP where the waste loads are relatively low and provides lesser needs for mechanisation. In case of ASP both clarifiers generate voluminous sludge that requires sludge treatment and processing before disposal. However EA agitates all wastewater and the sludge in a single clarifier. This results in high concentration of inert solids than in secondary sludge. Therefore a longer HRT with adequate mixing time is required for the digestion of primary solids in addition to organic matter in the dissolved form that produces an aged sludge. This requires greater energy per unit volume of the waste oxidised. Unlike conventional ASP aged sludge is produced in extended aeration process. **Land Area requirement:** 0.08 Ha/MLD (0.1 Ha/MLD-Tertiary Treatment included) **Power requirement:** 186 kWh/d/MLD
4	**Feasibility** Extended aeration is typically used to minimize design costs for waste disposal from small communities, commercial facilities and establishments, or schools. Compared to conventional ASP, a longer mixing time with aged sludge offers a stable biological ecosystem better adapted for effectively treating waste load fluctuations. In some instances C sources as sugar is added to sustain essential micro biota for treatment when the feed has no carbonaceous matter. Sludge has to periodically removed, as sludge volume approaches the storage capacity.
5	**Economics** Infrastructure Capital Cost: Rs. 68 lakhs/MLD OM Cost: Rs. 11.75 lakhs/MLD/Y Running cost: 0.32 paisa/litre
6	Suitability in the present context: **Unsuitable**

III	**Trickling Filters (TF)**
1	**Treatment Process: Trickling Filters (TF)**
2	**Sketch** 
3	**Technical details and Operation** Trickling filters are aerobic attached growth systems and are the most common biological treatment process in this category that efficiently removes wastewater organics. The TF comprises a bed made up of a highly permeable medium. This acts as a substratum to which several organisms are attached forming a bio-film, through which the wastewater percolates and falls off. The filter media are rocks or dense plastic matter used as packing material. The bio-film or the slimy layer absorbs the essential organic matter present in the wastewater and are also adsorbed on to the slimy layer. The outermost portion of the slimy layer comprise of aerobes that degrade the organic matter aerobically. With more exposure of the slimy layer with the nutrients in wastewater, the thickness of the bio-film grows and thus at deeper layers relative concentration of O_2 is low, thereby promoting the growth of anaerobic microflora just near the filter medium. As the bio-film thickness increases in this attached growth process, the organic matter is completely degraded before it reaches the microbes near the surface of the filter media. This results in deprivation of nutrients which consequently leads to death of the surface micro-biota and are thus removed on their own by the velocity of the flowing liquor that is known as "sloughing". The liquid after filtration is collected with the help of an underdrain system, in addition to bio solids, that gets detached from the surface of the medium. The collected treated water is then clarified with the help of a settling tank, where the solids are separated from the treated wastewater. **Land Area requirement:** 0.25-0.5 Ha/MLD **Power requirement:** 180 kWh/d MLD
4	**Feasibility** This technology can only be used following primary clarification since high solids loading will cause the filter to clog. Since trickling filters only receive liquid waste, they are not suitable where water is scarce or unreliable. Moreover, trickling filters require some specific material (i.e. pumps and replacement parts) and skilled design and maintenance. A low energy (gravity) trickling system can be designed, but in general, a continuous supply of power and wastewater is required. However, energy requirement for operating a trickling filter is less than for an activated sludge process or aerated lagoons (extended aeration). Compared to other technologies (e.g., WSP), trickling filters are compact, but are still best suited for peri-urban or large, rural settlements. Trickling filters can treat domestic blackwater or brownwater, greywater or any other biodegradable effluent. They are typically applied as post-treatment for upflow anaerobic sludge blanket reactors or for further treatment after activated sludge treatment. Trickling filters can be built in almost all environments, but special adaptations for cold climates are required. Proper insulation, reduced effluent recirculation, and improved distribution techniques can lessen the impact of cold temperatures.
5	**Economics:** Infrastructure/Capital Cost: Rs. 4-5 million/MLD OM Cost: Rs.5 lakhs/MLD/Y Running cost: 0.141 paisa/litre
6	Suitability in the present context: **Unsuitable**

IV	Up-flow Anaerobic Sludge Blanket Reactor (UASB)
1	**Treatment Process: Up-flow Anaerobic Sludge Blanket Reactor (UASB)**
2	**Sketch** 
3	**Technical details and Operation** Up-flow anaerobic sludge blanket (UASB) technology is an anaerobic wastewater treatment technique. The treatment process involves formation of a blanket of granular sludge that remains in suspension in the reactor. The wastewater is pumped upwards, through the blanket of sludge and in the mean time the organic matter present in the wastewater in degraded by the anaerobic microflora present in the sludge. The upward flow due to pumping in conjugation with the settling action of the sludge granules due to gravity helps in the suspension of the sludge blanket with the help of wastewater derived flocculants. The sludge forming process is slow, which initiates with the formation of small minute aggregates over which bacteria grows and eventually these aggregates form into dense and compact bio-films called granules. Anaerobic environment in conducing for the production of biogas in UASB that has high % of CH_4. This gaseous by product can be captured and generate energy that reduces the running power cost. The UASB reactors are suitable for diluted wastewaters (<3 % TSS with particle size ~1 mm). **Land Area requirement:** 0.1 Ha/MLD (0.11 Ha/MLD-Tertiary Treatment included) **Power requirement:** 126 kWh/d/MLD
4	**Feasibility** A UASB is not appropriate for small or rural communities without a constant water supply or electricity and skilled labour. It is particularly adapted for densely populated urban areas as it has low land requirements. The technology is relatively simple to design and build, but developing the granulated sludge may take several months. The UASB reactor has the potential to produce higher quality effluent than Septic Tanks, and can do so in a smaller reactor volume. Although it is a well-established process for large-scale industrial wastewater treatment and high organic loading rates up to 10 kg BOD/m^3/d, its application to domestic sewage is still relatively new. It is often used for brewery, distillery, food processing and pulp and paper waste since the process typically removes 80-90% of COD. Where the influent is low-strength or where it contains too many solids, proteins or fats, the reactor may not work properly. Temperature is also a key factor affecting the performance. UASB reach high treatment levels regarding organics and the produced biogas can be used for energy conversion. Pathogens, however, as well as nutrients are not removed. Due to the low nutrient removal, the effluent is adapted for reuse in agriculture after further treatment or considering some special health protection measures. UASB are not adapted for colder climates.
5	**Economics:** Infrastructure/Capital Cost: Rs. 6.8 million /MLD OM Cost: Rs.11.53 lakhs/MLD/Y Running cost: 0.28 paisa/litre
6	Suitability in the present context: **Suitable but requires further treatment**

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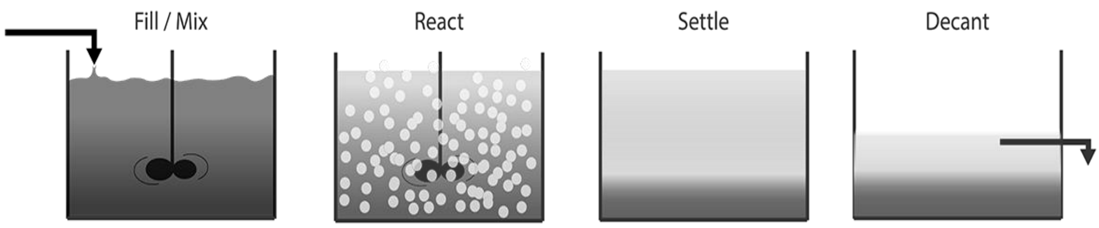
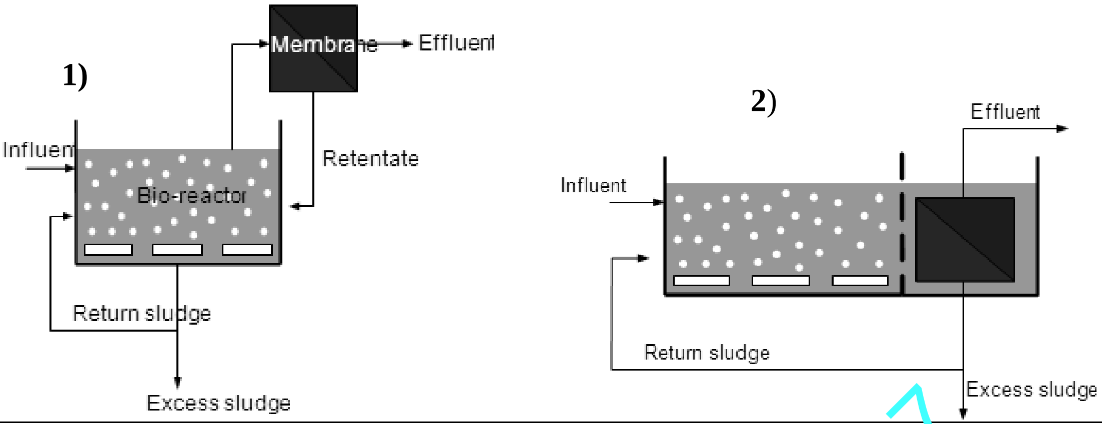
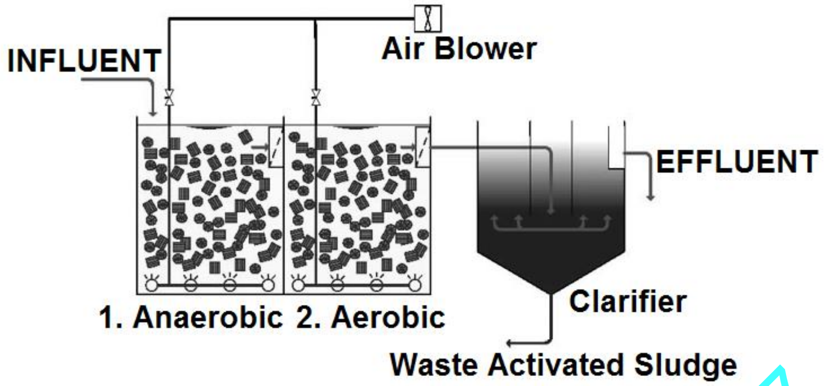
V	Sequential Batch Reactor (SBR)
1	**Treatment Process: Sequential Batch Reactor (SBR)**
2	**Sketch** 
3	**Technical details and Operation** A sequencing batch reactor (SBR) is a treatment process that consists of a sequence of steps that are carried out in the same containment structure, usually a tank reactor. They are also referred to as “fill-and-draw” systems. Although SBR systems exist that do not use aeration (anaerobic SBRs), a typical SBR system is designed to include aeration in the treatment step. A typical sequence for a SBR system is: 1. FILL, when the tank is filled with fresh wastewater, 2. REACT, when aeration and mixing are used to promote microbial removal of waste constituents, 3. SETTLE, when aeration and mixing devices are turned off to allow settling of suspended solids, and 4. DRAW, when clear effluent is drawn from the top of the reactor. Waste solids can be removed from the reactor after the DRAW stage from the bottom of the tank, or during the REACT stage while the wastewater is completely mixed. The SBR treatment process requires a liquid waste input, so it is more suitable for flush systems than for scrape or pit-storage systems. **Land Area requirement:** 0.045 Ha/MLD (0.05 Ha/MLD-Tertiary Treatment included) **Power requirement:** 154 kWh/d/MLD
4	**Feasibility** SBRs are typically used at flow rates of 5 MGD or less. The more sophisticated operation required at larger SBR plants tends to discourage the use of these plants for large flow rates. As these systems have a relatively small footprint, they are useful for areas where the available land is limited. In addition, cycles within the system can be easily modified for nutrient removal in the future, if it becomes necessary. This makes SBRs extremely flexible to adapt to regulatory changes for effluent parameters such as nutrient removal. SBRs are also very cost effective if treatment beyond biological treatment is required, such as filtration.
5	**Economics:** Infrastructure/Capital Cost: Rs. 7.5 million /MLD OM Cost: Rs.8.51 lakhs/MLD/Y Running cost: 0.29 paisa/litre
6	Suitability in the present context: **Suitable but requires further treatment**

VI	**Membrane Bio Reactor (MBR)**
1	**Treatment Process: Membrane Bio Reactor (MBR)**
2	**Sketch** 
3	**Technical details and Operation** A membrane bioreactor functions with a coupled activity of membrane filtration with a biological active sludge system. Such systems help in replacement of the sedimentation basin as observed in classical biological purification and aids in separation of sludge from the effluent. This helps to ensure that all floating matter is retained, whereby sedimentation is no longer a restrictive factor for sludge concentration. A membrane reactor is thus able to process significantly higher sludge concentrations (10-20 g/l) with a lower reactor volume, compared to conventional systems. The membrane can either be placed next to the biological basin (1. External or separate system), or in the basin (2. Internal or submerged). External systems involve continuous cross-flow circulation along the membranes. Both tubular and flat plate membranes are used to realise this. An internal system involves the effluent being extracted from the active sludge using under-pressure. This normally involves the use of hollow fibres or flat plate membranes. Micro and ultra filtration membranes are used for both types of MBR. **Land Area requirement:** 0.45 Ha/MLD (No Tertiary Treatment required) **Power requirement:** 302 kWh/d/MLD
4	**Feasibility** Membrane reactors are have been used throughout the world, for industrial as well as municipal wastewaters now. Membrane bioreactors can be used for biologically degradable wastewater flows as municipality wastewaters. The quality of the MBR permeate is greatly determined by the quality of the influent. Disruptive substances (e.g. long fibres or sharp particles) that can block or damage the membrane must be removed before wastewater is added to the MBR. Undissolved matter can normally be sufficiently removed using a simple sieve (gauze width 0.5 - 2 mm). Dissolved substances, primarily high calcium content and aluminium salts, can also cause damage to the membranes. Specific toxic partial flows from the chemical industry are not suitable unless sufficiently diluted with other process effluents. Excess sludge is produced as a by-product and necessitates from the system on a regular basis. The cleaning fluids also need to be disposed of. AOX could form if cleaning is carried out using NaOCl. Pure oxygen (O_2) can be used to introduce sufficient oxygen into the MBR. This will result in fewer problems with foam and odour-forming.The MBR combines a biological wastewater purification system with a physical process, which increases the complexity. Both steps require specific attention to process execution and optimisation of control parameters. Full-scale MBR systems are normally thoroughly automated. Close follow-up is needed to allow the process to run correctly.
5	**Economics:** Infrastructure/Capital Cost: Rs. 30 million/MLD OM Cost: Rs. 1.2 lakhs/MLD/Y Running cost: >2 paise/litre
6	Suitability in the present context: **Suitable but can only used at decentralised levels**

VII	**Moving Bed Biofilm Reactor (MBR)**
1	**Treatment Process: Moving Bed Biofilm Reactor (MBR)**
2	**Sketch** 
3	**Technical details and Operation** A Moving Bed Biofilm Recator (MBBR) reactor consists of a tank with submerged but floating plastic (usually HDPE, polyethylene or polypropylene) media having specific gravity less than 1. The large surface area of the plastics provide abundant surface for bacterial growth. Biomass grows on the surface as a thin film whose thickness usually varies between 50-300 μm. Medium or coarse bubble diffusers uniformly placed at the bottom of the reactor maintains a dissolved oxygen (DO) concentration of > 2.5-3 mg/L for BOD removal. Higher DO concentrations are maintained for nitrification. To retain the media flowing out of the tank, screens are placed on the downstream walls. A clarifier or a DAF is placed downstream of the MBBR tank to separate the biomass and the solids from the wastewater. No sludge recycle is required for this process. Wastewater enters the Moving Bed Biofilm Reactor MBBR where the biomass attached to the surface of the media degrades organic matter resulting in BOD removal and/or nitrification depending on the type and characteristic of the wastewater. Organic carbon is converted to carbon dioxide and leaves the system while the ammonia and nitrogen in the organics are converted to nitrates through nitrification process. Oxygen required for the process is provided through the diffusers installed at the bottom of the reactor. The treated wastewater then flows through the screens to the downstream clarifier/DAF where the biomass and solids are separated from the wastewater. **Land Area requirement:** 0.045 Ha/MLD (0.55 Ha/MLD-Tertiary Treatment included) **Power requirement:** 224 kWh/d/MLD
4	**Feasibility** It is stable under load variations, insensitive to temporary limitation and provides consistent treatment results Normally it generates low solids and requires no or minimum polymer for solid/liquid separation MBBR requires a small footprint that is typically 1/3 rd the space required for ASP. Involves a low capital cost and is comparable to cost of ASP and is much is cheaper than the MBR process. This has provisons for up-gradation i.e. existing plants can be upgraded easily with MBBR. MBR is easy to operate, has automatic sludge wasting, has no sludge Return and no MLSS, and there no issue of media clogging.
5	**Economics:** Infrastructure/Capital Cost: Rs. 7.5 M/MLD OM Cost: Rs.0.06-0.12 M/MLD/Y Running cost: Rs.0.35/m^3
6	Suitability in the present context: **Suitable but can only used at decentralised levels**

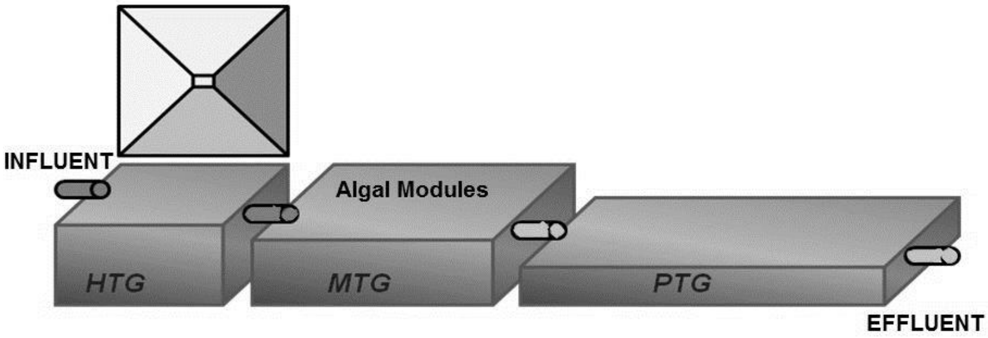
VIII	Cascading Algal Bioreactor (CAB)
1	**Treatment Process: Cascading Algal Bioreactor (CAB)**
2	**Sketch** 
3	**Technical details and Operation** A cascading Algal bioreactor consists of a series of reactors mainly comprisisng of an initial anaerobic reactor, followed by micro aerophilic reactor and an aerobic reactor. This reactor is entirely gravity driven and works on spilling over after retention of 3-4 days. This basically works with an array of microbes working differently in various reactors as a function of nutrient concentration and redox. The open surface areas in the reactors 2 and 3 allows for aeration and sunlight penetration that helps in growth of select algal species. This bioprocess uses a combination of both attached and suspended algal consortia for wastewater treatment and solids removal. The water at the effluents requires a minimum detention for clarification. High DO levels upto 200 % saturation, is achievable with high nutrient removal ability. 99.99 % bacteria removal also takes place due to a higher retention and high light penetration together with photosynthesis aided pH increase mechanism. The initial reactor with a high C load becomes anaerobic and largely works with algal bacterial symbiosis. A baffled clarifier is used to separate the biomass from the effluent. This algal biomass that is often found to be valorisable can be further used as a feedstock for biofuel. No sludge recycle is required for this process and bulk of the biomass used is algae. However a small algal population can be recycled for efficient algal retention in the system. **Land Area requirement:** 0.3 Ha/MLD (0.31 Ha/MLD-Tertiary Treatment included) **Power requirement:** 6 kWh/d/MLD
4	**Feasibility** These bioreactors require a slightly higher area and open spaces for their operation. CAB can also be used to treat other categories of waste water as dairy, tannery, agricultural, poultry, aquaculture waste water etc. at a higher efficiency with a minimal cost. Such type of systems can be more adaptable due to its provisions for revenue generation by selling algal biomass as bio-diesel feed-stocks, single cell proteins, commercially important metabolites and pigments. These systems have chances of washouts and thus proper flow regulations are required. There are chances of bio-fouling and growth of undesired anoxic bacteria in the aerobic zones due to overloading. Seasonal grazer attacks are also possible due to favourable physico-chemical environment.
5	**Economics:** Infrastructure/Capital Cost: Rs. 2 lakhs/MLD OM Cost: Rs.4.46 lakhs/MLD/Y Running cost: 0.11 paisa/litre
6	Suitability in the present context: **Suitable at decentralised levels**

Figure 4.1 provides comparative account of performance of various wastewater treatment options. Table 4.2 lists the treatment efficiency and area requirement for WWTP, while Table 4.3lists the relative advantages of various treatment technologies and Table 4.4 gives the comparative assessment of capital and OM Cost. Proposed wastewater treatment set-up for Bellandur sewage influx is given in Figure 4.2 and for Varthur lake is given in Figure 4.3.

Table 4.2: Treatment efficiency and area requirement for WWTP

Parameter	Treatment Technologies					
	ASP/EA	UASB+EA	SBR	MBR	MBBR	CAB
Treatment efficiency						
BOD, mg/l	<20	<20	<10	<5	<30	<30
COD, mg/l	<250	<250	<100	<100	<250	<100
TSS, mg/l	<100	<100	<10	<5	<100	<100
Bacterial removal (log orders)	~2-3	~2-3	~3-4	~5-6	~2-3	~4-5
TN rem. Efficiency (%)	10-20	10-20	70-80	70-80	10-20	70-
TP rem. Efficiency (%)	-	-	80-90	-	-	60-
Area Requirements						
Area Requirement (Ha/MLD)	0.09	0.1	0.045	0.045	0.045	0.3
Sec + Tertiary Treatment	0.1	0.11	0.05	0.045	0.055	0.31

Table 4.3: Relative advantages of various treatment technologies

Criteria	ASP/EA	UASB+EA	SBR	MBR	MBBR	AP	Comments
Quality of Treated effluent	++	++	+++	++++	++	++	++++ ➔ very high
Nutrient Removal potential	+	+	+++	++	+	+++	+++ ➔ high
Low Land Requirement	++	+ ++	+++	+++	+++	+	++➔ medium
Low Capital Cost potential	+++	+++	++	+	++	+++	+➔ low
Low Power Requirement	++	++++	+++	+	++	++++	++++ ➔ very high
Electricity generation potential	+	++	+	+	+	+ +	+++ ➔ high
Low O & M Skills potential	+++	+++	++	+	+++	++++	

Table 4.4: Capital and OM Cost

Cost estimation	Treatment Technologies					
	ASP/EA	UASB+EA	SBR	MBR	MBBR	CAB
Capital Cost						
Capital Cost in Rs.	68	68	75	300	68	2
OM Cost						
Power (kWh/d/MLD)	186	126	154	302	224	6
Power cost [@ Rs. 6 per kWh]	46	31	38	76	56	6
Annual Power Cost	4.07	2.75	3.37	6.65	4.9	0.5
Annual Repair Costs	2.38	2.48	1.84	--	1.94	1.76
Annual Chemical Costs	5.3	6.3	3.3	--	5.3	7.2
Total Annual OM Costs	11.75	11.53	8.51	--	12.14	4.46
*Annual Man Power Cost	14.04	14.04	8.64	--	10.32	10.68
Treatment Cost, paisa/litre	0.32	0.28	0.29	--	0.33	0.11

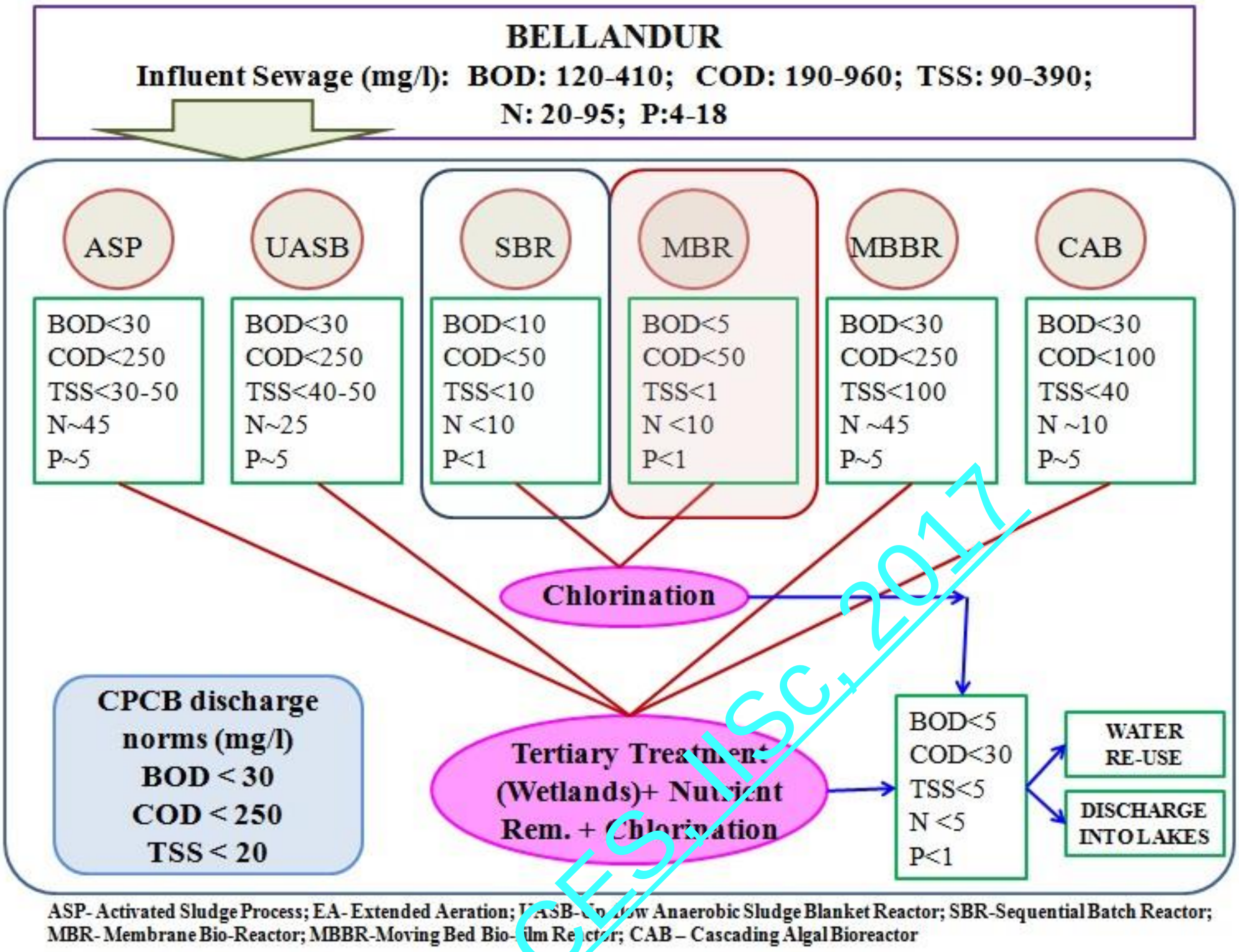


Fig. 4.1: A comparative account of treatment performance of the WWT technologies

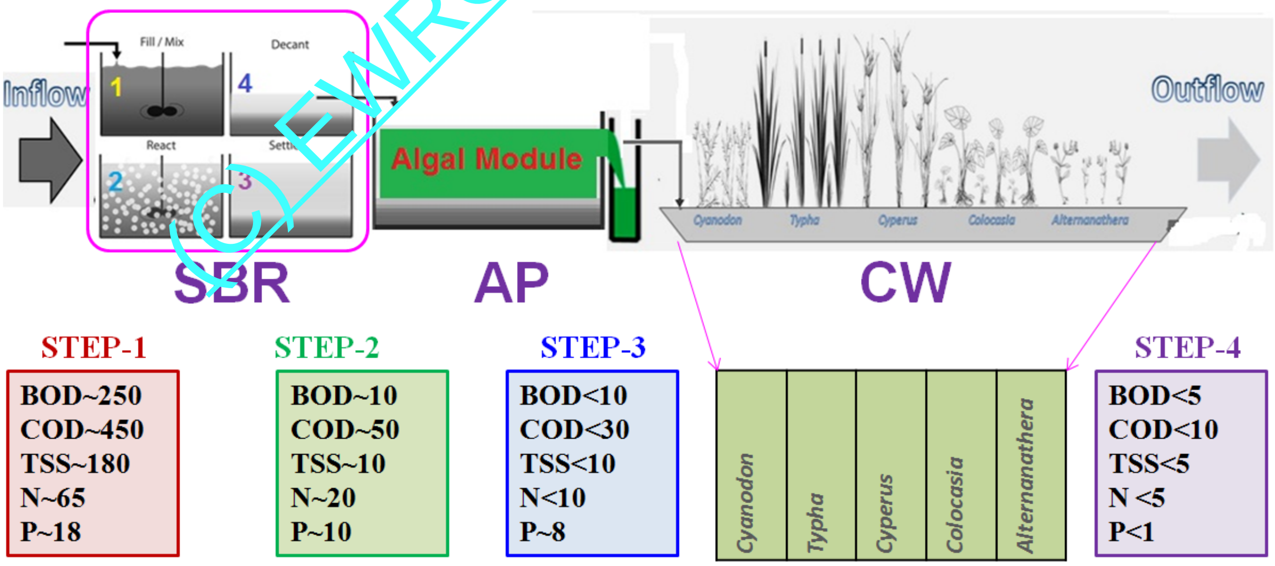


Fig. 4.2: Proposed wastewater treatment set-up for Bellandur sewage influx

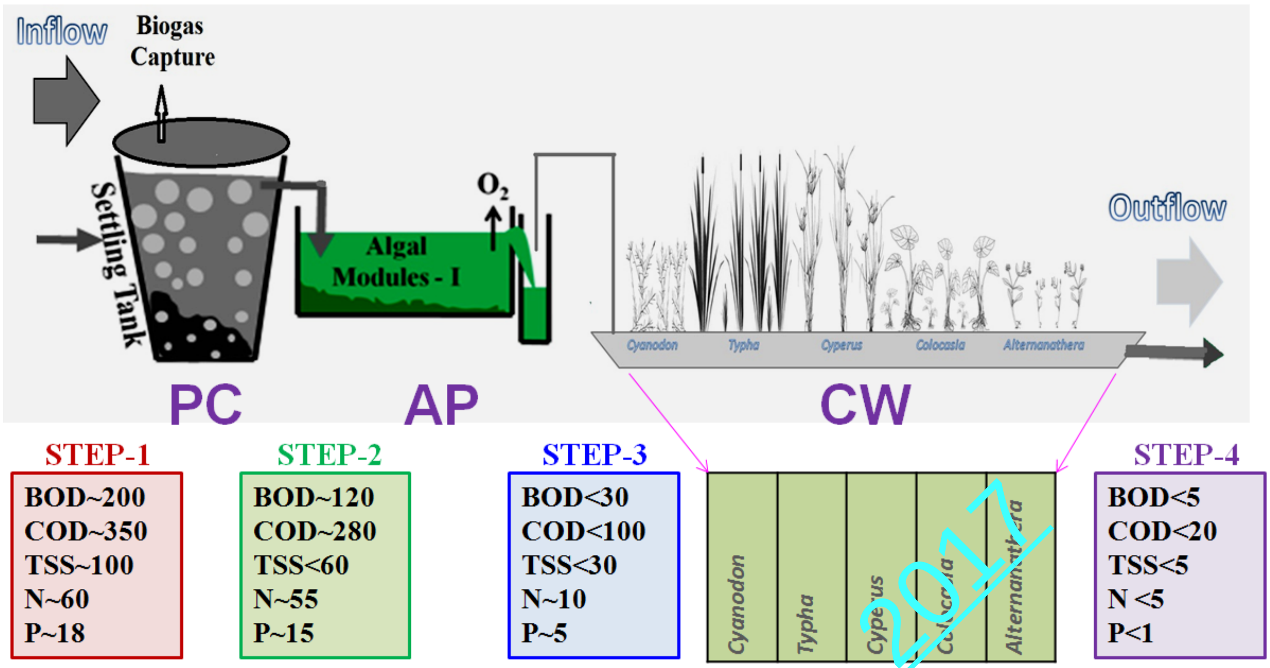


Fig. 4.3: Proposed wastewater treatment set-up for Varthur sewage influx

4.2 Proposed Treatment option for Bellandur and Varthur lakes

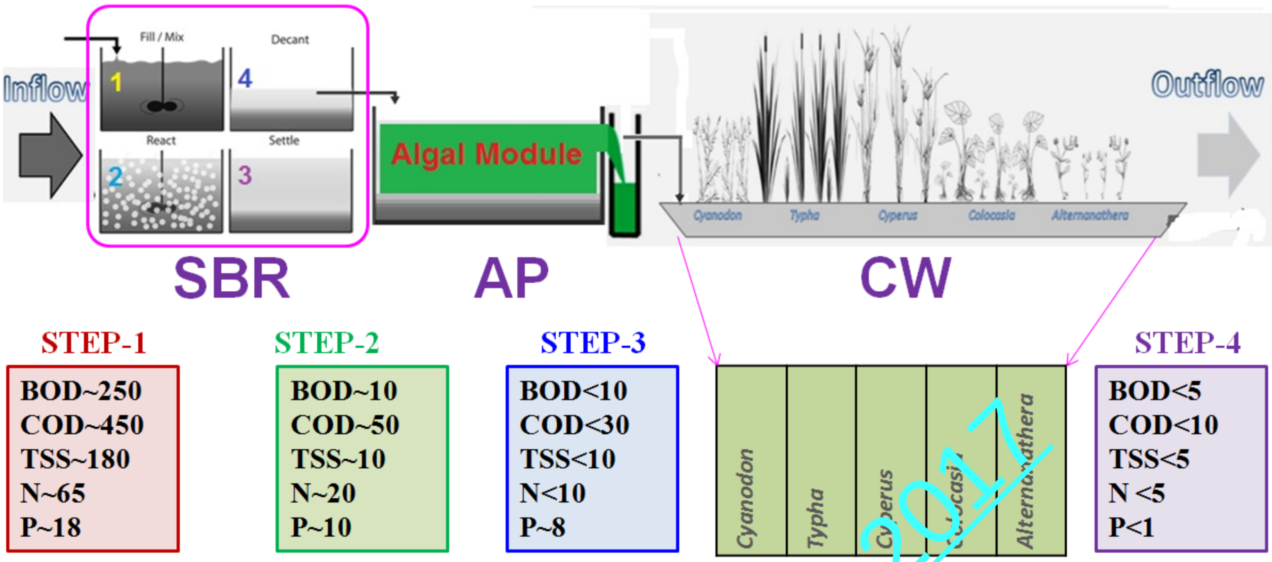
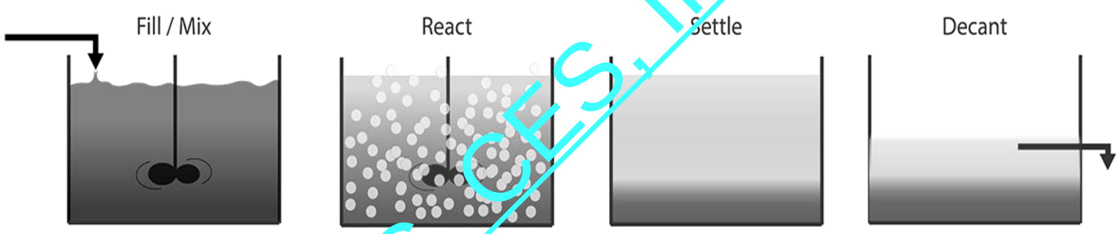
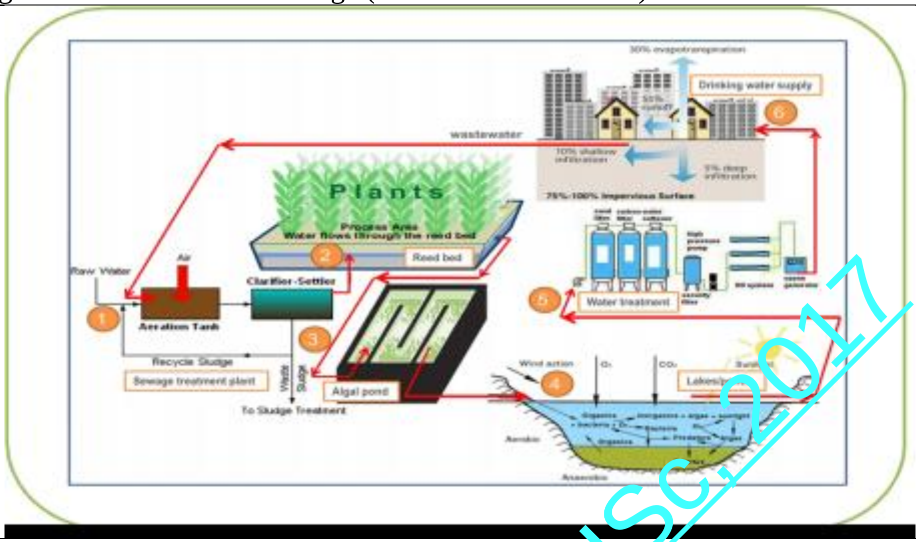


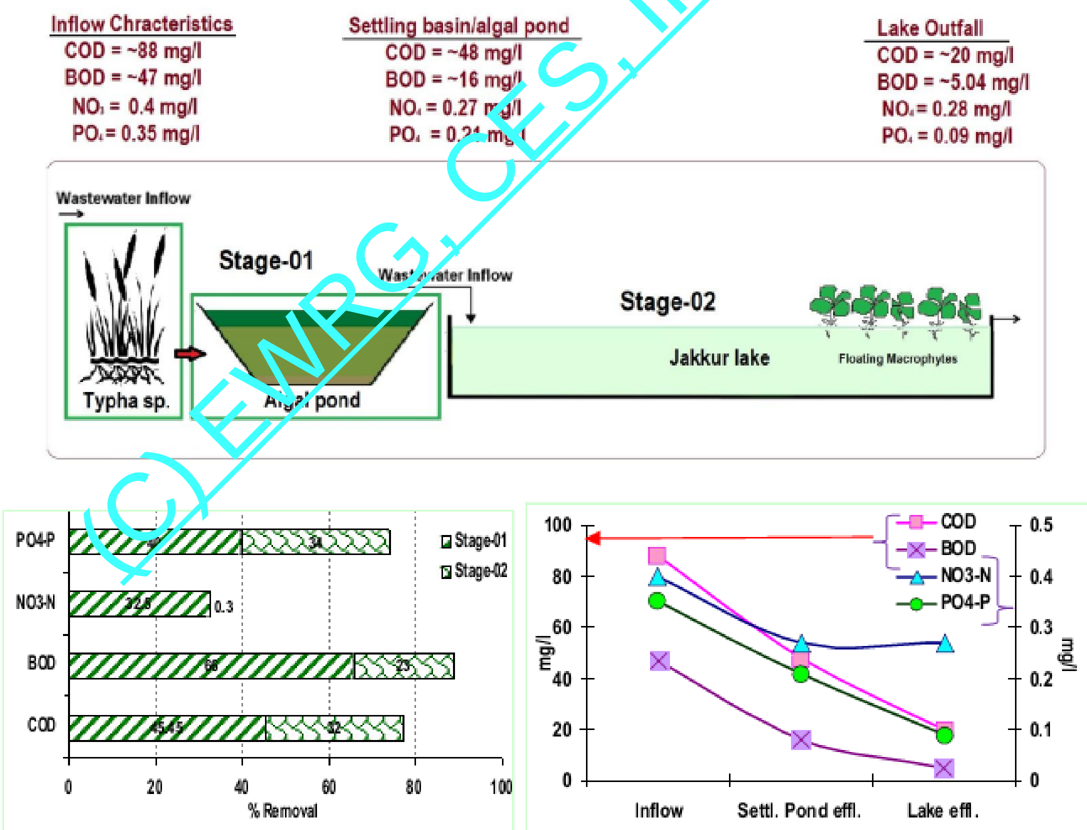
Figure 4.2: Proposed wastewater treatment set-up for Bellandur sewage influx

1	**Treatment Process: Sequential Batch Reactor (SBR)**
2	
3	**Technical details and Operation** A sequencing batch reactor (SBR) is a treatment process that consists of a sequence of steps that are carried out in the same containment structure, usually a tank reactor. They are also referred to as "fill-and-draw" systems. Although SBR systems exist that do not use aeration (anaerobic SBRs), a typical SBR system is designed to include aeration in the treatment step. A typical sequence for a SBR system is: 5. FILL, when the tank is filled with fresh wastewater, 6. REACT, when aeration and mixing are used to promote microbial removal of waste constituents, 7. SETTLE when aeration and mixing devices are turned off to allow settling of suspended solids, and 8. DRAW, when clear effluent is drawn from the top of the reactor. Waste solids can be removed from the reactor after the DRAW stage from the bottom of the tank, or during the REACT stage while the wastewater is completely mixed. The SBR treatment process requires a liquid waste input, so it is more suitable for flush systems than for scrape or pit-storage systems. **Land Area requirement:** 0.045 Ha/MLD (0.05 Ha/MLD-Tertiary Treatment included) **Power requirement:** 154 kWh/d/MLD
4	**Feasibility** SBRs are typically used at flow rates of 5 MGD or less. The more sophisticated operation required at larger SBR plants tends to discourage the use of these plants for large flow rates. As these systems have a relatively small footprint, they are useful for areas where the available land is limited. In addition, cycles within the system can be easily modified for nutrient removal in the future, if it becomes necessary. This makes SBRs extremely flexible to adapt to regulatory changes for effluent parameters such as nutrient removal. SBRs are also very cost effective if treatment beyond biological treatment is required, such as filtration.

5	**Economics:** Infrastructure/Capital Cost: Rs. 75 lakhs/MLD OM Cost: Rs.8.51 lakhs/MLD/Y Running cost: 0.29 paisa/litre
6	Suitability in the present context: **Suitable but requires further treatment** **Nutrient can be removed through integration with constructed wetlands and algal ponds (Figure 4.3)**

Model suggested for treatment of sewage (similar to Jakkur Lake)





4.3 Constructed Wetlands

The loss of ecologically sensitive wetlands is due to the uncoordinated pattern of urban growth happening in Bangalore. This is due to a lack of good governance and decentralized administration evident from a lack of coordination among many para-state agencies, which has led to unsustainable use of the land and other resources. Failure to deal with water as a finite resource is leading to the unnecessary destruction of 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 for:

- **Restoring and conserving the actual source of water**—the water cycle and the natural ecosystems that support it—are the basis for sustainable water management.
- **Reducing the environmental degradation that is preventing in attaining the goals** of good public health, food security, and better livelihoods.
- **Improving the human quality of life** that can be achieved in ways while maintaining and enhancing environmental quality.
- **Reducing greenhouse gases to avoid the dangerous effects of climate change** is an integral part of protecting freshwater resources and ecosystems.

A comprehensive approach to water resource management is needed to address the myriad water quality problems that exist today from nonpoint and point sources as well as from catchment degradation. Watershed-based planning and resource management is a strategy for more-effective rejuvenation, protection and restoration of aquatic ecosystems and for protection of human health. In this regard, recommendations to improve the situation of the lakes are:

- **The need for good integrated governance systems in place** with a single agency with statutory and financial autonomy to act as the custodian of lakes for maintenance and action against polluters.
- **Effective judicial systems** for speedy disposal of conflicts related to encroachment
- **Access to information** for the public through digitisation of land records and availability of this geo-referenced data with query based information systems
- **Measures to clean and protect lakes**
    - Removal of encroachments from lakes, lake water beds and storm water drains, regular cleaning of lakes.
    - Proper measures such as fencing to protect lakes and prevent solid waste from going into lakes
    - Install water fountains (music fountains) which enhances the aesthetic value of the lake and also aid as recreation facility to IT professionals (working in IT sector in this locality) and elderly people. This also helps in enhancing oxygen levels through aeration.
    - Introduce ducks (which helps in aeration)
    - Introduces fish (surface, column and benthic dwellers) which helps in maintaining food chain in the aquatic ecosystem. This has to be done in consultation with fish experts.
    - No exotic fish species introduction avoid commercial fish culturing (commercial fishery)
- Decentralised treatment of sewage and solid waste (preferably at ward levels). Sewage generated in a locality /ward is treated locally and letting only treated sewage into the lake (Integrated wetlands ecosystem as in **Jakkur lake**). Integrated wetlands system consists of sewage treatment plant, constructed wetlands (with location specific macrophytes) and algal pond integrated with

a lake. Constructed wetland 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. 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. Microbes aid in the removal of nutrients and are influenced by wind, sunlight and other factors (Ramachandra et al., 2014). This model is working satisfactorily at Jakkur. The sewage treatment plant removes contaminants (evident from lower COD and BOD) 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 in the lake helps in the removal of pathogen apart from nutrients. However, this requires regular maintenance through 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 rapidly urbanizing landscapes (such as Bangalore, Delhi, etc.) would help in meeting the water demand and also mitigating water scarcity through recharging of groundwater sources with remediation.

- **Better regulatory mechanisms** such as
  - To make land grabbing a cognizable, non bailable offence
  - Implementation of the polluter pay principle
  - Ban on construction activities in the valley zones
  - Restriction of diversion of the lakes for any other purposes
  - Decentralised treatment of sewage and solid waste and restriction for entry of untreated sewage into the lakes
- **Encouraging involvement of local communities**: Decentralised management of lakes through involvement of local communities in the formation of local lake committees involving all stakeholders.

Area required for Constructed Wetlands: Taking advantage of remediation capability of aquatic plants (emergent macrophytes, free floating macrophytes) and algae, constructed wetlands have been designed and implemented successfully for efficient removal of nutrients (N, P, heavy metals, etc.). Different types of constructed wetlands (sub surface 0.6 m depth, surface: 0.4 m, could be either horizontal or vertical) are given in Figure 4.3. Area required for constructed wetlands depends on the influent sewage quality and expected treatment (BOD removal, etc) is given in equation 1 (Vymazal et.al, 1998). Estimates show that to treat 1 MLD influent, area required is about 1.7 hectares. Figure 4.4 gives the design of wetlands to treat 1 MLD.

$A = Q_d(\ln C_o - \ln C_t) / K_{BOD}$

where A = area; Q_d= ave flow (m^3/day); C_o & C_t = influent & effluent BOD (mg/L); K_{BOD} = 0.10

For example to treat influent (raw sewage: BOD: 60-80) and anticipated effluent (with BOD 10), area required is about 1.7 to 2 hectares.

Figure 4.3: Variants of constructed wetlands

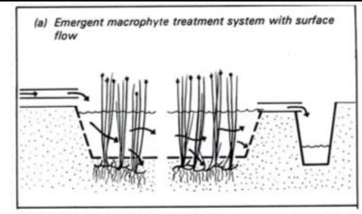
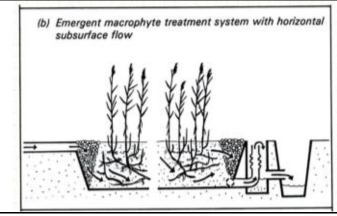
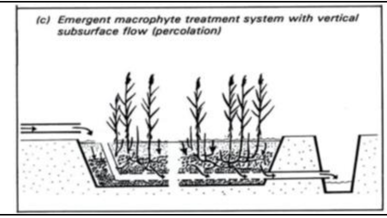
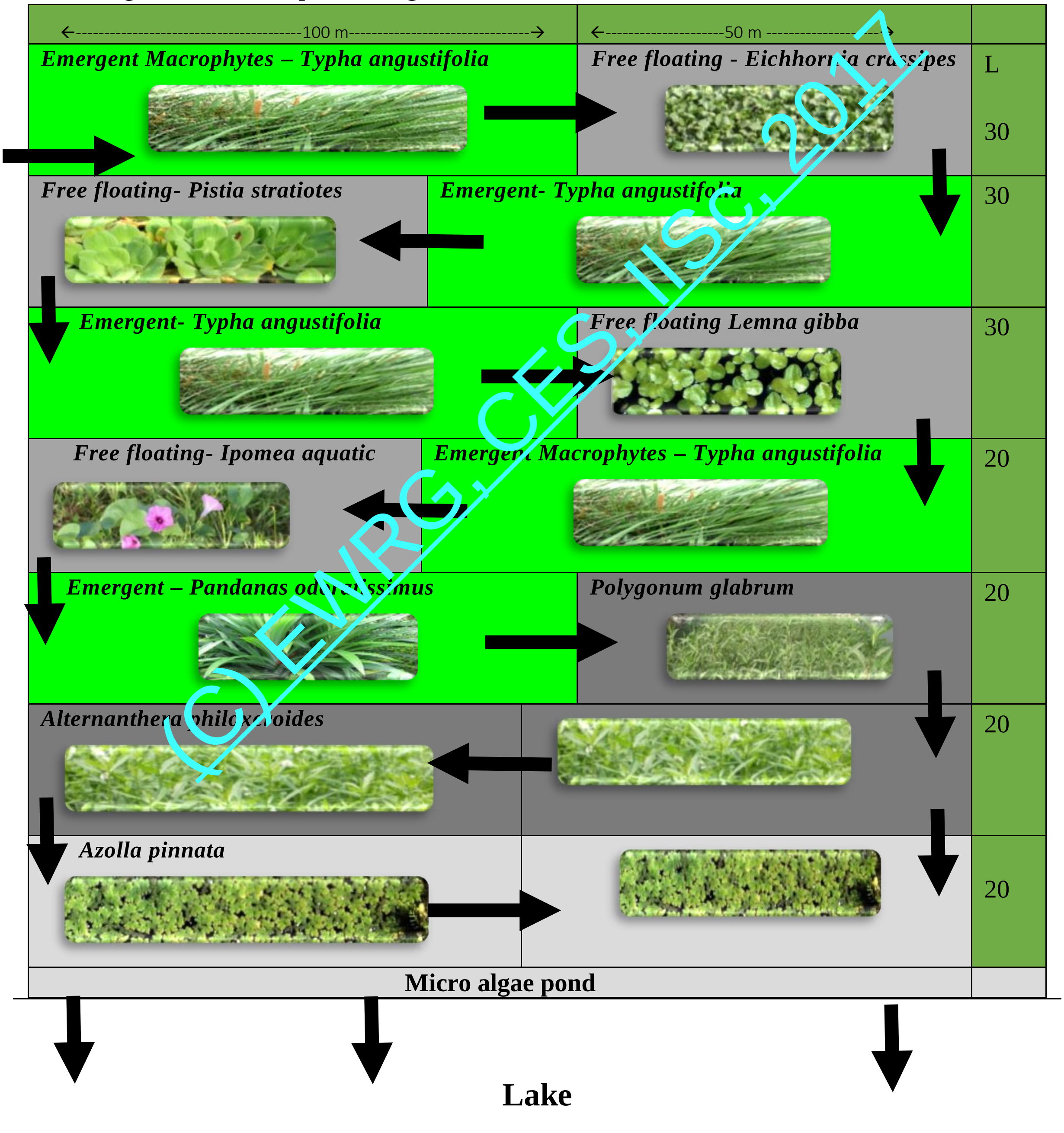
		
Emergent macrophyte	Sub-surface flow	Percolation

Figure 4.4: Conceptual design of wetlands



Nutrient and heavy metal removal by Macrophytes

Macrophyte	Removal efficiency				Reference	Type of waste water/method
	N	P	COD/BOD	Heavy metals		
Water hyacinth	65% (nitrate)	65% (phosphate)	75%		Shahabaldin *et al.*, 2013	Domestic wastewater/batch method
	50%(TN)	50%(TP)	50%		Costa *et al.*, 2014	Piggery waste with 20 days HRT
	21.78%-TN	23.02%-TP	64.44%-COD		Jianbo Lu *et al.*, 2008	Duck farm
	72%-N	63%-P			Tripathy *et al.*, 2003	Dairy effluent
				Cr(95%)	Mahmood *et al.*, 2005	Textile wastewater
				Hg-119ng /g Cd-3992µg/g Cu-314 µg/g Cr-2.31mg/g Ni-1.68 mg/g	Molisani et al., 2006 KK Mishra et al., 2007 Hu et al., 2007 Verma et al., 2008	
	2161 mg N/m²/day or 7887 kg N/ha/yr	**542 mg P/m²/day or 1978 kg P/ha/yr**			K.R Reddy and J.C.Tucker, 1983	microcosm aquaculture system
	Summer-1278 mg N/m²/day **Winter-254 mg N/m²/day**	**Summer-243 mg P/m²/day** **Winter-49 mg P/m²/day**			K. R. REDDY AND W. F. DE BUSK , 1985	microcosm retention ponds
Pistia stratiotes	**Summer-985 mg N/m²/day** **Winter-258 mg N/m²/day**	**Summer-218 mg P/m²/day** **Winter-72 mg P/m²/day**			K. R. REDDY AND W. F. DE BUSK , 1985	microcosm retention ponds
				Hg-0.57mg/g Cr-2.5mg/g Cd-2.13mg/g	Mishra et al., 2009 Verma et al., 2008	

				Ni-1.95mg/g		
	Summer-292mg N/m^2/day **Winter-70 mg N/m^2/day**	**Summer-87mg P/m^2/day** **Winter-18 mg P/m^2/day**			K. R. REDDY AND W. F. DE BUSK , 1985	microcosm retention ponds
				Ti-221 µg/g Cu-400 µg/g Pb-8.62 mg/g	Babic et al., 2009 Boule et al., 2009 Uysal and Taner 2009	
Lemna minor	**194.9 ± 18.9 g TN/m^2/yr**	**10.4 ± 1.7 g TP/m^2/yr**	**3869 ± 352g COD/m^2/yr**		Umesh et al., 2015	Manure slurry from dairy farm, surface flow wetland
	Summer-292mg N/m^2/day **Winter-70mg N/m^2/day**	**Summer-87mg P/m^2/day** **Winter-18 mg P/m^2/day**			K. R. REDDY AND W. F. DE BUSK , 1985	microcosm retention ponds
Lemna gibba				Cr-897 µg/g As-1022 µg/g	Mkandawire et al., 2004	
Spirodela polyrhiza	**Summer-151mg N/m^2/day** **Winter-135mg N/m^2/day**	**Summer-34mg P/m^2/day** **Winter-34 mg P/m^2/day**			K. R. REDDY AND W. F. DE BUSK , 1985	microcosm retention ponds
Azolla	**Summer-108mg N/m^2/day** **Winter-48mg N/m^2/day**	**Summer-33mg P/m^2/day** **Winter-10mg P/m^2/day**			K. R. REDDY AND W. F. DE BUSK , 1985	microcosm retention ponds
Salvinia	**Summer-406mg N/m^2/day** **Winter-96mg N/m^2/day**	**Summer-105mg P/m^2/day** **Winter-32mg P/m^2/day**			K. R. REDDY AND W. F. DE BUSK , 1985	microcosm retention ponds
	48-54 g/m^2				Maltais-Landry et al., 2009	Mesocosm with daily total N

Typha angustifolia						loading rates 1.16 g/m^2
				Cr-20210 µg/g Zn-16325 µg/g 7022 µg/g	Firdaus-e-Bareen and Khilji, 2008	
	922 kg N/ha	**114 kgP/ha**			Abdeslam Ennabili et al., 1998	Field study: Coastal wetlands (freshwater or brackish systems) were studied in three river mouth areas in the Tingitan Peninsula
Combination of Water hyacinth, duckweed and blue-green algae	>90%(nitrate)	>90% (phosphate)	BOD-97%	20-100%	Sinha *et al.*, 2000	Sewage water

Quantities of elements that could be removed by continual culture of some aquatic plants (kg/ha/year) (Reference:handbook of utilization of aquatic plants,FAO, http://www.fao.org/docrep/003/x6862e/X6862E11.htm)

Element	***Water hyacinth (Eichhornia crassipes)*** (kg/ha/year)	***Alternanthera philoxeroides*** (kg/ha/year)	***Typha latifolia*** (kg/ha/year)
Nitrogen (N)	1980	1780	2630
Phosphorus (P)	320	200	400
Sulphur (S)	250	180	250
Calcium (Ca)	750	320	1710
Magnesium (Mg)	790	320	310
Potassium (K)	3190	3220	4570
Sodium (Na)	260	230	730
Iron (Fe)	19	45	23
Manganese (Mn)	300	27	79
Zinc (Zn)	4	6	6
Copper (Cu)	1	1	7

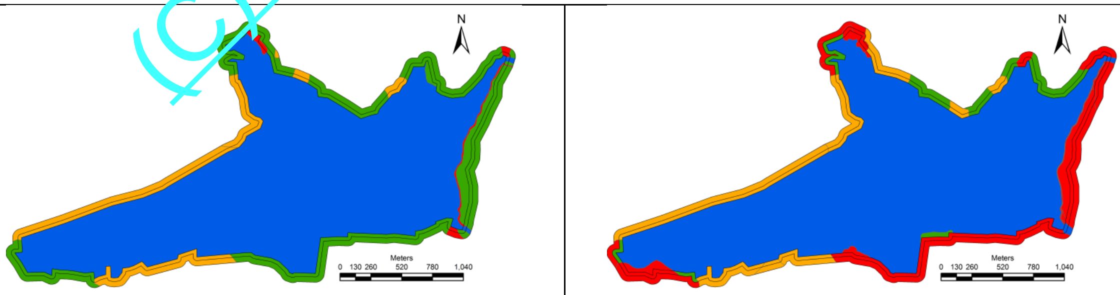
5.0 ENCROACHMENTS & VIOLATIONS OF NORMS

Bangalore wetlands have been facing persistent threats due to (i) encroachments and unauthorised construction in the lake bed, wetlands, and rajakaluves (ii) violation of prohibited and regulated activities in the valley zone / sensitive zone with the irrational development activities (contrary to the norms of **CDP:** Comprehensive Development Plan/ **RMP:** Revised Master Plan, **2015, 2031**), (iii) violation of regulated activities in the buffer zone (30 m as per BDA, 75 m as per NGT) (iv) dumping of municipal solid wastes, demolished building debris, excavated earth, etc., (v) sustained inflow of partially treated or untreated sewage (by BWSSB and high-rise buildings in the lake bed), (vi) disposal of industrial effluents into the drains connecting the lake, (vii) removal of interconnectivity among lakes – by encroachment of Rajakaluve and drains connecting lakes, (viii) dumping of untreated sewage through tankers (Figure 3.1), (ix) dumping of bio-medical waste, etc.

Bellandur lake and buffer zone of 75 m: Figure 5.1 depicts the land use changes during 2002 and 2016 in the lake bed and the buffer zone of 75 m. Lake bed encroachments are due to soil filling (C & D waste, solid waste from the city) and unauthorised buildings which has increased from about 0.5 % (2002) to 3.1% (2016). Similarly in the buffer zone, built up areas have increased from 1.5% (2002) to 45 % (2016) at the cost of vegetation cover (agriculture, horticulture). Figures 5.2 and 5.3 give violations in the lakebed and buffer zone.

2002	2016

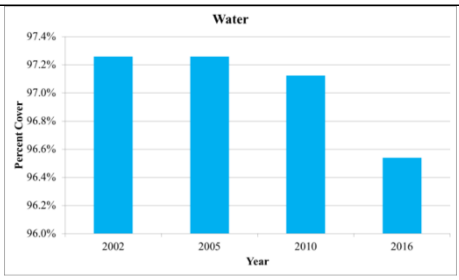
Figure 5.1: Land cover dynamics in Bellandur Lake and buffer zone

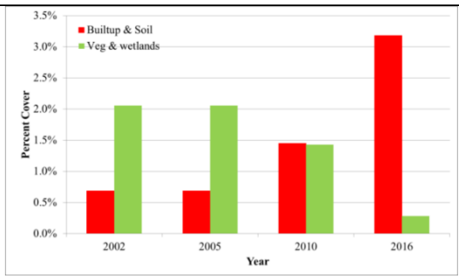


2002	2016

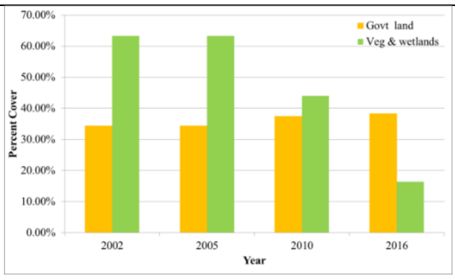
Water | Govt Land | Built up, Soil dumping | Vegetation, Wetland — Source: EWRG, CES, IISc, 2016

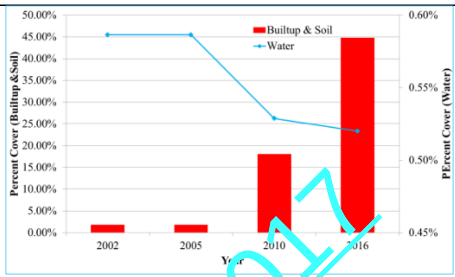
Figure 5.2: Landscape dynamics up to 75m buffer zone of Bellandur Lake.





a) Lake Source: EWRG, CES, IISc, 2016





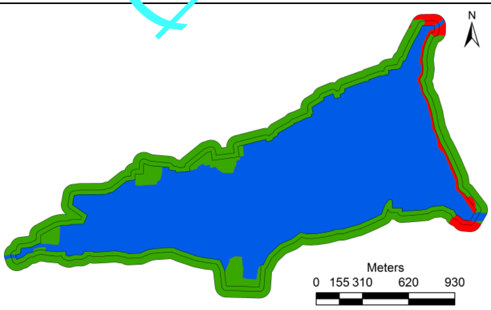
b) 75 m buffer zone Source: EWRG, CES, IISc, 2016

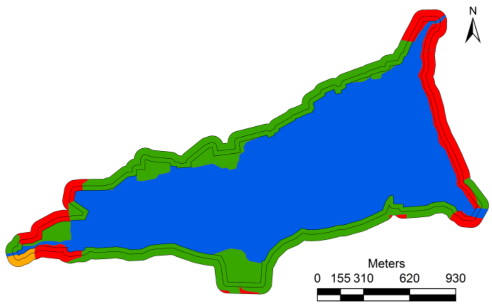
Figure 5.3: Landscape dynamics in Bellandur Lake

Varthur lake and buffer zone of 75 m: Figure 5.4 depicts the land use changes during 2003 and 2016 in the lake bed and the buffer zone of 75 m. Lake bed encroachments due to soil filling (C & D wastes) and construction of buildings (Figures 5.5 and 5.6) is about 0.8 % (2003) to 1.2% (2016). Similarly, in the buffer zone, built-up areas have increased from 5% (2002) to 30 % (2016) with the decline of vegetation (agriculture, horticulture).

2003	2016

Figure 5.4: Land cover dynamics in Vathur and buffer zone

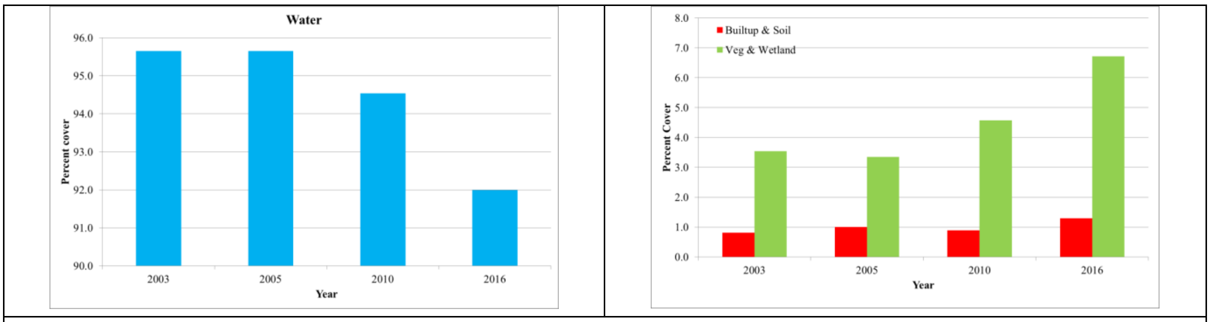




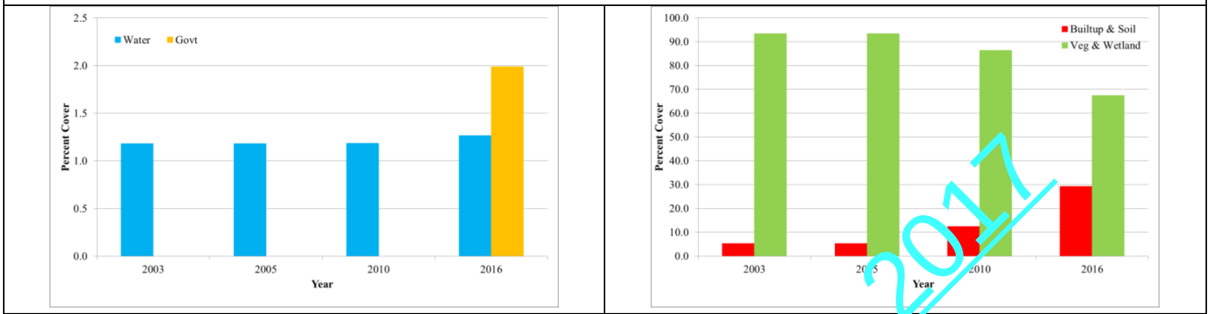
2003	2016

Water Govt Land Built up, Soil dumping Vegetation, Wetland Source: EWRG, CES, IISc, 2016

Figure 5.5: Land use dynamics in Bellandur lake and buffer zone



a) Lake



b) 75 m buffer zone

Figure 5.6: Landscape dynamics in Varthur Lake

Valley zones*:* Pristine Bellandur-Varthur wetland ecosystem has been experiencing threat due to the large scale catchment alterations with changes in the land use land cover. The region forms a part of primary valley, which is sensitive regions as per the revised master plan 2015 (RMP 2015 of BDA). The landscape forms an integral part of the protected area (as it is in valley zone) as per the CDP 2015. This wetlands is now being converted with mixed land use i.e., Built-up with both residential and office complexes. Alterations in the wetland began in 2004 and aggravated post 2008. The alterations of these wetlands initiated by filling the low lying areas with excavated earth debris, followed by other construction activities. The land fillings have breached both rajakaluve and lakes. Rajakaluve have reduced in width from as high as 35m to less than 8 m, apart from the loss of natural stream network connecting the lakes and rajakaluveys. Major violations in Bellandur-Vathur wetlands are:

- LAND USE CHANGES WITH THE CONSTRUCTION ACTIVITIES IN THE PRIMARY VALLEY – SENSITIVE REGIONS (as per RMP, 2015 of BDA: The region is located in the primary valley of the Koramangala Challaghatta valley. Primary valleys in Bangalore **are sensitive regions** as per sensitive zone notification - Circular/35/BBMP/2008, dated: 26/11/2008) and buffer zone for primary valley is 100 m.
- The region is a wetland as per **KARNATAKA LAKE CONSERVATION AND DEVELOPMENT AUTHORITY ACT, 2014 - KARNATAKA ACT NO. 10 OF 2015; *KAR. ACT 12, pg 462*; *National Wetland Atlas, SAC Ahmedabad, 2009; Wetland rules, MoEF, Govt of India, 2010; RAMSAR Definition of wetlands.***
- Removal of wetlands affects Intergeneration Equity.

- Depriving local residents of water: Wetlands helps in recharge of groundwater in the region.
- Encroachment of Rajakalve and streams (connecting Bellandur and Varthur lakes).
- Deprives local residents of clean, air and water (as per Article 21 of the Constitution of India).
- Dumping of building debris and excavated earth in Wetlands and also in water-spread area of Bellandur and Varthur lake.
- Encroachment of Bellandur and Varthur lake.

Figure 5.7 depicts the landscape dynamics in the valley zone between Bellandur and Varthur Lakes. Large scale landscape changes found to occur since 2004, and the process of urbanization is occurring from west to east (Bellandur to Varthur). The wetlands and agriculture lands encompassing 98.5% of the valley zone in 2002 have drastically decreased to 25.68% by the year 2016 which is due to land use conversion for construction (residential/commercial/infrastructure) which has increased from 1.44% in 2002 to 74.32% in 2016. This rampant growth in the valley zone have removed lakes and raja kaluveys that altered the function of natural system of cleansing water, recharging ground water. Table 3 highlights extent of landscape alterations and unauthorized occupation of Valley zone.

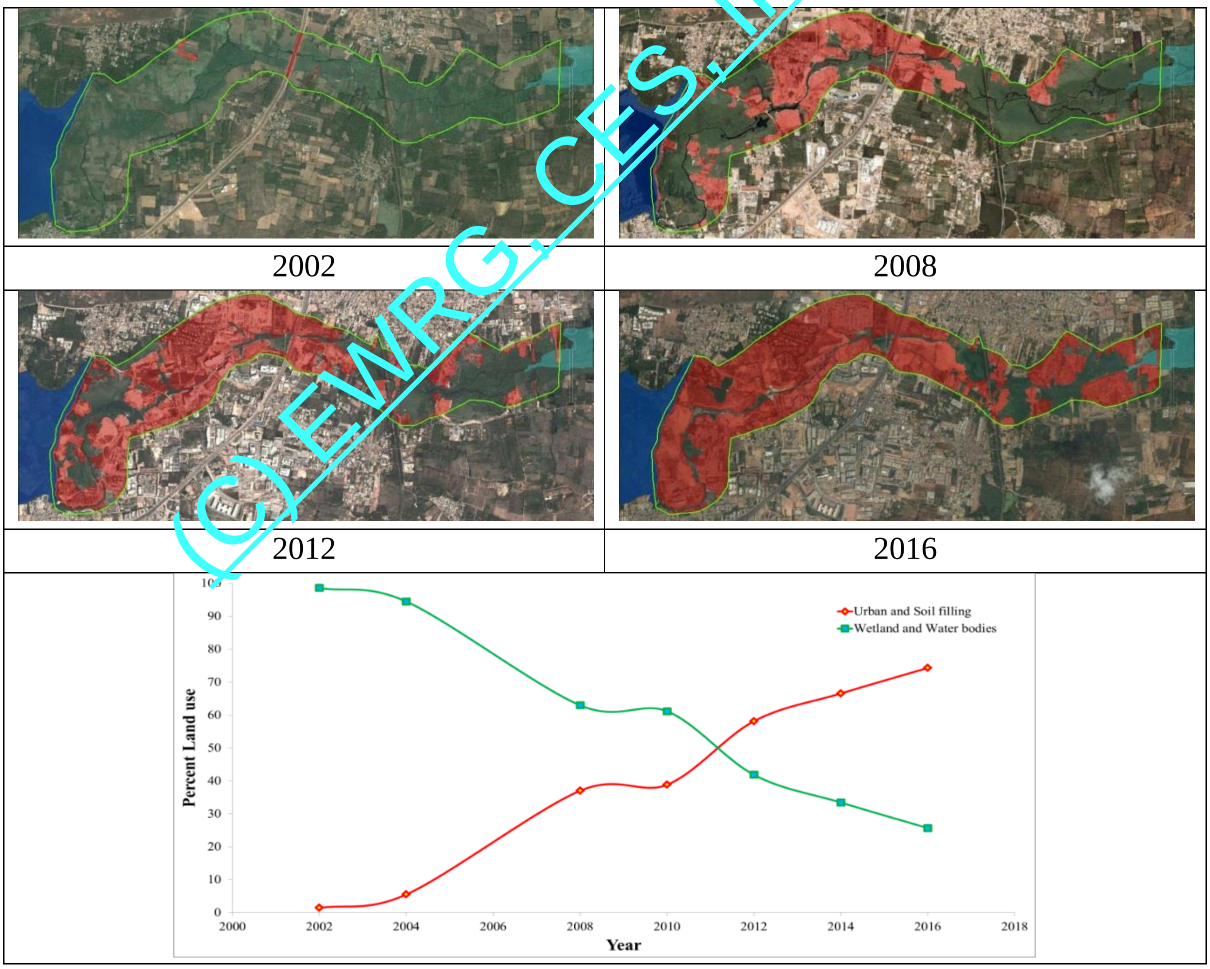


Figure 5.7: Land use dynamics in Bellandur Varthur Valley Zone

Table 3: Land use changes in the valley zone (Virtual Globe: Google earth)

	Area in Hectares						
Land use / Year	**2002**	**2004**	**2008**	**2010**	**2012**	**2014**	**2016**
Urban and Soil filling	5.2	20.2	135.3	141.9	212.4	243.2	271.5
Wetland, Agriculture and Water bodies	360.0	345.0	230.0	223.4	152.9	122.2	93.8
	Area in Percent						
Urban and Soil filling	1.44	5.53	37.04	38.84	58.15	66.56	74.32
Wetland, Agriculture and Water bodies	98.56	94.47	62.96	61.16	41.85	33.44	25.68

Figure 5.8 depicts the revenue map of Bellandur Varthur valley zone (Bellandur Ammanikere). Rampant landscape changes in the valley zone have reduced the width (Figure 5.9) or encroached the natural drainages and rajakaluveys. Rajakaluveys of 25m to 35 m width have reduced in width to less than 5m to 8 m (example is depicted in Figure 5.9). Figure 5.10 and Table 4 details kharab lands in the valley zone between Bellandur and Varthur lake. 1058.96 Guntas (26.47 Acres) of land in the valley zone falls under the category of kharab lands and is distributed in villages of Ammanikere Bellandur Khane, (576.8 Guntas), Bellandur (431.2 Guntas), Kariyamma Agrahara (16 Guntas), Yamlur* (41 Guntas).

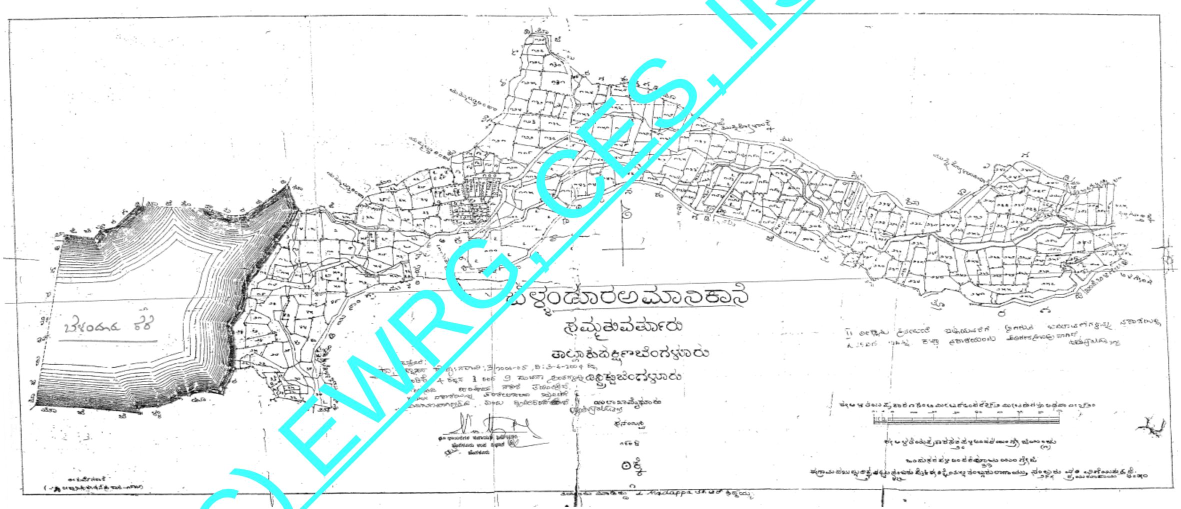
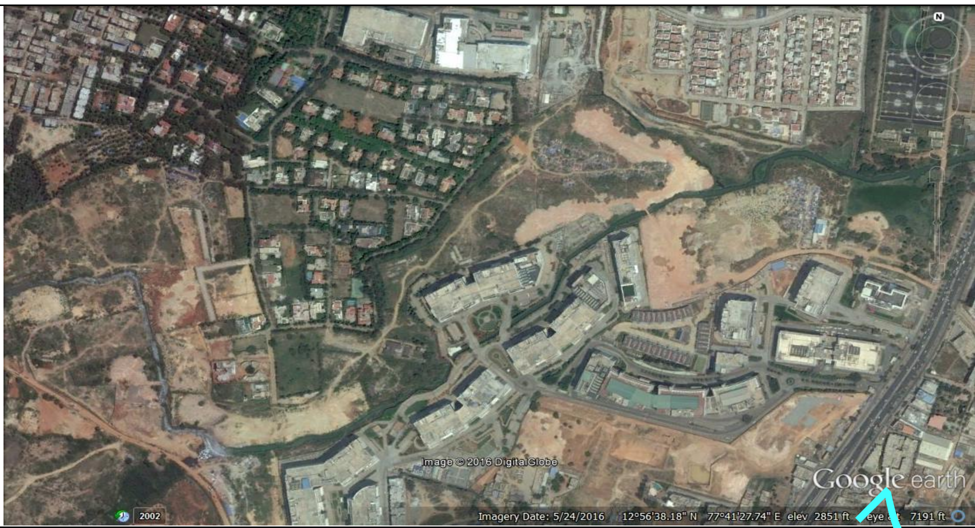


Figure 5.8: Revenue Map of Bellandur Ammanikere

1904 (Revenue Map) | 2002 (map overlaid on Google earth)



View of landscape in 2016 (Google earth)

Figure 5.9: Alteration of natural drains and rajakaluveys

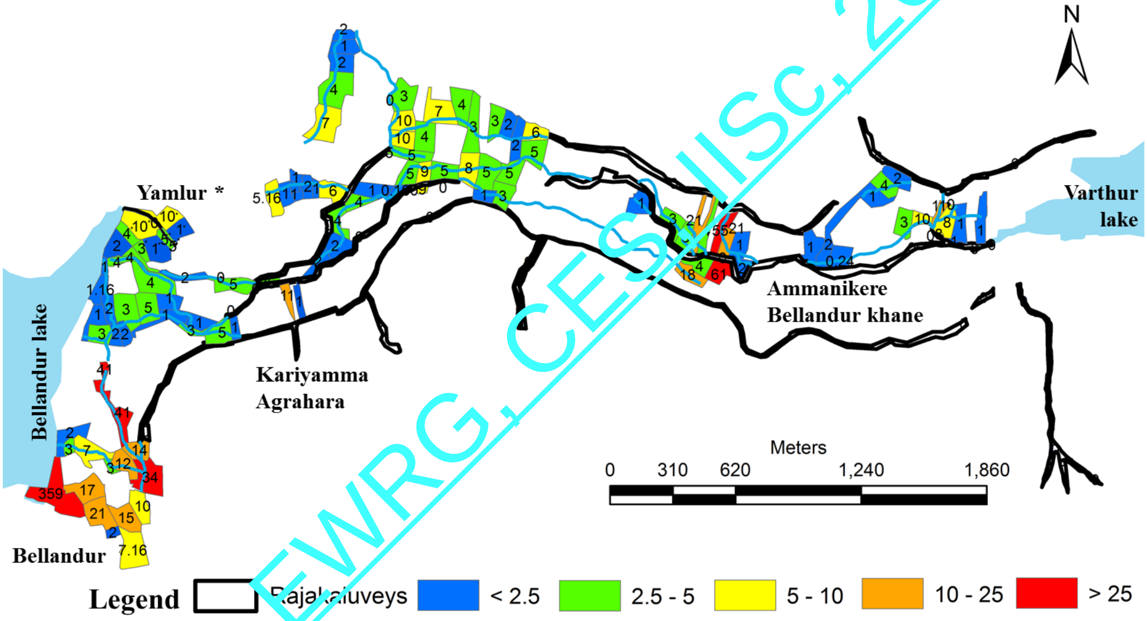


Figure 5.10: Kharab lands in the Valley zone between Bellandur and Varthur lakes

Table 4: Kharab lands in the valley zone

Ammanikere Bellandur Khane					
Survey Number	Area (Gunta)	Survey Number	Area (Gunta)	Survey Number	Area (Gunta)
2	1	98	2	168	3
3	1.16	99	1	169	2
6	4	106	4	170	2
7	4	107	2	171	6
8	1	108	2	172	5
9	1	116	4	201	1
10	5	117	1	209	3
11	3	120	6	212	3

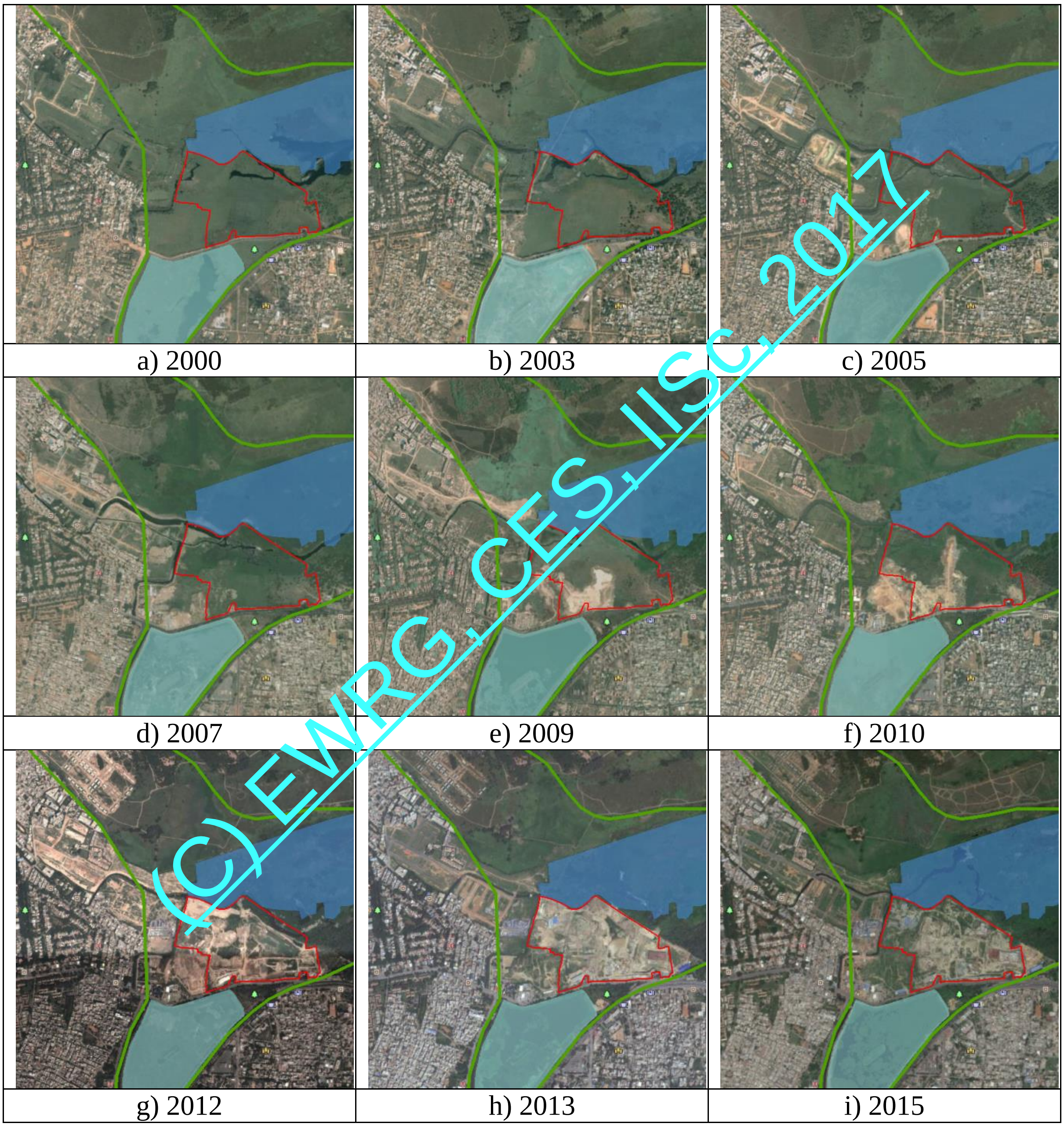
12	2	124	7	213	21
13	2	125	4	215	4
14	2	126	2	217	4
15	3	127	1	218	18
16	1	128	2	221	61
25	2	140	5	222	21
26	3	141	5	223	55
27	7	142	0.16	227	1
30	12	145	9	228	2
31	3	148	5	241	1
38	34	151	4	244	1
39	14	152	10	245	2
42	41	153	10	248	2
53	3	154	3	249	4
54	1	157	7	250	1
55	5	159	4	253	0.24
56	1	160	3	256	14.08
63	5	161	8	272	10
64	2	162	5	273	3
93	5.16	163	1	280	11
94	2	164	3	282	8
96	1	165	5	283	1
97	1	166	2	285	1
Total Area (Guntas)			**570.8**		
Total Area (Acres)			**14.27**		

Bellandur		**Yamlur ***		**Kariyamma Agrahara**	
Survey Number	Area (Gunta)	Survey Number	Area (Gunta)	Survey Number	Area (Gunta)
4	359	54	20	17	4
8	17	55	1	19	11
10	10	56	10	22	1
11	15	57	1	**Total (Gunta)**	**16**
13	21	58	3	**Total(Acre)**	**0.4**
14	2	59	4		
18	7.16	60	2		
Total (Gunta)	**431.16**	**Total (Gunta)**	**41**		
Total(Acre)	**10.78**	**Total(Acre)**	**1.025**		

* Verification required

Total Area (Guntas)	**1058.96**
Total Area (Acres)	**26.47**

Bellandur-Agaram Valley zone: Figure 5.11 depicts the landscape dynamics during 2000 to 2015 (mapped on temporal Google Earth data – http://*earth.google.com*). The remote sensing data of 2009 – 2015 substantiates the unabated construction activities in the valley zone (without proper compliance and gross violations of environmental norms). Table 5 highlights extent of landscape alterations and unauthorized occupation of wetlands (Agara-Bellandur wetland). Figure 5.12 gives cadastral map (1904, scale: 1 in 7920) of the region with land uses - drainage network, agriculture land parcels, tank boundaries, etc.



a) 2000 | b) 2003 | c) 2005
d) 2007 | e) 2009 | f) 2010
g) 2012 | h) 2013 | i) 2015

Figure 5.11: Land cover dynamics in the valley zone

Table 5: Extent of encroachment and illegalities

Year	wetland
2007	63 Acres 37.5 Guntas
2010	66 Acres 32.3 Guntas
2012	72 Acres 15.9 Guntas
2013	74 Acres 12.1 Guntas
2015	74 Acres 12.1 Guntas

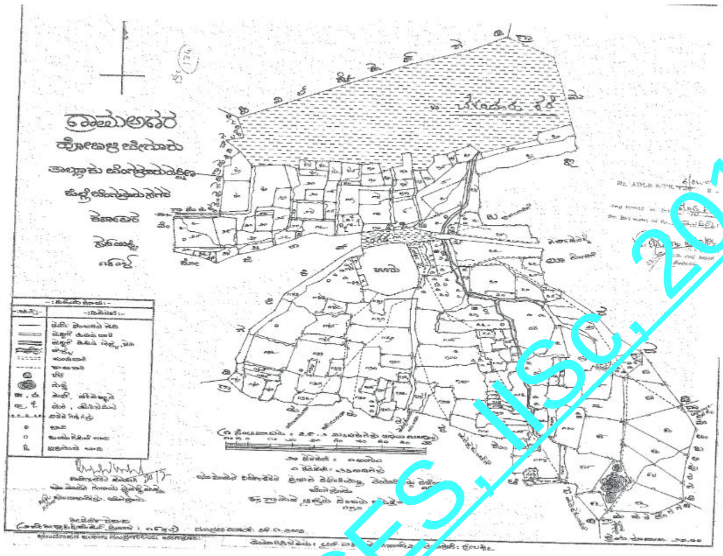


Figure 5.12: Cadastral Map with lakes (1904)

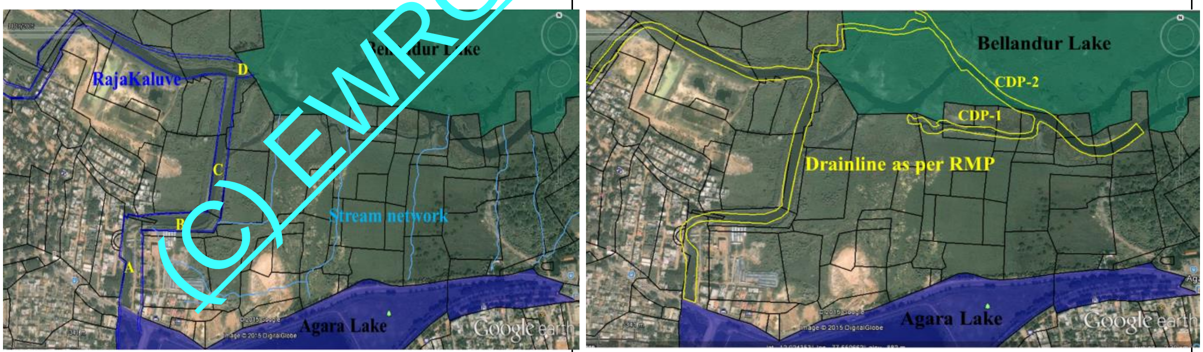


Figure 5.13: Rajakaluve, streams and lakes as per cadastral maps, satellite data and RMP 2015

Figure 5.13 highlights interconnected lake system in Agara-Bellandur region with rajakaluves and stream network. Figure 5.13 also indicates the narrowing down of rajakaluves for the period 2000 to 2015, (for the cross sections A, B, C, D). Rajakauluves have declined between 23% and 57% of the original width during the year 2000 to 2015. Table 6 lists applicable various norms for wetlands conservation.

Table 6: Various norms for lakes and rajakaluve conservation

Activities around lakes	**Norms to protect and conserve Wetlands**
Encroachment of lake bed and loss of interconnectivity among lakes	The Hon'ble Supreme Court in Civil appeal number 1132/2011 at SLP (C) 3109/2011 on January 28,2011 has expressed concern regarding encroachment of common property resources, more particularly lakes (and raja kaluves) and it has directed the state governments for removal of encroachments on all community lands. Eviction of encroachment: Need to be evicted as per Karnataka Public Premises (eviction of unauthorised occupants) 1974 and the Karnataka Land Revenue Act, 1964
Buildings in the buffer zone of lakes	In case of water bodies, 75.0 m buffer of 'no development zone' (as per recent National Green Tribunal direction) is to be maintained around the lake (buffer region to be as per revenue records) • As per BDA, RMP 2015 (Regional Master Plan, 2015) • Section 17 of KTCP (Karnataka Town and Country Planning) Act, 1961 and sec 32 of BDA Act, 1976 • Wetlands (Conservation and Management) Rules 2010, Government of India; Wetlands Regulatory Framework, 2008.
Construction activities in the valley zone (SEZ by Karnataka Industrial Areas Development Board (KIADB)) **in the valley zone**	This is contrary to sustainable development as the natural resources (lake, wetlands) get affected, eventually leading to the degradation/extinction of lakes. This reflects the ignorance of the administrative machinery on the importance of ecosystems and the need to protect valley zones considering ecological function and these regions are 'NO DEVELOPMENT ZONES' as per CDP 2005, 2015
Alterations in topography	Flooding of regions would lead to loss of property and human life and, spread of diseases.
Increase in deforestation in catchment area	Removing vegetation in the catchment area increases soil erosion and which in turn increases siltation and decreases transpiration
Documentation of biodiversity	• The biodiversity of every water body should form part of the School, College, People's Biodiversity Registers (SBR, CBR, PBR). • The local Biodiversity Management Committees (BMC) should be given necessary financial support and scientific assistance in documentation of diversity. • The presence of endemic, rare, endangered or threatened species and economically important ones should be highlighted • A locally implementable conservation plan has to be prepared for such species
Implementation of sanitation facilities	• The lakes are polluted with sewage, coliform bacteria and various other pathogens

	• Preserving the purity of waters and safeguarding the biodiversity and productivity, dumping of waste has to be prohibited • 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
Violation of regulatory and prohibitory activities as per Wetlands (Conservation and Management) Rules, 2016 and 2010; Regulatory wetland framework, 2008	Environment Impact Assessment (EIA) Notification, 2009. **Wetlands (Conservation and Management) rules 2010, Government of India; Regulatory wetland framework, 2008** **Regulated activity** • Withdrawal of water/impoundment/diversion/interruption of sources • Harvesting (including grazing) of living/non-living resources (may be permitted to the level that the basic nature and character of the biotic community is not adversely affected) • Treated effluent discharges – industrial/ domestic/agro-chemical. • Plying of motorized boats • Dredging (need for dredging may be considered, on merit on case to case basis, only in cases of wetlands impacted by siltation) • Constructions of permanent nature within 50 m of periphery except boat jetties • Activity that interferes with the normal run-off and related ecological processes – up to 200 m **Prohibited activity** i. Conversion of wetland to non-wetland use ii. Reclamation of wetlands iii. Solid waste dumping and discharge of untreated effluents
Damage of fencing, solid waste dumping and encroachment problems in Varthur lake series	High Court of Karnataka (WP No. 817/2008) had passed an order which include: • Protecting lakes across Karnataka, • Prohibits dumping of garbage and sewage in Lakes • Lake area to be surveyed and fenced and declare a no development zone around lakes • Encroachments to be removed • Forest department to plant trees in consultation with experts in lake surroundings and in the watershed region • Member Secretary of state legal services authority to monitor implementation of the above in coordination with Revenue and Forest Departments • Also setting up district lake protection committees
Polluter Pays principle	**National Environment Policy, 2006** The principal objectives of NEP includes : • Protection and conservation of critical ecological systems and resources, and invaluable natural and man-made heritage • Ensuring judicious use of environmental resources to meet the needs and aspirations of the present and future generations

	• It emphasizes the "Polluter Pays" principle, which states the polluter should, in principle, bear the cost of pollution, with due regard to the public interest
Prevention of pollution of lake	**National Water Policy, 2002** Water is a scarce and precious national resource and requires conservation and management. Watershed management through extensive soil conservation, catchment-area treatment, preservation of forests and increasing the forest cover and the construction of check-dams should be promoted. The water resources should be conserved by retention practices such as rain water harvesting and prevention of pollution.
Discharge of untreated sewage into lakes	**The Environment (Protection) Act, 1986** • Lays down standards for the quality of environment in its various aspects • Laying down standards for discharge of environmental pollutants from various sources and no persons shall discharge any pollutant in excess of such standards • Restriction of areas in which industries, operations or processes shall not be carried out or carried out subject to certain safeguards
The water pollution, prevention and its control measures were not looked upon	**Water (Prevention and Control of Pollution) Act, 1974** • It is based on the "Polluter pays" principle. The Pollution Control Boards performs the following functions : • Advice the government on any matter concerning the prevention and control of water pollution. • Encourage, conduct and participate in investigations and research relating to problems of water pollution and prevention, control or abatement of water pollution. • Inspects sewage and effluents as well as the efficiency of the sewage treatment plants. • Lay down or modifiy existing effluent standards for the sewage. • Lay down standards of treatment of effluent and sewage to be discharged into any particular stream. • Notify certain industries to stop, restrict or modify their procedures if the present procedure is deteriorating the water quality of streams.
Pathetic water scenario and insufficient drinking water in Bangalore	The depletion of ground water and drying up off lakes has affected the water availability to meet the current population. At the 4% population growth rate of Bangalore over the past 50 years, the current population of Bangalore is 8.5 million (2011). Water supply from Hesaraghatta has dried, Thippagondanahalli is drying up, the only reliable water supply to Bangalore is from Cauvery with a gross of 1,410 million liters a day (MLD). There is no way of increasing the drawal from Cauvery as the allocation by the Cauvery Water Disputes Tribunal for the entire urban and rural population in Cauvery Basin in Karnataka is only 8.75 TMC ft (one thousand million cubic – TMC ft equals 78 MLD), Bangalore city is already drawing more water-1,400 MLD equals 18 TMC—than the allocation for the entire rural and urban population in Cauvery basin

6.0 FROTHING IN BELLANDUR AND VARTHUR LAKE: CAUSES AND REMEDIAL MEASURES

A sustained inflow of sewage (~500 MLD) into Bellandur and Varthur lakes brings in a variety of natural and synthetic dissolved organic compounds, along with excrements. The frothing happens due to the activity if the surface-active agents or surfactants that reduce the surface tension of water, allowing air bubbles to persist at the water's surface (figure 6.1). These detergents essentially consists of phosphates (~30 % STPP), and a portion of which is up-taken by aquatic plants while the balance gets trapped in the sediments.

Fig. 6.1: Foam formation in the outfalls of Bellandur lake a) Initiation of foam formation by entrapment of air at the fall levels of the lake b) Foam piling up due to high flow and mixing c) Foam occupying the entire surface of the channel d) Froth spilling over mesh barricade (fixed by BDA to prevent froth getting into roads)

Pre-monsoon showers coupled with gusty winds leads to the churning of lake water with upwelling of sediments. Vigorous mixing of surface water coupled with high flow across narrow channels, leading to bubble formation that persist and build up as foam (Fig. 6.1: a-d). In the lakes, foam /froth gets accumulated along windward shores. Continuous sewage fed in Bellandur and Varthur lakes, has been witnessing foam at downstream in chocked channels or below fall/discharge point since one decade (Mahapatra et al., 2013a).

Sources of these surfactants: Macrophytes and algae inhabiting the lake waters produce many organic compounds (Ramachandra et al., 2009; Mahapatra and Ramachandra, 2013, Mahapatra et al., 2013a,b,c, Ramachandra et al., 2013; Mahapatra et al., 2014), which have surfactant properties. Natural surfactants include carboxylic fatty acids derived from lipids from macrophytes/weeds etc. These are released into water and contribute to a large variety of soluble organic material known as dissolved organic carbon (DOC). Though DOC is produced within lake waters, the major source is the sustained inflow of sewage from the vicinity of the lakes and the watershed. Higher DOC concentrations in lakes, generally impart a brown colour to the water and foam. This highlights that the foam is caused by synthetically produced surfactants released through sewage to surface waters. Synthetic surfactants are widely used in household cleaning products (detergents/soaps), cosmetics and personal care products (shampoo, toothpaste etc.). Common detergents also contains branch-chained alkyl benzene sulfonate surfactants, which are non-biodegradable and results in extremely persistent foam accumulating below the fall levels in the lake and other wastewater outfalls.

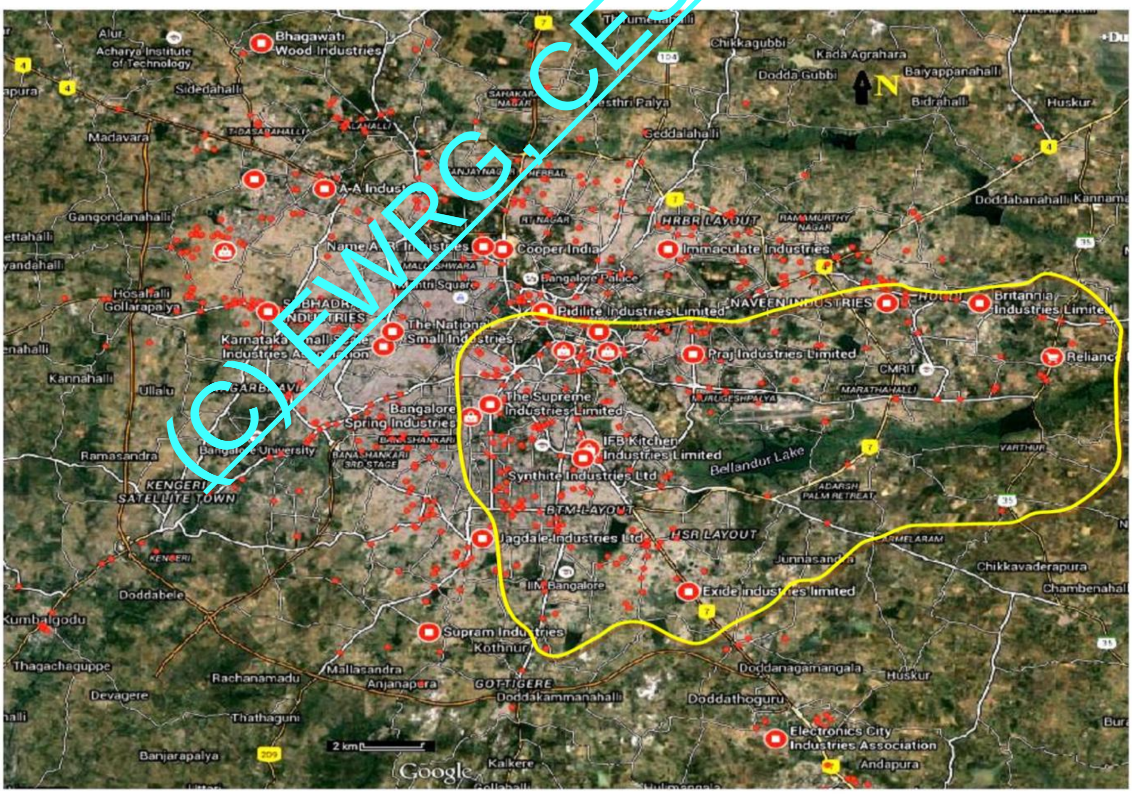


Fig. 6.2: Distribution of industries in the vicinity of Bellandur and Varthur lake and also industries scattered in the city (overlaid on Google earth image http://earth.google.com)

Detergents and soaps mostly contain phosphate (P) softeners to enhance the effectiveness of surfactants through the reduction of water hardness. P loading in lakes has contributed to nutrient enrichment with the proliferation of cyano-bacterial blooms and macrophytes (aquatic plants). There are set of advanced detergents that exclude phosphates but contain biodegradable linear alkyl benzene sulfonate surfactants, such as sodium or ammonium lauret or lauryl sulfate. Surfactants are also used by many industries (Fig. 6.2) as wetting agents, dispersants, defoamers, de-inkers, antistatic agents, and in paint and protective coatings, pesticides, leather processing, plastics and elastomer manufacturing, and oil extraction and production.

Many industries that are present (Fig. 6.2 in the upstream of Bellandur and Varthur lakes (Ramachandra and Solanki, 2007) have also contributed to high levels of surfactants in the waters due to the release of untreated effluents in addition to the domestic sewage. These surfactants are very persistent in the environment, bio accumulate in organisms and humans with various biological consequences. Alkyl phenol ethoxylates for example, which continue to be widely used by industry, have been shown to have estrogenic properties eliciting reproductive effects in fish and other organisms. Similarly, per-fluoro octanoic acid and per-fluoro octane sulfonate, which were commonly used in the production of stain resistant and non stick coatings including Scotch guard and Teflon, also have estrogenic and carcinogenic properties. In contrast to natural foam, fresh detergent based foam is of white colour with noticeable odour. Bellandur and Varthur lake have been receiving a mix of untreated and partially treated wastewaters (~500 million litres per day, MLD), from major residential areas and some industries, both synthetic and natural compounds that are present have contributed to the formation of foam.

Surface tension is an important property of water. It results from cohesion – the attraction of water molecules for one another. Cohesion gives water the ability to form droplets and contributes to the formation of waves and currents, which play an important role in the distribution of temperature, dissolved gases, nutrients, micro-organisms and plankton. At the surface of the lake (i.e the air-water interface), cohesion creates a thin 'film' or tension. This allows insects like water striders to 'walk' on water and forms a special habitat for some aquatic organisms adapted to living on this surface film (mosquito larvae for example). Surfactants are amphipathic molecules, that is, they contain both hydrophilic (water-attracting) and hydrophobic (water-repelling) components. The hydrophilic component can form bonds with water and competes with other water molecules as they attract one another.

In this manner, surfactants reduce the overall attraction between water molecules, thus diminishing surface tension. Lower surface tension causes water to become more 'fluid' or elastic, and when air gets in the resulting bubbles can persist for some time. Surfactants have contributed to 50% of foaming due to a reduced surface tension and balance is due to the intrusion of air into these waters to form the foam bubbles. In the studied lakes wind-induced currents and incipient waves cause turbulent mixing of air and water. Foaming often increases during runoff and rainstorms that transport the surfactants.

The foam collected from the Varthur outfalls were white in colour with a greasy/oily dark materials sticking on the surface of the foam bubbles (Fig 6.3.1). The foam had a pungent odour with sulphide smell unlike the natural foam that has an earthy or fishy aroma. The analysis conducted on foaming abilities showed, mean bubble size decrease with time, and finally ends up in sizes < 2 mm in diameter. The initial bubble sizes range from 2-4 cm (Fig. 6.3.2). These white foams progressively turn off-white and then settle as dark grey residue over time. Experiments conducted in laboratory shows, the persistent nature of the foam that lasts up to 6 days (Fig. 6.4).

Moreover, the foam volumes were observed to be higher during the 2ndand 3rd day that correlated with the mean bubble size. The foam diminishes after the 6th day due to low stability. Earlier reports on wastewater systems have indicated onset of foaming is because of surfactants and bio-surfactants, abundant in wastewater and sludge. They have both hydrophobic and hydrophilic properties and tend to accumulate at air–liquid interfaces increasing surface activity. When air/gas is introduced into solution, a thin liquid film is formed around the gas bubbles as they reach the air–liquid interface preventing them from bursting. The foaming persistence tests carried out in the laboratory by stirring showed the presence of surfactants indicating highest foaming abilities. The liquid phase of the foam samples contained significant amounts of surface active groupsduring the analysis period. However the foaming potential decreased after 4 days this can be attributed to the decrease in the interactions between solid particles and the surfactants and hence the stability of the foam. Studies on wastewater systems highlights that sludge, (Mahapatra et al., 2013a) containing surfactants and the foaming potential is enhanced or reduced depending on the surfactant–surfactant and particle–surfactant interactions (Glaser et al., 2007 and Eisner et al., 2007). More importantly increase of temperature in liquids containing surfactants result in increased surface activity (lower surface tension) enhancing the foaming potential (Barber, 2005) which was also observed in the present study as the foaming events are periodic and are often noticed during the summer at lake outfalls. In order to gain a better understanding of foam creation and stabilization, the liquid phase of foams generated at the outfalls of Varthur lake was analysed for carbon assays as COD, BOD and solids. The BOD and COD values were ~0.6 g/l and 1.14 g/l respectively. High total solids (TS) of ~110 g/l were observed in the liquid phase of the foam sample out of which ~92 g/l were total volatile solids (TVS). The ash content was ~16.2 g/l and the total dissolved solids (TDS) were ~7 g/l.

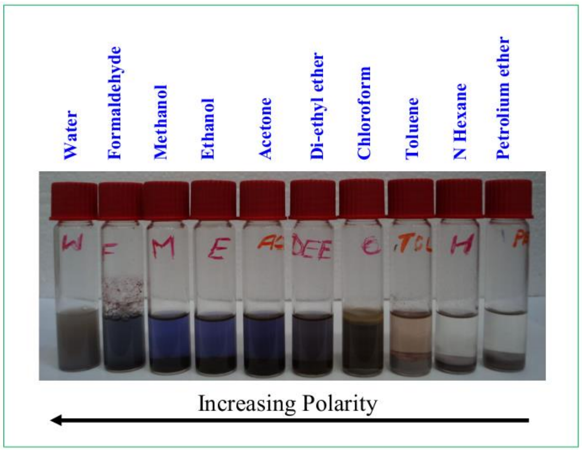


Fig. 6.3.1 and 6.3.2: Collection of foam sample from Varthur lake and analysis of elution of the liquid phase of the foam in different solvents in the order of increasing polarity

Parameters	V1	V2	Foam
Water temperature (°C)	27.1	26.9	27.2
TDS (mg/l)	448	454	7000
EC (µS)	749	764	17000
pH	7.46	7.35	6.98
DO (mg/l)	2.6	0	-
BOD (mg/l)	24.39	60.98	650.41
COD (mg/l)	40	88	1140
Alkalinity (mg/l)	336	336	12000
Chloride (mg/l)	117.86	122.12	3195
Total Hardness (mg/l)	206	224	13000
Ca Hardness (mg/l)	57.72	64.13	3607.2
Mg Hardness (mg/l)	36.03	38.85	2282.45
Phosphate (mg/l)	1.263	0.881	74.59
Nitrate (mg/l)	0.541	0.361	129.72
Sodium	169.5	161	770
Potassium	35	34	230

Fig. 6.3.3: Frothing at Varthur kodi outfalls and analysis of froth

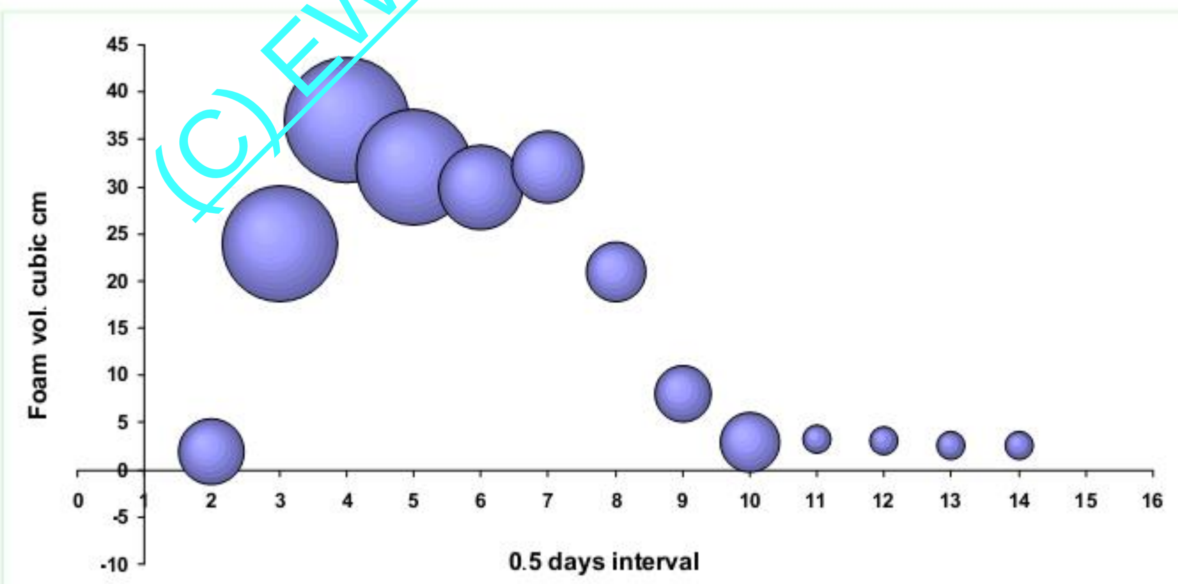


Fig. 6.3.4: Analysis of foaming capacity of the froth

Hydrophobic compounds present in the DOC foam were confirmed by eluting the foam in non-polar and polar solvents (Mahapatra et al., 2013a-c; Mahapatra et al., 2014a,b). The solvents comprised of water, formaldehyde, methanol, ethanol, acetone, di-ethyl ether, chloroform, toluene, n-Hexane and petroleum ether that were arranged in order of decreasing polarity. The results showed the presence of amphipathic molecules as shown in Fig. 8. The analysis showed presence of both polar and non polar compounds in the liquid phase of the froth. The froth analysis showed higher values of TP >2 g/l with orthophosphate values >75 mg/l indicating higher P content in waters owing detergents and also P up-welling due to anaerobic conditions in the sediment layer of the lakes, aided my macrophyte cover over the lake surface. Laboratory analysis of the commonly used detergents as Surf Excel, Ariel, Rin etc. showed higher presence of polyphosphates with TP (~20-25 %) indicating detergents rich in P. Earlier studies on sludge sediments in Varthur lake indicated greater P influx from sediments during anaerobic conditions mostly during summer. The organic matter settled in the bottom of the lake resuspends owing to change in redox environment, that up-wells large quantities of immature sludge which imparts the dark grey colour to the lake water. Consequently, the water at the outfalls was grey in colour with higher particulate matter arising from sludge.

The Bellandur and Varthur lake waters are moderately hard waters (~215 mg/l of total hardness), with high Ca and Mg concentrations. As a result, foaming is not usually excessive in these waters. The incidence of high foam is also associated with high Na content in the lake in comparison to Ca and Mg. When the water is soft foam may occur more frequently. Foam is usually harmless if they are only from vegetative origin where the foaming agents are primarily proteinaceous or carbonaceous matter. In this case only a small amount of fatty acids or other foaming agents are required to produce foam. Only about 1% of the foam is made up of the foaming agent, the remaining 99 % being air and water. The foams originating from the wastewaters, detergents and other industrial origin surfactants will have significant impacts to the aquatic ecosystem and human health. These foam can accumulate compounds that are repelled by water (hydrophobic), so foam can be enriched significantly with particulate organic and inorganic compounds such as nutrients (N, P, C), cations (K, Na, Ca, Mg), heavy metals (Cd, Cu, Fe, Pb, Zn, Cr, Ni, Hg, Ar etc.) and chlorinated hydrocarbons. Therefore when these foams get in direct contact with human beings, depending on the specificity, they can cause many stimulatory effects that can trigger the immune response in the body. Moreover, the organisms that inhabit the surface layer would be more exposed to these contaminants and this could form a pathway to introduce contaminants into the food web.

Fire associated with foam in Bellandur lake: Flammability is the ability of a substance to burn or ignite, causing fire or combustion. Incidence of foam catching fire (Fig. 6.5.1 and 6.5.2) are due to compounds with high flammability i.e. mostly higher hydrocarbons and organic polymers from nearby industries in the vicinity of Bellandur lake. High wind coupled with high intensity of rainfall leads to upwelling of sediments with the churning of water as it travels from higher elevation to lower elevation forming froth due to Phosphorous. Discharge of untreated effluents (rich in hydro carbon) with accidental fire (like throwing cigarettes, beedi) has led to the fire in the lake.

Fig. 6.5.1) Flames over the surface of the froth during the night observed at the Yamalur-Bellandur lake outfalls 6.5.2) Flames due to the residual black (oily/greasy materials – heterogenous phase) on the surface of the foam.

The foam is a very periodic event (annual) which happens mostly in the pre-monsoon period at the outfalls of Bellandur and Varthur lake. The foam built up at the dry periods can be attributed to churning and associated sediment re-suspension from the lake bottom. This phenomena is also triggered due to anaerobic environments in the sediments that leads to a reducing environment (-340 to -280 mV – oxidation reduction potential; ORP; Mahapatra et al., 2013a-c) where the sludge/sediment bound P along with the decomposed plant parts, oil and greasy materials gets resuspended in the water (Mahapatra et al., 2013a,b). This produces a solid black layer on the surface of water that comprise of macrophyte/plant derived organic acids. With high wind velocities and water flow, this black particle that is mostly soluble in oil phase (hydrophobic in nature) gets deposited on the surface of the foam or bubbles. Frequent aeration of the lake waters falling off from the outfalls via splashing, forms gas bubbles that increase the liquid interfacial area where at times charging occurs. Apart from charge generation at the surface, continuous aeration aids in formation of persistent froth that lasts from hours – days. This foam is also the source of very fine mist as it bursts. The rate at which the bubble bursts is dependent on the static spark that helps in disruption of the foam.

P in Detergents: Alternatives to Phosphorus in Detergents: There has been a series of events that has very clearly highlighted the linkages of enhanced usage and influx of P with a phenomenal increase in P enrichment in surface and ground waters. During seventies and early eighties, 19th century such instances had brought about an increase in global consensus and the public awareness mostly in the European nations and triggered regulations on P loads from Industry and Urban sources. In India there has been a widespread use of P based detergents that has resulted in contamination of ground and surface waters rendering these water unsuitable for any use. One of the major constituents that form a bulk of the detergents is the builder material that is often made up of Sodium tripolyphosphate (STPP) that significantly contributes to P enrichment. The levels of P enrichment in urban water systems is enormous ranging from 0.5 to >10 mg/l of labile P. Abundant P in these systems have substantially contributed to increased biomass productivity and a leap in the net primary productivity of the urban aquatic systems that ahs resulted in rampant proliferation of aquatic macrophytes and weeds at the same time aided in the large scale algal blooms often seen sin the surfaces of these urban water bodies. The sludge P values in the initial reaches of the wastewater fed water bodies like Bellandur is ~1-3 %. During shifts in redox environments these P becomes bioavailable and results in increased primary productivity of the system. The sediment P levels varies from 0.1 – 0.28 %, mostly as NaOH soluble P forms indicating high fraction of mineralisable P in these lake systems. Two main solutions for cutting short rapid and high P influx into the system is a) Introduction of non-P based builders in detergents for example Zeolite, that can completely replace Sodium tripolyphosphates (STPP - amounts to ~50% bio-available P in municipal wastewaters) commonly seen in detergents and b) Augmenting the existing wastewater treatment system for nutrient removal and recovery. This requires various measures that aids in framing and implementatation of laws to completely replace P based builders to alternative non-P based household laundry detergents. Already the European Commission (EC) has implemented non-P based culture in detergents through the European Union (EU) and recommends appropriate measures to improve the present P enrichment scenario. The two main essential P sources in urban conglomerates are the municipal wastewaters and to a lesser extent agriculture. In most of the Bangalore's catchment that has an inadequate treatment facility and treatment is mostly upto secondary levels. Municipal wastewaters represent the single largest P source in urban municipalities. In case of certain areas where people practice agriculture, horticulture and floriculture, a minute amount of P (synthetic fertilisers) escapes from these landscapes, where top soil erosion and land run off are the crucial means of entry of fertiliser P into the channels and freshwater lakes. It has been estimated that P from detergents contributes to an estimated 65% of P in municipal wastewaters and the rest are from excrements etc. Based on the conclusion of the present study, the recommendations are a) A ban on production of polyphosphate based detergents in Indian systems which will help in usage of trusted non P based detergents, that would bring down the P loads contributed from detergents in municipal wastewaters and also significantly reduce P loads from all garment, textile and other industries that uses detergents substantially; b) Nutrient removal and recovery mechanisms to be augmented into the existing treatment systems by the help of phyto-phyco modules.

P is limiting and crucial: Phosphorus is the **most crucial nutrient** in living systems and is a key component of the genetic makeup of living organisms known as gene that essentially comprises of DNA and RNA. The phosphates in the bound forms as reducing powers are also the only energy currency to the cells in the form of ADP/ATP, that helps in production of metabolic energy and there by sustaining various coupled and biochemical processes in the cells. Belonging to the group V of elements, Phosphorus with its unique capacities of delivering and storing energy in pyrophosphates bonds is irreplaceable. The P acts as a limiting nutrient in agricultural and aquatic processes, and is thus indispensable as a source of food source and essential nutrients depended mostly on mineral inputs as phosphatic fertilisers. ~85 % of the mineral phosphates mined from various regions across the globe have been used for manufacturing fertiliser. At such unprecedented rate of mining P for meeting the global food demands and ensuring the food security in future, the natural lithological/terrestrial P pools in the system is diminishing at an alarming rate. The fact that P resources are non renewable and the world 'P' reserves are scant, it becomes highly imperative to identify potential P pools in nature and use sustainability concepts to pool back P reuse and recycle from the P enriched sub-systems. The P distribution in nature in unlike other essential nutrients as N and C, where the P is mostly in mineral origin, where as the major nutrient pools for N and C are the atmosphere. This makes P very unique and critical in terms of limitation in availability and as rare sources. Globally ~26-34 % i.e. 11-15 % of P by weight are found in P rock minerals (Steen, 1998)where P_2O_5 content is ~31 %, which means ~ 13.5 % P on a weight basis (Kratz et al, 2007). The global mining of P has been reported to be at a rate of ~160 million tonnes/annum and the total P deposits in these areas are ~16 billion tonnes (USGS, 2010) which is going to last for another 120 years at the present rate of exploitation and has been well documented and predicted by a number of scientific studies (Wagner, 2005; Rosmarin, 2004). During the mining process, numerous environmental externalities are witnessed a) with large open pit mines, continuous operations results in huge dust emissions and the generation a large quantities of mining wastes and ore tailings; b) during the production of H_3PO_4 from the P rich rocks, extensive acidification through sulphuric acid is undergone that produces voluminous phosphogypsum (5 ton/ton of phosphates) which is often disposed into large water systems as sea and oceans; c) the by-products produced during the mining and processing operation have squat utility due to the presence of hazardous substances as heavy metals like Cd and other naturally occurring radioactive elements as Ur and Th (Villabla et al., 2008).

During mineral processing phosphoric acid is formed by treating phosphate ore (apatite) with sulfuric acid that produces phosphogypsum a by-product

$$Ca_5(PO_4)3X + 5\ H_2SO_4 + 10\ H_2O \rightarrow 3\ H_3PO_4 + 5\ CaSO_4.2\ H_2O + HX$$

where X includes OH, F, Cl, or Br

The mining and extraction of P are being practised only at a few locations that are known to be the global reserves of P i.e. China, Morocco, parts of Western Sahara, South Africa, Russia and the U.S. The major producers being China, U.S, Morocco and Russia (USGS, 2010). The geographical distribution of P reserves is highly uneven like oil wells and can be the reasons for instabilities across the major economies of the world, where western European nations and countries like India have to incur huge costs on import of P, having literally no domestic P generation. With the present extent of mining, as we go deeper into the lithological strata's the phosphate ore quality drastically deteriorates, evident from an increase in Cd and Ur, that are highly hazardous and practically impossible to separate from these P rich minerals (Kratz & Schnugg, 2006).

Industrial processing without proper removal of these heavy metals from these minerals will result in extensive deposition of these hazardous elements in agricultural and farm lands. It has been observed that the organic matter content of the soil (fertility) has been rapidly declining with the natural denudation and erosion process coupled with anthropogenic soil utilisation. This has led to a very poor nutritional status of the soil witnessed mostly in the developing nations. In order to achieve higher food productivities and ensure global food security in future for a better quality of life and higher standard of living, a high demand for these rock based fertilisers are essential. Moreover to achieve this there is a shift from agrarian food culture to a meat and dairy based diet pattern that increase the present load on fertilisers to several folds.

Reports suggest an annual growth rate of ~1 % until 2030 that would lead to >25 % more rock phosphate utilisation compared to present usage (FAO, 2000) that increases further load on energy (Fig. 6.6 and 6.7; Table 6.1).

Table 6.1: For the production of 1 ton of P_2O_5 (0.44 ton of P), the type of energy and materials consumption required (modified from Villabla, 2008)

	Mining	Mineral Processing	Total
Input	Electricity 697 MJ Diesel 125 MJ Explosives 3,3 MJ	Water Electricity 1,128 MJ Flotation reagents Diesel 396 MJ	Total Primary energy consumption 5,500 MJ
Output	Waste 21.8 tons Mine water Diesel exhaust gases	Waste water Tailings 6.5 tons Diesel exhaust gases	Total Solid waste generation 28 tonnes

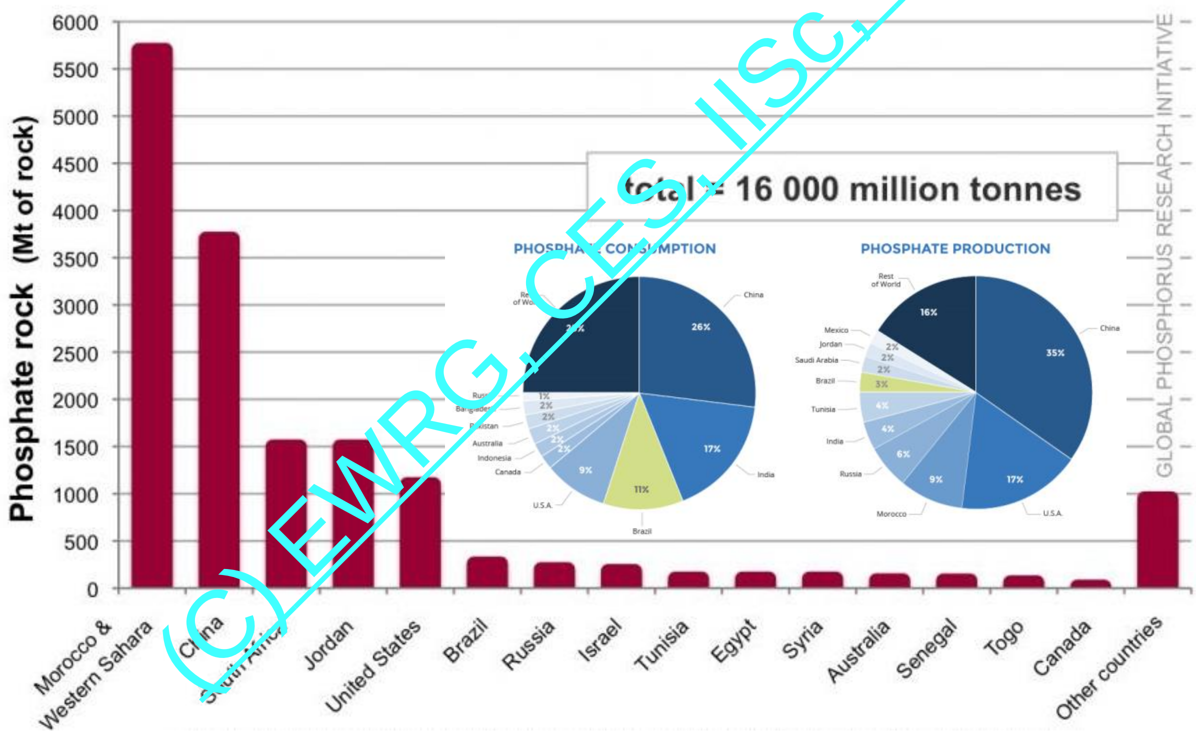


Fig. 6.6: Rock Phosphate abundance and distribution, USGS (Jasinki, 2010)

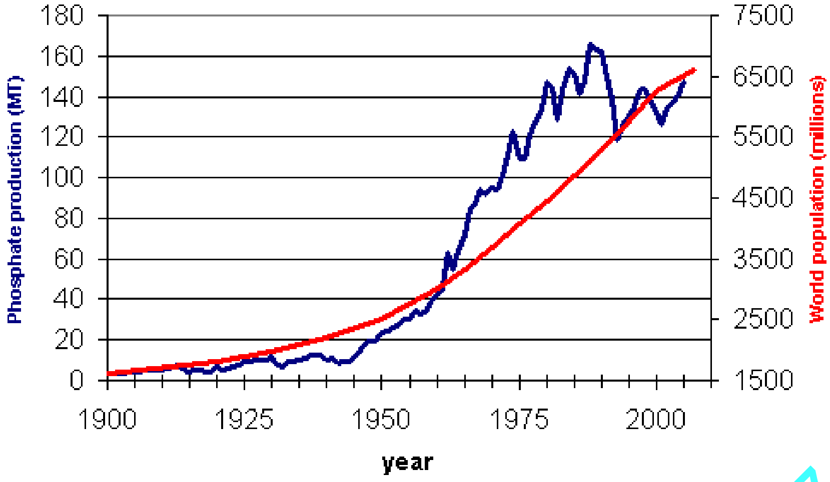


Fig. 6.7: Increase in P production with increased population growth, USGS, 2010

As apparent from the above curves, the population and the increasing demand for P goes hand in hand. However when it comes to the utilities if these P based resources, these systems are rather very inefficient. According to studies conducted on P budgeting and balance across various sub-systems (Bacinni and Brunner, 1991) only 10 % of P that is intended to be used for agriculture goes into food, there by incurring huge losses into the pedosphere and the hydrosphere, from where mining back P becomes complicated and difficult. Thus efficient P management in these spheres becomes utmost important to conserve the present day nutrient pools.

One of the major sources of P in wastewaters are the human excrements, household detergents and 'P' from other commercial and industrial sources. Urban runoff contributes to a very small amount of P loads. The P inputs from both the vegetative sources and the animal sources in our food both accounts to each ~ 0.8 – 1.2 g, while the P contributed by the detergents in around 0.2 g per day per person. An average Indian household generated ~ 1.8 – 2 g of P per capita per day, where bulk of the P in these waste are present in urine ~0.8 – 1.2 g; feces ~0.4 – 0.6 g and others utilities ~0.3 grams.

P role in surface waters: P routes into surface water bodies from various non-point sources as agricultural runoff and from point sources like municipal and industrial wastewater discharges. In Indian due to lack of norms / standards in P levels in household detergents used in laundry and dishwashers, these detergents contain bulk of phosphates as builders and interestingly ~50 % of the labile P (inorganic and soluble forms) present in municipal wastewaters are from these sources alone (Fig. 6.8).

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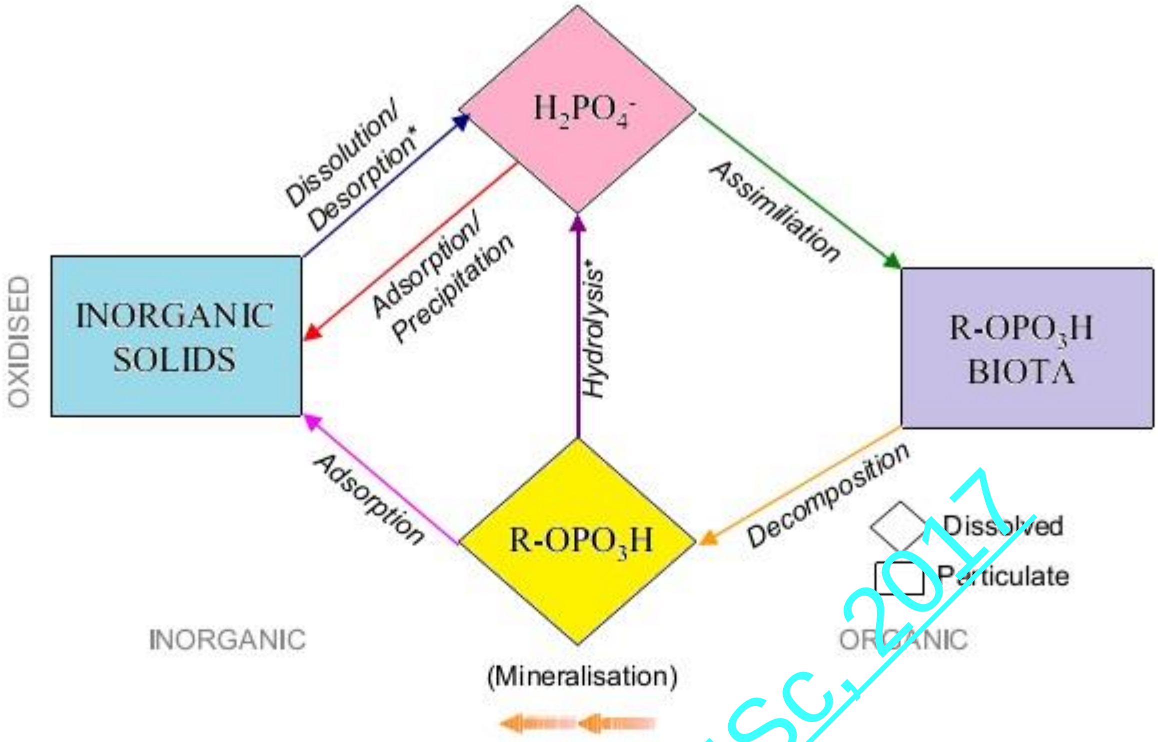

Fig. 6.8: P biochemical Cycle (terrestrial and aquatic environments)

N and P as very basic nutrients trigger aquatic plant and algal growth in surface waters and increase the primary productivity of these waters. A combination of organic nutrients with various ionic radicles and metals act as important metabolic precursors for bio-synthesis of vital energy rich molecules as fats and proteins required for the growth and development. Phosphorus is usually known as limiting nutrients that restricts the growth, and is the most crucial element that addresses nutrient enrichment in surface waters. Bulk of the 'P' in aquatic systems are in the form of Organic P (70 %) mostly found in the living and dead biomass and the rest comprise of the soluble and the particulate P.

Internal P cycling: In most of the lakes or surface waters, the sediments play a vital role in flux regulations and role in soluble P in waters. Annually large quantities of P are deposited in the bottom sediment owing to various physical and chemical processes; at the same time there is an ample remobilisation/resuspension of P from these sediments under certain conditions that maintains a minimum level of soluble P in these aquatic environments. Various factors affect the P exchanges across the sediment-water interface. Some of these important factors are dissolved oxygen levels, nature of the redox environment, pH, complexometic reactions, precipitations and activities of sediment microflora.

It has been observed that P concentrations in these sediments are much higher compared to those present in overlying waters. The mechanism of resuspension of P is directly linked with the dissolved oxygen concentration in these environments, where DO levels below 2 mg/l helps in the release of soluble P from these sediment pools. Under anaerobic conditions this phenomena increases manifolds. But, the P release flux is dependent on various factors as the surface properties of the particles/minerals in the sediments, acidic or basic environments, their abilities of adsorption and desorption, the oxidising/reducing nature of the overlying waters, the nature of organic C and the various biotic components in these systems.

P chemistry in very interesting with its unique abilities of forming bonds with various metal oxides, as Fe, Mn, Zn and Cu. The affinity of P to these metal oxides is governed by the prevailing redox environment at the interface between the sediment and the water layers. In aerated water systems, P readily binds with Fe oxides. However, in contrasting conditions under anaerobic environment, the Fe with the highest oxidation state i.e. +3 gets reduced to +2 ferrous, thereby releasing the soluble P into the overlaying waters. This is one of the major mechanisms of re-suspension of P from the bottom sediments under low redox conditions with high residence time.

Studies conducted in the major lakes of Bangalore city showed 11-37 mg/l TP; 1.8-16 mg/l OP; 2-4 g/kg TP in sediments; 1.2-2.8 % TP in sewage sludge; 84-111 mg/l in interstitial waters. The total P influx into Bellandur and Varthur lake systems was computed to be around ~ 18 – 10 tonnes/day. Of which ~45 % of P is trapped in the sediment pool.

Changing tropic conditions in lakes due to P accumulation: Based on the P concentrations and the prevailing trophic conditions the lake can be divided into five different categories as per OECD norms for trophic classification (Table 6.2)

Table 6.2: Trophic status of surface waters with P concentrations

Class	Trophic Level	Total P (µg/L)
1	Oligotrophy	<10
2	Oligo-mesotrophy	<20
3	Mesotrophy	<50
4	Eutrophy	<100
5	Hypertrophy	>100

The primary productivity of the surface waters is mainly dependent on the external nutrient loads. However the trophic status of the water in also to a larger extent dependent upon the internal 'P' loading for those water bodies that have history of nutrient enrichment. However to curtail appearance of thick algal blooms, the first step is to cut short the external loadings. However the trophic conditions in an aquatic system is influenced by the bathymetry, morphometry, mixing, flushing rates, the nature and the type of the catchment as well as the sediments, the trophic status and the history of nutrient loads.

Detergents as one of the major reasons for P enrichment in urban conglomerates: Soaps and detergents primarily comprise of surface active groups generally called as surfactants made of chemicals that aids in cleaning dirt. Soaps when used with hard water, have low cleansing action due to the presence of minerals. Thus builders that help in improving the efficiency of these surfactants have become major ingredients in soaps and detergents. These builders enhance the surface activity by counteracting minerals responsible for hardness in water, oil and grease emulsification, soil particle/dirt re-suspension and avoiding deposition. Phosphates have been by far the most extensively used builders in detergents, primarily acting on as water softener and agent for suspending dirt in aqueous systems. And has been also responsible for nutrient enrichment in surface waters (Feisthauer et al., 2004).

A looks at the utilities of detergents in India, shows tremendous use of these detergents, but facilities for recovery of detergent constituents and treatment being extremely scarce. Like other nations, India realises the implication of detergents as a potential chemical pollutant on the surface and various receiving waters through the Environment protection law (1989). Even, then these are being used relentlessly even today. Reports suggest a 1.5 fold decadal growth in the use of detergents (2.8 kg/cap/annum, 1994; >4 kg/cap/annum, 2005). Moreover, there is a high utility of the detergent bars, with annual growth of ~8 %, where ~35% of the detergents comprise of Sodium tri-polyphosphate (STPP). Such numbers highlights grave concerns on the present day deposition of such huge amount of P in aquatic systems. Most laundry detergents in India are phosphate based, as there are no norms, control or regulation of phosphates use resulting in deterioration of receiving waters.

Today, the Nations action plan towards the control of nutrient enrichment in very meagre, through the establishment of treatment plants that only treats water up to secondary levels, and the issue remains largely ignored. Though our constitution has several laws to prohibit the usage of phosphates in the day to day chemicals like the Environment Protection law (1989) and the Hazardous Waste Rules (1998) that clearly categorises the major forms of P as phosphine and phosphates as toxic chemicals. However these rules are not yet applied in the manufacturing of the household laundry soaps and detergents. Though the Bureau of Indian Standards (BIS) have set up certain grades/standards for eco-labelling with the help of Ecomark, way back in 1991. These eco-labelling indicated the brands that had surfactants that are biodegradable and packaging in recyclable and biodegradable materials.

For Indian systems where there are no norms for the use/disposal of P linked commodities, separate legislation is required to limit the P content in detergents or potential substitution of P in detergents by Zeolite are required. Lessons from European nations, the US and Canada can be take, that have attempted a ban in the sale of P-rich detergents until 2010. And have devised several strategies to minimise runoff and P input into aquatic systems.The detergents may vary depending upon utilities for example laundry detergents used in washing clothes (hand/washing machine); fabric conditioners; dishwash detergents and liquids. Generally these detergents include a set of basic compounds as the builders, the surfactants and the stain removal agents.

The builders firstly helps in providing a platforms for the water softeners imparting best water interfaces for the operation of surfactants, mostly by deactivating the freely wandering minerals in hard waters, that restricts the action of surfactants. The surfactants help in separation of phases by solubilising the dirt, by getting attached with it that renders them for mixing in water phase. These can be of various categories i.e. cationic, anionic, neutral/amphoteric. In Indian markets there is a widespread use of these anionic based surfactants in the household detergents which mostly comprise of linear alkyl benzene sulphonate (LAS) and Do-decyl benzene sulphonate (DBS). The stain removers act as very crucial agents comprising of bleaching agents and enzymes that elp in the rapid degradation/oxidation of the dirt/coloured/sticky materials ultimately removing the colour or the stain from the fabric.

Other than this various other components are used in detergent that comprise of fragrance imparting agents, enzyme activators, bleach activators, fabric conditioners, alkali etc. Builders are one of the key components of detergents, that are needed firstly for reducing water hardness that helps in enhancing surfactant efficiency by catching ca and Mg ions and encrust the surface of fabrics, secondly, these builders stabilise excessive pH conditions that are required for dirt/soil removal, thirdly they help in improving the overall solubilisation of the various components in the detergents, moreover the dirt in the fabric gets dispersed and mover out into the solution. Most importantly the builders offer a platform or skeleton for holding together the powder grains in the detergent. Present day builders are mostly made up of STPP that are environmentally harmful as they cause nutrient enrichment. Possible substitutes to these builders can be zeolite (Zeolite A) and combination of polycarboxylic acid and sodium carbonate. Zeolites are non hazardous as these are made up of alumino-silicates. Citrates can also be used as potential builders, but the cost for synthesis is pretty much high. The various builders that are used presently and can be potentially used with their possible impacts on environment are provided in Table 6.3.

There can be a lot of variations in the components of these detergents and differs across brands. While the conventional powders have similar constituents the advanced/concentrated/compact detergent powders may vary (Table 6.3). The STPP based conventional detergent powders generally have 15-30 % STPP with <5% PCA, whereas the advanced concentrated detergent forms can have many combinations of STPP i.e. 5-15 % or > 30 with 5 % PCA or 30 % STPP, with carbonates and silicates (~10 %). However in case of Zeolite based conventional powders 15-30 % Zeolites with <5% PCA is used compared to concentrated detergents where roughly similar proportion of Zeolite i.e.e 15-30 5 is used with addition of Percarbonates (15-30 %). A comparison of the difference in various constituents in detergents conventional and advanced is provided in the Table 6.4.

Table 6.3: Available builders and alternatives to STPP for detergents

Sl No.	Builder components	Org/Inorg	Abbreviation	Actions and Impacts
1	Sodium tripolyphosphate	Inorg.	STPP	Contains 25% P, main cause of eutrophication in rivers, lakes and coastal waters
2	Zeolites (A, P, X, AX)	Inorg.		No environment effect. Increases sludge quantity. Co-built with other additives, especially PCAs.
3	Polycarboxylic acids	Org.	PCAs	Poorly-biodegradable, adsorb to sludge. Fate in environment – limited studies and yet to be realised; potentially used with zeolites.

4	Citrates	Org.		Act as a potential chelator, more effective on Mg than Ca ions, contributes substantial BOD load at wastewater treatment works. Can be used especially for liquid detergents
5	Nitrilotriacetic acid	Org.	NTA	Increased dissolved heavy metals - Rapidly solubilises heavy metals through chelation. Is banned in EU
6	Carbonates	Inorg.	CO_3^{2-}	Aids in water softening by precipitating free Ca ions; in hances and stabilises alkalinity
7	Silicates	Inorg.	SiO_X	Avoids corrosion – supplying oxygen and increases alkalinity
8	Phosphonates	Org. P	$C\text{-}PO(OH)_2$ /$C\text{-}PO(OR)_2$ R-alkyl, aryl	Poorly biodegradable, metal ion chelator, anti-redeposition agent
9	Soap	Org. salts	RCOO-X X-Na/K	Inhibiting excess foaming in mechanically driven system
10	Ethylenediaminotetracetic acid	Org.	EDTA	Poorly degradable. Dissolves metal ions
11	Carboxymethyloxysuccinate Carboxymethyltartronate	Org.	CMOS CMT	Weak chelator also observed with STPP. Poor biodegradation, not trapped in primary solids; not generally used in EU.
12	Carboxymethyl cellulose	Org.	CMC	Does not allow re-deposition, helps in repulsion of soil/dirt particles from fabric

Table 6.4: Constituents of detergents conventional and compact (advanced)

Constituents (%)	Detergents (Conventional)		Detergents (Advanced)	
	P rich	P free	P rich	P free
Sodium tripolyphosphate (STPP)	20-25	0	50	0
Zeolite	0	25	0	20-30
Polycarboxylates (PCAS)	0	4	0	5
Organic phosphonates	0 to 0.2	0.4	0	0.2
Sodium silicate	6	4	5	4
Sodium carbonate	5	15	4	15-20
Surfactants	12	15	14	15
Sodium perborate**	14	18	10	13
Activator	0 to 2	2.5	3	5
Sodium sulphate	1 to 24	9	4	5
Enzymes	1	0.5	0.8	0.8
Anti-redeposition agents	0.2	1	1	1
Optical brightening agents	0.2	0.2	0.3	0.3
Perfume	10	0.2	0.2	0.2
Water	--	5	8	5

**monohydrated perborate is used in advanced detergents as high impact bleach
**tetrahydrated perborate used in conventional detergents

Compared to STPP based detergent systems, the Zeolite A based systems are environmentally friendly and does not fertilise aquatic resources. Zeolite A is inert and insoluble alumino-silicate, and can only contribute to high total suspended solids (TSS) and would lead to high quantity of sludge generation. If all the household detergent systems are substituted by Zeolite based systems, the mix of Zeolite and PCA can constitute upto 10 % of the dry solids in the sludge. The only concern for Zeolite based systems i.e. Zeolite A is its little affinity for heavy metals, however no evidences have been discovered yet. Zeolites have been known ti improve sludge settleability. In case of high heavy metal concentrations in the sludge/sediments, the hydrolysis of Zeolite A can potentially re-relaese these metals in soluble forms to the overlying waters. Similarly the PCA'a comprise of synthetic polymers, whose biodegradability in very low (~20 %) [Morse et al., 1994]. PCA's are mostly captured in sludge/sediments with having no impact on the environment, and the detection of these compounds in the effluents is difficult as are a mixture of compounds.

Set of Solutions and Recommendations for avoiding P influx into aquatic systems: Rapid deterioration of aquatic systems due to environmental impacts of P presses the need for implementing various measures/control strategies and restrictions on the use of possible P sources as household detergents to bring down P loads into surface waters. The last two decades have witnesses a global consensus on the impacts of P on fast declining freshwaters reserves on earth. As an effort of resurrection and checking the environmental implications several nations have implemented schemes and legislations to avoid P based ingredients in detergent commodities. The growing consensus across nations and increasing studies on P based pollution in aquatic systems suggests a reduction by 80-90% to restore the trophic status in many of the aquatic systems. A forbid of utilities of 'P' based detergents can bring down the 40% of the P loads in aquatic systems, that would contribute significantly as attempts to safeguard our future water resources. Furthermore, improved wastewater treatment facilities with effective N capture mechanisms as Algal modules further aid in another 30 % restrictions of P influx into aquatic systems. In many of the countries a stringent law on restrictions on use of P in detergents and efficient wastewater treatment facilities has already resulted in the improved surface water. In this regards identifying a suitable alternative to P based ingredients in detergents i.e. builders is essential. Zeolite A-PCA; Sodium citrate, ethylenediaminotetraacetic acid (EDTA) and Nitrilotriacetic acid (NTA) are some of the possible alternatives for substituting phosphorus completely from detergents. Sodium citrate is expensive and are ineffective in removal of hardness in water primarily caused by abundance if Ca and Mg cations. As builders EDTA and NTA have reduced efficiency in dispersion of particulates compared to P based detergents as STPP. In addition to this NTA have abilities to bind to cancer causing heavy metals in sewage sludge and enhance the mobility of these harzardous trace elements.

However detailed studies on its impacts in environments, economy and feasibility as a potential substitute to P based detergents have to be undertaken. Many of the European nations and US have completely substituted STPP by Zoelite and this intervention has rendered improved water quality in many of the freshwater systems in Europe and US. Taking lessons from the above mentioned success stories, the developing nations as India must also strictly restrict the use of P in detergents and parallely plan for economic and efficient nutrient removal systems during wastewater treatment to curtail any further P enrichment and resulting environmental degradation. Zeolite A (aluminium silicates) has been proved by far as the most acceptable and safe alternative to STPP, being inert, non toxic in aquatic systems. Many developed economies as US, Germany, Switzerland and other European nations have extensively adopted zeolite A as environmentally friendly substitute for STPP. Based on the studies of preponderance of phosphates in domestic wastewater, surface waters and sludge/sediments and the increasing enrichments of these urban surface waters with large quantum of nutrient loads from untreated wastewaters comprising of P inputs from detergents and human excrements, the following actions needs to be implemented

1. Implementation of strict and mandatory rules and legislations to regulate/remove 'P' based ingredients in household laundry detergents. As almost all detergents brands available in market invariably constitutes bulk of 'P' based ingredients due lack of sufficient rules and laws,
2. Identification of P detergent manufacturing units and inventorisation of phosphates based products in these units. Together with this a national accounting of total P imports, distribution, manufacturing into various end products and disposal of these commodities encompassing all sectors has to be prepared.
3. More research and development on fate of P based ingredients in aquatic systems, from various sectors (Agricultural, Municipal etc.) has to be undertaken.
4. Incorporating mandates for nutrient (N and P) removal and recovery to the existing wastewater treatment systems that only focuses on BOD/COD and TSS removal as a criterion for disposal of water into streams and other surface water bodies.
5. Seeking participation from the local communities in surface and ground water management and strictly applying the polluters pay principle to the rapidly declining surface waters would ensure conservation and protection of the fresh water resources.

There are a number of cases where zeolite has been applied in river and lake systems and there have been significant improvements in the water quality. Tables 6.5 and 6.6 provide a comparative account on a case by case basis in improvement of water quality.

P enrichment in River - CASES	**Initiation (History)**	**Actions taken /implemented**	**Reduction of P inputs achieved**	**Effect on quality/ improvements**
Belgium – Wallonia Meuse and Schelt rivers	STPP based detergents Poor standard of sewage treatment	Change to Zeolite based detergents Improvements in sewage treatment	Not quantified	Partial improvement
France - Seine and Loire rivers	STPP based detergents	Partial change to Zeolite based detergents	~50% for the Seine	Partial improvement

	Sewage treatment does not remove P Intensive agriculture locally	Improvements in sewage treatment	Marginal for the Loire	
Germany - Rhine river	STPP based detergents Sewage treatment does not remove P	Change to Zeolite based detergents Complete implementation of the UWWT directive including P removal	55-60%	Partial improvement
Hungary - Danube & Black Sea	Mainly STPP based detergents Poor standard of sewage collection& treatment	Unknown	Unknown	Unknown
Italy - Po river and N. Adriatic	STPP based detergents Sewage treatment does not remove P	Change to Zeolite based detergents Improvements in sewage treatment	30-40%	Partial improvement in quality of the N. Adriatic
Netherlands	STPP based detergents Sewage treatment does not remove P Intensive agriculture	Change to Zeolite based detergents Sewage treatment removes P Measures to control agricultural P sources	50%	10% reduction in Chlorophyll a

Table 6.5: Cases of improvement of river systems with Zeolite application

P enrichment in Lakes - CASES	**Initiation (History)**	**Actions taken /implemented**	**Reduction of P inputs achieved**	**Effect on quality/ improvements**
France - Lac du Bourget	Catchment runoff, detergents	Regulations on use of detergents	70%	Eutrophic to meso/eutrophic. Still in transition
Germany - Lake Haussee	Detergents	Ring sewer. No domestic sewage input	90 %	Eventual recovery of the lake, >5 years after reducing P inputs
Italy - lago d'Iseo	STPP based detergents Sewage treatment does not remove P	Change to Zeolite based detergents P removal at main STW and diversion of some flow	60%	Lake still in transition from eutrophic condition

Italy - lago Endine	Mainly STPP based detergents Poor standard of sewage collection& treatment	Change to Zeolite based detergents Ring sewer	80%	Lake still in transition from eutrophic to oligotrophic conditio
Switzerland - lake Geneva	STPP based detergents Sewage treatment does not remove P	Change to Zeolite based detergents sewage treatment works remove P	60%	Significant improvement
USA - lake Erie	STPP based detergents Sewage treatment does not remove P	Change to Zeolite based detergents Major sewage treatment works Remove P	85% from municipal wastewater, 50% overall	Significant improvement, recovery not complete

Table 6.6: Cases of improvement of lake systems with Zeolite application

Source:

Ramachandra T V, Durga Madhab Mahapatra, Asulabha K S, Sincy Varghese, 2017. Foaming or Algal Bloom in Water bodies of India: Remedial Measures - Restrict Phosphate (P) based Detergents, ENVIS Technical Report 108, Environmental Information System, CES, Indian Institute of Science, Bangalore 560012

Ramachandra T V, Asulabha K S, Sincy V, Sudarshan Bhat and Bharath H.Aithal, 2015. Wetlands: Treasure of Bangalore, ENVIS Technical Report 101, Energy & Wetlands Research Group, CES, IISc, Bangalore, India

Ramachandra T V, Asulabha K S, Sincy V, Vinay S, Bharath H.Aithal, Sudarshan P. Bhat, and Durga M. Mahapatra, 2015. Pathetic status of wetlands in Bangalore: Epitome of inefficient and uncoordinated Governance, ENVIS Technical Report 93, CES, Indian Institute of Science, Bangalore 560012

7.0 SUSTAINABLE WATER: STRATEGIES AND CHALLENGES

Sufficient water is available to meet everyone's requirement, provided (i) water harvesting is undertaken through surface water bodies; this requires rejuvenation of lakes and reestablishment of interconnectivity; harvesting of rainwater (at decentralized levels), treatment; (ii) treatment and reuse of sewage. However, the success of sustainable water path depends on the political will, bureaucracy shedding their colonial style of functioning and more importantly citizen's assertion for their right for equal quantity and quality of water.

Availability	Water yield (rain)	14.80 TMC
	Sewage (generation 20.05 TMC) if treated	16.04 TMC
	Total	30.84 TMC
Demand	Domestic purposes (@ 150 lpcd) If @ 135 lpcd	20.05 TMC 18.34 TMC
Status	Surplus	10.79 -12.50 TMC

Average annual rainfall in Bangalore is about 787 mm with 75% dependability and return period of 5 years. Catchment wise water yield analysis indicates about 49.5% (7.32 TMC) of water yield in the Vrishabhavathi valley (including Arkavathi and Suvarnamukhi), followed by 35.2% (5.2 TMC) in Koramangala Challaghatta valley and 15.3% (4.2 TMC) in Hebbal valley and the total annual water yield in Bengaluru is about **14.80 TMC.** Domestic demand of water (at 150 lpcd) is 20.05 TMC per year (1573 MLD). This means about 73% of Bangalore's water demand can be met by efficient harvesting of rain water. Quantification of sewage generated shows that about 16.04 TMC (1258 MLD) of sewage is generated in the city.

Sewage treatment with complete removal of nutrients and chemical contaminants can be achieved by adopting decentralized treatment plants similar to the success model (secondary treatment plant integrated with constructed wetlands and algae pond) at Jakkur lake. In addition to this, water available with efficient rainwater harvesting is about 14.8 TMC. This accounts to total of 30.85 TMC of water that is available annually would cater the demand of 20.05 TMC, provided the city administration opts for decentralized optimal water management through (i) rainwater harvesting by rejuvenating lakes - the best option to harvest rain water is through interconnected lake systems, (ii) treatment of sewage generated in households in each locality (opting the model functional since 2010 at Jakkur lake – STP (Sewage Treatment Plant) integrated with constructed wetlands and algal pond; (iii) conservation of water by avoiding the pilferages (due to faulty distribution system); (iv) ensuring water supply 24x7 and (v) ensuring all sections of the society get equal quantity and quality of water. Rejuvenating lakes in the region helps in retaining the rain water. Treating sewage and options to recycle and reuse would minimize the demand for water from outside the region.

However, this model of decentralised harvesting of water and reuse of treated sewage is not an attractive proposition for the current breed of decision makers with the colonial style of functioning/mind-set. The financial gain is much higher in the case of mega projects (such as water diversion) compared to these decentralised models. This is the sole reason for the local administrators to degrade decentralised water harvesting structures and alienating local community. The main reason for deliberate inefficient management of water resources is to maximise the net return for the ruling class themselves than the overall growth of the region with water security. The analysis illustrates that the city has at least 30 TMC (Bangalore city) of water, which is higher than the existing demand (20.08 TMC, at 150 lpcd and 2016 population), if the city adopts 5R's (Rejuvenate, Retain, Recycle - Reuse, and Responsible citizens' active participation with good governance).

Scope for decentralized rainwater harvesting: During 1800, the storage capacity of Bangalore was 35 TMC. In 70's, lakes covered an area of nearly 3180 hectares and now the spatial extent of lakes cover an area of 2792 hectares. The current capacity of lakes is about 5 TMC and due to siltation, the current storage capacity of the lakes is just about 1.2 TMC, i.e., nearly 387 hectares of water bodies disappeared besides reduction in the storage capacity by 60%. Bangalore being located on the ridge, forms three watersheds – Koramangala Challagatta valley, Vrishbhavathi Valley and Hebbal Nagavara Valley. Earlier rulers of the region, created interconnected lake systems taking advantage of undulating terrain. Number of lakes in the Koramangala Challaghatta Valley is about 81, followed by the Vrishabhavathi Valley (56) and the Hebbal Nagavara Valley (46). In order to enhance the water retaining capability in the catchment, it is essential to rejuvenate lakes and undertake large scale watershed programme (soil and water conservation). Lakes are the optimal means of rainwater harvesting at community level. This entails

(i) Reestablishing interconnectivity among lakes (requires removal of all encroachments without any consideration, as the water security of a region is vital than the vested interests, who have unauthorisedly occupied without respecting future generation's food and water security). This would also reduce the frequency of floods and consequent damage to life and property,

(ii) removal of all encroachments of lakes and lake bed, and maintaining buffer region with the good riparian vegetation cover (without any artifacts),

(iii) rejuvenation and regular maintenance of water bodies. This involves de-silting of lakes to (a) enhance the storage capacity to retain rainwater, (b) increase the recharge potential – will improve groundwater table, (c) ensure recharging without any contamination,

(iv) allowing only treated sewage (removal of chemical and biological contaminants) through adoption of integrated wetlands ecosystem (Jakkur lake model),

(v) creation of wetlands with native vegetation and regular harvesting of macrophytes; food and fodder, which supports local people's livelihood, and

(vi) maintaining at least 33% green cover with native vegetation (grass, trees, shrubs) in the catchment and planting riparian vegetation in the buffer region. This would help infiltration of water and retain this water.

Land use analysis in Bangalore City shows 1005% increase in urban (built-up) area between 1973 and 2016 i.e., from 8.0% (in 1973) to 77% (in 2016). Land use prediction using Agent Based Model showed that built up area would increase to 93.3% by 2020, and the landscape is almost at the verge of saturation.

Background: Water is one of the fundamental elements of the universe from which early life originated millions of years ago on earth. Every life on the earth is primarily dependent on water which hosts innumerable aquatic species from single cell creatures to gigantic blue whales. As the evolution of human took place, civilized human settled down on the fertile river banks. In other words, river banks are the motherhood for civilized human and most of the civilization around the world. These river or lake banks gave water for drinking and also for cropping along with mineral rich soil. Civilized men knew the importance of water and respected these water bodies. Advantages of traditional water harvesting structures are:

- water made to stand for a period so as to allow infiltration / percolation and recharging of groundwater aquifers to sustain good water levels in the surrounding wells;
- a saturated sub soil/top soil, enhances the green cover in the surroundings;
- green cover in the catchment reduces soil erosion and hence sedimentation of rivers; and
- mitigation of floods and reduces the velocity of runoff.

However, these practices took backseat, during the imperial period (1800 till independence i.e. 1947) of British rule with the push for large scale river valley and canal projects and also due to lack of maintenance and management of small water harvesting structures. Apart from this, high and oppressive taxes and irrigation cess (towards the repair works of these structures) led to the decimation of irrigation tanks during the period of colonial rulers.

The centralized irrigation systems coupled with increased incidences of untimely rainfall and higher temperature, lack of annual maintenance, deforestation in the catchment and receding community participation, led to the decline of thousands of traditional water harvesting systems. As a consequence of these, the thousands of lakes and tanks are silted with the decrease in the overall storage capacities and groundwater recharge. Unplanned urbanization has led to the increase in urban conglomerates, with drastic reduction in land cover of the catchment, which substantially reduced the water holding capacity of the catchment. Higher incidences of flooding and soil erosion, is the direct consequence of damaging the water harvesting structures. Therefore, it is necessary to inculcate the traditional knowledge on sustainable water harvesting and management practices in the educational curricula. At a village/ward level it's necessary to identify the appropriate investment strategies and make the local Panchayats/ward member responsible for the operation and maintenance of the tanks. This will help in adopting the decentralized water harvest and management practices in the arid and semi-arid regions that are economical and technically feasible alternative to meet the regional water demand.

A well-known and success model of lake ecosystem is at Jakkur in Bangalore with integrated wetlands ecosystem (Secondary treatment plant integrated with constructed wetlands and algae pond). Complete removal of nutrients and chemical contaminants happens when treated sewage (secondary treated) passes through constructed wetlands and algae pond, undergoes of bio-physical and chemical processes. The water in the lake is almost potable with minimal nutrients and microbial counts. This model has been functional successfully for the last 5 years after interventions to rejuvenate the lake. This system is one of the self-sustainable ways of lake management while benefitting all stakeholders - washing, fishing, irrigation and local people. Wells in the buffer zone of 500 m now have higher water levels and without any nutrients (nitrate). Groundwater quality assessment in the same region, before rejuvenation of

Jakkur Lake had higher nitrate values. Adoption of this model also ensures nutrient free and clean groundwater, which helps in achieving the goals of providing clean water to the local community.

Another very good example of constructed water body is of the centenary pond at IISc, created solely to harvest rainwater. Taking advantage of undulating terrain in the campus, storm water drain is routed to a low lying area. The spatial extent of the water body is about one hectare and stores on an average 0.1 million liters. This water body is now an abode of a variety of aquatic animals and has been an attractive to several resident and migratory birds. The creation of these water bodies has helped in a good ambience and maintaining a good biodiversity in the region besides providing a very good aesthetics and is a now a means of stress relief for the students learners of higher education. These successful experiments highlight that water quality can be maintained to meet the local requirements by optimal management of bio-physical dynamics in a water body.

Deterioration of traditional water harvesting practices in other parts of burgeoning Bangalore has resulted in the inequity in water distribution and growing water scarcity, which has escalated water conflicts during the 20th century. Irresponsible management of natural resources is evident from

- sustained inflow of untreated sewage and industrial effluents;
- dumping of solid waste (with 70% being organic); and
- transport of untreated wastewater in storm water drains (water drains are essentially arteries of a landscape carrying water).

Due to these unauthorized practices, vital constituents of the landscape (wetlands and drains,) have become breeding ground of disease vectors, stinking cesspool and emitters of GHG's (Greenhouse gases: methane, carbon di-oxide, etc.), etc. These practices are posing serious threat to public health and hygiene with an irrecoverable loss in aquatic biodiversity. Unplanned and un-coordinated rapid urbanization has further stressed the natural resources in the region. The water demand of the urban conglomerates is met with piped water supply or from water transported from distant areas. Coupled with this, substantial degeneration of the traditional knowledge has resulted in deterioration of tank management practices. Sustainable water management of water resources through revival of traditional water harvesting strategies and comprehensive watershed restoration and management by involving local stakeholders is essential for adequate groundwater recharge and for maintaining water balance in the region.

Recommendations: The restoration and conservation strategies has to be implemented for maintaining the ecological health of aquatic ecosystems, aquatic biodiversity in the region, inter-connectivity among lakes, preserve its physical integrity (shorelines, banks and bottom configurations) and water quality to support healthy riparian, aquatic and wetland ecosystems. The regular monitoring of water bodies and public awareness will help in developing appropriate conservation and management strategies.

Source: Ramachandra T V, Vinay S, Durga Madhab Mahapatra, Sincy Varghese, Bharath H. Aithal, 2016. Water situation in Bengaluru, ENVIS Technical Report 114, Environmental Information System, CES, Indian Institute of Science, Bangalore 560012

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ANNEXURE I

MACROPHYTES: ESTIMATION OF SPATIAL EXTENT AND BIOMASS PRODUCTIVITY

Aquatic plants are an important component of lake ecosystems and are often regarded as indicators of lake environmental changes; they play an important role in maintaining the structure and function of lake ecosystems. Aquatic plants are the primary producers of aquatic ecosystems, being a kind of food source of many kinds of fish and other aquatic animals. They can regulate the lake water body, degrade various pollutants, and improve the transparency. In addition, aquatic plants can provide habitat to many organisms and increase the spatial niche of aquatic ecosystems. Therefore, it is important to know the distribution of aquatic plants and their communities to analyze the status of aquatic plants in the lake area. Biomass estimation of wetland plants plays an important role in understanding dynamic changes of the wetland ecosystem.

Biomass estimation was undertaken through quadrat method (1mx1m). Spatial extent was assessed using temporal remote sensing data. Data analyses reveal that spatial extent varies from 173.24 ha (Oct 2015 and 180.00 ha in oct 2016) to 219.17 ha (April 2015, 221.07 ha in April 2017). The productivity ranges from 11-33 t /ha (in fresh infested regions, constitute about 45% of spatial coverage), 70-80 t/ha (in the moderate cover regions, constitute about 35% of spatial coverage) and 120 t/ha (in densely packed regions, constitute about 20% of spatial coverage).

Introduction

Aquatic macrophytes is a term given to a vast category of aquatic vascular plants. Plant species normally found growing in wetlands, either in or on the water, or where soils are flooded or saturated long enough for anaerobic conditions to develop in the root zone are called as macrophytes (Cowardin et.al 1979). The aquatic macrophytes occur mainly in the shallow region of lakes ponds, pools, marshes streams and rivers etc. They belong to following 3 categories on the basis of their habit:

i. Submerged macrophytes: Largely or completely submerged plants, the roots may or may not be present (*Ceratophyllum, Hydrilla, vallisneria* etc)
ii. Emergent macrophytes: Plants not submerged in water, further subdivided into two (a) erect leaved emergent plants: rooted plants with principle photosynthetic surfaces projecting above the water (*Typha*, *Scirpus* etc) (b) floating leaved emergent plants: rooted plants with floating leaves (*Nymphaea*, *Nelumbos* etc)
iii. Floating macrophytes: Entire plant will be floating on the water surface (*Eichhornia*, *Lemna*, *Pista* etc)

Macrophytes are of considerable ecological and economic importance. They contribute significantly to the productivity of water bodies; mobilize mineral elements from the bottom sediments and provide shelter to aquatic macro-invertebrates and fishes. They also respond to changes in water quality and have been used as indicators of pollution. When there is enough room for colonization and abundant availability of nutrients, macrophytes show a high growth rate. They assimilate nutrients directly into their tissues. Due to these they were used to solve eutrophic problems of freshwater bodies and to remove pollutants.

COMMON MACROPHYTES IN WETLANDS OF INDIA

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

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, waste water treatment

Life cycle: Grows slowly during cooler winter months, starts rapid growth once temperatures rise. Grows from seed and through vegetative reproduction, with vegetative reproduction the most important method of propagation. *E. crassipes* is very responsive to nutrients (especially nitrogen and phosphorus) and high growth rates are always associated with eutrophic, nutrient-rich conditions. The growth of *E. crassipes* is extremely rapid and the plant may double its population size in 6 to 18 days. Seeds are produced in capsules at base of each flower. Flowering can begin as early as October and continue through summer. Each flower stays open 1-2 days before beginning to wither. When all flowers have withered, stalk gradually bends to water and, after about 18 days, releases seeds from capsules at base of each dead flower. Seeds sink to substrate and persist there for at least 15 years.

Harvesting: once in 15 days

Uses: Phytoremediation, waste water treatment, stems are used as a source of fibres for making cord or pulp for making paper, used as fodder and manure, biogas production, often cultivated as ornamental plant.

Nutrient content (%dry weight): P-0.1-1.2%;N-1.0-4.0%

Nutrient Removal capacity (kg/ha/day) – N-12.78; P-2.43

Name: *Alternanthera philoxeroides*
Common name: Alligator weed
Habitat: grow in a variety of habitats, including dry land but usually found in water.
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 grow on stalks.
Fibrous roots arising at the stem nodes may hang free in water or penetrate into the sediment/soil.
Flowering: December-April
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.

Life cycle: Alligator weed forms new shoots in spring from nodes on existing stems or rhizomes. It flowers from mid-summer to March, but does not produce viable seed. Regrowth occurs quickly from stems or underground rhizomes buried in soil when favourable conditions return. In aquatic situations, stems break and float away to form new mats or take root in shore sediments.
Flowering: December-April
Nutrient content (%dry weight): N-1.5-3.5%;P-0.2-0.9%
Nutrient Removal capacity (kg/ha/day) – N-4.88; P -0.55

Name: Polygonum glabrum
Common name: Common Marsh Buckwheat
Morphology: Stems erect, shrubby, upto 2.5 m tall, leaf blades shortly petiolate, blades narrowly lanceolate, glabrous except for midrib and some lateral nerves, flowers in terminal and axillary, 7-10 cm long spike-like racemes
Habitat: Perennial or annual, found along water courses and tanks but is also found in marshes. It is often dominant along large rivers
Significance: Tender branches used as vegetable, also used for dispelling fever and colic.

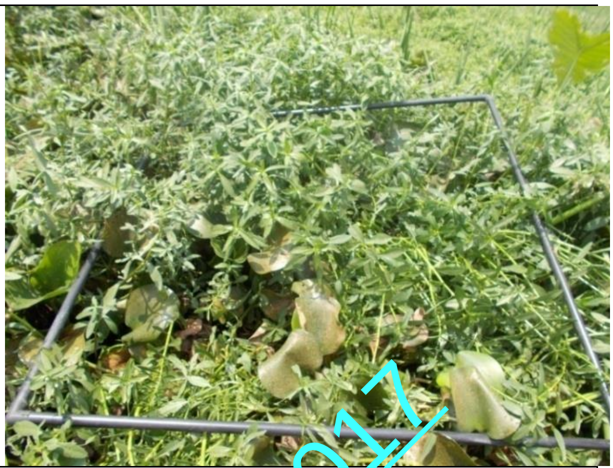
Name: Pistia stratiotes **Common name:** water cabbage, water lettuce **Description**: Aquatic free-floating, odorous monoecious herb with thick, soft leaves that form a rosette. Roots hanging submersed beneath floating leaves. Leaves can be up to 14 cm long and have no stem. They are light green, with parallel veins, wavy margins and are covered in short hairs which form basket-like structures which trap air bubbles, increasing the plant's buoyancy. **Habitat:** waters with high nutrient content, particularly those that have been contaminated with human loading of sewage or fertilizers Impact: major weed of lakes, dams, ponds, irrigation channels and slow-moving waterways in tropical, subtropical and warmer temperate regions. It can completely cover water bodies, disrupting (lowering DO) all life on the water.	 
Name: Polygonum glabrum **Common name**: Common Marsh Buckwheat **Morphology**: Stems erect, shrubby, upto 2.5 m tall, leaf blades shortly petiolate, blades narrowly lanceolate, glabrous except for midrib and some lateral nerves, flowers in terminal and axillary, 7-10 cm long spike-like racemes **Habitat**: Perennial or annual, found along water courses and tanks but is also found in marshes. It is often dominant along large rivers Significance: Tender branches used as vegetable, also used for dispelling fever and colic.	

Methods

Estimation of fresh biomass (wet weight) of macrophytes: Macrophyte biomass per unit area was found by random sampling method. Macrophyte samples (triplicates) were collected randomly from 1 m^2 quadrats of lake. All the macrophyte samples falling under 1 m^2 quadrat were removed and fresh weight (biomass) was determined after draining the water. The coverage area of macrophyte in the Lake during different months of a year was estimated by mapping using Google Earth. The productivity of macrophyte coverage area was calculated by multiplying fresh biomass per m^2 and total coverage area. Quadrat method of sampling is followed (50 cmX50cm or 1mX1m for emergent).

Vegetation mapping: This is done 1) to calculate total macrophytic biomass of different species in a water body 2) to understand the distribution pattern of vegetation 3) to monitor the changes caused by a pollutant on these patterns at various times.

1 m^2 quadrat samping (water hyacinth)



Quadrat sampling (mixture of *Alternanthera* and water hyacinth)

Figure 3: Quadrat sampling method

- **Treatment of samples:** Immediately after collection wash the plants to remove adhered soil, epiphytes etc. Drain out the excess water after washing. Take the fresh weight of sample. Transport the samples to the lab in polythene bags.
- **Biomass estimation:** After determining fresh weight of the samples, keep the samples in hot air oven at 105°C for 24 hrs for the determination of dry weight. Biomass is usually estimated as dry matter per unit area.
- **Macrophyte cover:** Macrophyte cover of Bellandur Lake was estimated for the years 2015 and 2016 by using Google Earth. The macrophyte cover was higher during the summer season (April). It covered 60% of the lake area during this season.

Literatures regarding Biomass of Water hyacinth: Grown in warm, enriched domestic sewage *Eichhornia* produces over 17.8 tonnes of wet biomass per hectare per day. Growth rate studies suggest that annual production rates of 212 metric tons of dried plant material per hectare (Wolverton and McDonald, 1976). A hectare of water hyacinths fed on sewage nutrients can yield 0.9-1.8 tonnes of dry plant material per day. DeBusk et al. (1981) have reported a yield of 10.4 g (dw) m-2 d-l in natural flowing waters in Florida (U.S.A.) for water hyacinth maintained at a density of 500 g (dw) m2 by weekly harvesting, equivalent to 8.5 kg (fw) m^2 for a six months period from April to September. We calculated for the corresponding period in the southern hemisphere, October to March, at a density of 10 kg (fw) m2, and a harvest every three weeks (average) a productivity of 202 g (fw) m-2, roughly equivalent to 11.7 g (dw) m2 d^{-l}. According to DeBusk et al. (1981) the increase in water hyacinth productivity with biomass level has a maximum at a density of about 20 kg (fw) m2.

E. crassipes specific growth rates, calculated from data shown in Table 1, range within 15.7–29.4 g (dry wt.) m−2 d−1. These results compare well with values reported for plants growing in the warm waters of middle Paraná River (Fitzsimons & Vallejos, 1986). Other studies reported growth rates around 5 g (dry wt.) m^{-2} d^{-1} and up to 147 g (dry wt.) m^{-2} d^{-1}, for cold and warm weather conditions, respectively (Yount & Crossman, 1970; De Busk et al., 1981; Reddy & De Busk, 1985; Cassabianca et al., 1992).

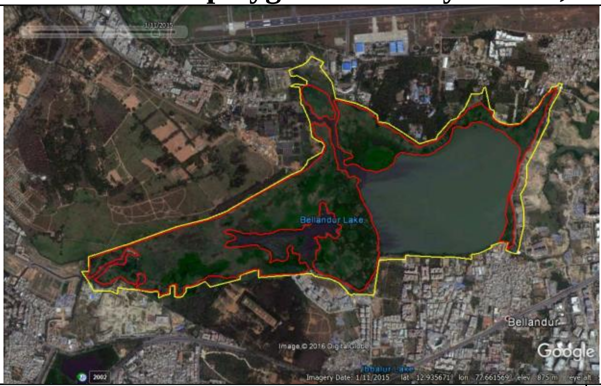
In growth rate studies water hyacinth were observed to produce 250-400 kg of dry plant material per acre per day when grown in nutrient enriched media such as domestic sewage. Based on this growth rate and surface area coverage of 100 tons per acre of wet plant material, 4 acres of water hyacinth could remove all nutrients from waste of 5000 people when harvested at a rate of one-third the surface area every two weeks. (National Academy of Sciences (U.S.)

Productivity of water hyacinth has been reported in many ways, making it difficult for inter comparison of the results. Cornwell et al. (1977) reported that the water hyacinth cultured in sewage effluent covered the pond surface in about 8 weeks (2 Apr.-27 May 1972). The calculated area doubling time was found to be 6.2 d. The area covered by water hyacinth growth is controlled by wind and wave action and the degree of compactness of the plants. Water hyacinth can grow in a vertical as well as horizontal direction, often reaching a height of 100 cm or more in dense stands. Wolverton and McDonald (1979a) observed a linear relationship between total length of plant and standing crop for waterhyacinth cultured in sewage effluent. Under normal conditions, loosely packed water hyacinth can cover the water surface at relatively low plant densities (10 kg wet wt m-2), and can reach a maximum density 50 kg wet wt m-" (Center & Spencer, 1981), before growth ceases.

RESULTS:

BELANDUR MACROPHYTE COVER AREA (2015)

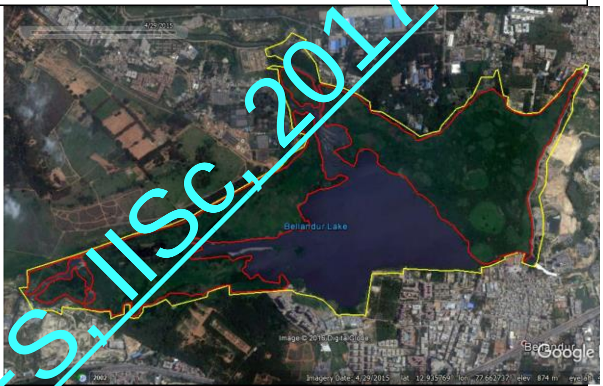
Yellow polygon-boundary of lake; red polygon-Macrophyte cover area



Jan 2015-189.9 Ha

Feb 2015-184.45 Ha

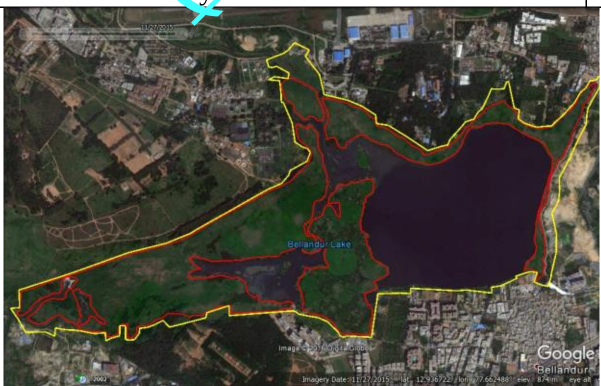
March 2015-203.9 Ha



April 2015-219.7 Ha

May 2015-202.34 Ha

October 2015-173.24 Ha



November 2015-175.18 Ha

December 2015-190. Ha

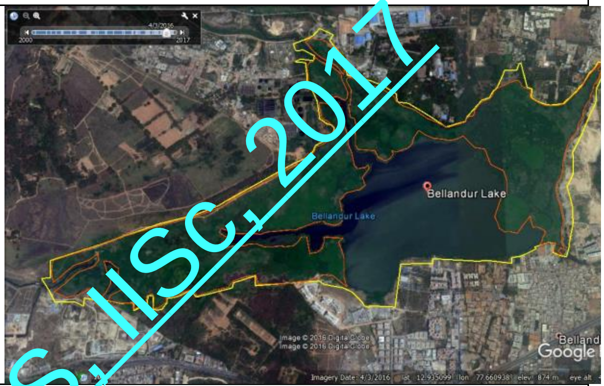
Figure 1: Google Earth image of Macrophyte cover area in Bellandur Lake during 2015

BELLANDUR MACROPHYTE COVER AREA 2016
Yellow polygon-boundary of lake; red polygon-Macrophyte cover area

Jan 2016-187.88 Ha

Feb 2016-189.9 Ha

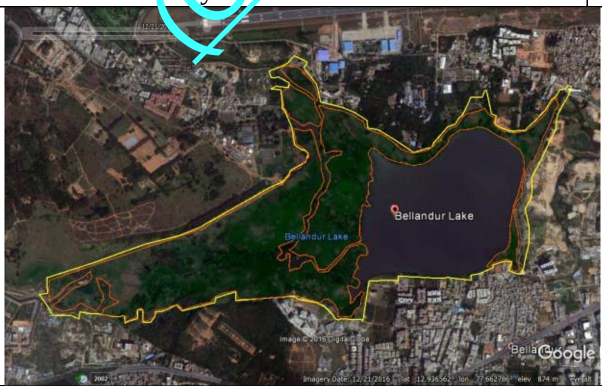
March 2016-209.16 Ha



April 2016-221.07 Ha

May 2016-208.86 Ha

November 2016-199.36 Ha



December 2016-209.51 Ha

January 2017-214.05 Ha

Figure 2: Google Earth image of Macrophyte cover area in Bellandur Lake during 2016

Biomass of fresh macrophytes

Densely populated region (multi-tier) about 1'	~120 tons/Ha (15-20% lake surface)
Moderately covered regions	70-80 (30-40% lake surface)
New spread regions	11-33 t/ha (40-45% of spread)

Biomass of mixed macrophyte sample (water hyacinth+ Alternanthera): 70-85 t/ha

Month	Macrophytes cover area during 2015(Hectares)	Macrophytes cover area during 2016(Hectares)
Jan	189.9	187.88
Feb	184.43	189.9
March	203.9	209.16
April	219.7	221.07
May	202.34	208.86
October	173.24	180.00
November	175.18	199.36
December	190.79	209.51

Table1: Macrophyte cover area of Bellandur Lake during the year 2015 and 2016

References

Bill Wolverton and Rebecca C.McDonald (1976) Dont waste waterweeds, New Scientist 12 August 1976; pp 318-320.

National Academy of Sciences (U.S.) Aquatic Weed Management: Some Prospects for the Sudan and the Nile Basin : Reports of a Workshop Held 24-29 November 1975, Khartoum, Sudan

Annexure II

AERATORS Vs. FOUNTAINS

1. The lake being shallow, micro bubble option of aeration (for the entire lake) is not viable.
2. Micro bubble option fails on economic criteria due to the relative higher initial and regular maintenance cost compared to the proven indigenous technologies suitable for shallow lakes
3. One of the serious impacts would be the habitat destruction of micro and macro benthos leading to instability and decline of fish spawning regions

SUGGESTIONS:

a. Remove macrophytes – regularly (till the nutrient inflow into the lake is checked / or treated sewage is let into the lake)
b. remove all blockades at outlets – so that water will move leading to natural aeration
c. install surface fountains, which enhances not only the aeration but also recreation value of the lake. Music fountains would aid in de-stressing as well as recreation

Surface Aeration v/s Bottom-up Aeration for Bellandur Lake

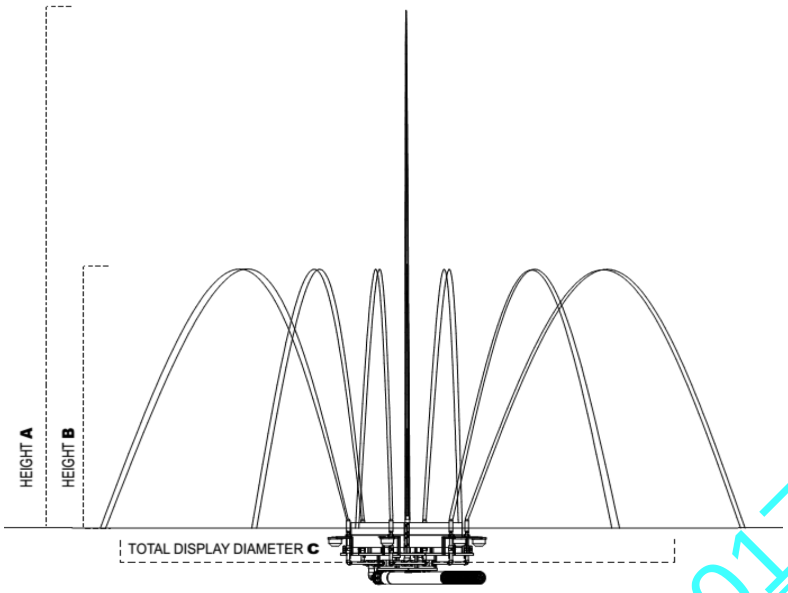
S No.	Description	Fountain (Surface Aeration)	Bubble Aerator (Bottom Up Aeration)
1	Oxygen transfer rate/efficiency	Oxygen transfer upto 6 to 12".	10 times higher
2	Cost	Operating cost is high.	relatively higher initial and regular maintenance cost
3	Power Consumption	Power requirement is higher	less power when compared to surface aeration.
4	Safety	Requires insulation of cables	Airline pipe can run to the air compressor which can be kept at some place isolated from water.
5	Frothing	No frothing	Frothing is inherent.
6	Clogging problem	No problem of clogging.	Clogging problem is inherent. System has a lifetime of 1-2 years. Biofilm may develop (clogging the filter). When this problem encounters, it starts consuming more energy.
8	Suitability	For shallow lakes	For deeper lakes (Suitable to install at deeper points in our case).
7	Miscellaneous	a. Evaporation rates may increase. b. prevents froth.	Frequent cleaning is required.

But in case of Bellandur Lake, the depth is not much and the water is always flowing so fountain system may work effectively at initial stage. Later it can be incorporated with the aerators as well depending on the condition and practicality.

Fountain Aerators

Source:http://www.vertexwaterfeatures.com/sites/default/files/Vertex_Fountain_AerationJet_Specs_LED_110716.pdf

A fountain aerator can cover a diameter of ~40 feet (Figure 1), i.e., nearly 12 meters diameter, covering a surface area of 115 sq.m., for Bellandur lake considering various placement option at 50 m center to center to 250 m center to center, and considering scenarios of covering entire lake of 900 ac or portion of lake over 0.5m current water depth i.e., 551 ac is as shown in table 1.



Fountain Only																
With LED Lights																
Motor HP	5	5	5	7.5	7.5	7.5	10	10	10	15	15	15	20	20	30	30
Volts	230	230	208	230	230	208	230	230	208	230	230	208	230	208	230	208
Phase	1	3	3	1	3	3	1	3	3	1	3	3	3	3	3	3
AMP	28	17	21	42	25	28	51	32	37	72	47	54	61	70	90	104
Side Jets	6	6	6	6	6	6	6	6	6	8	8	8	8	8	8	8
HT. A	20'	20'	20'	25'	25'	25'	30'	30'	30'	35'	35'	35'	40'	40'	45'	45'
HT. B	10'	10'	10'	12'	12'	12'	15'	15'	15'	20'	20'	20'	20'	20'	25'	25'
Dia. C	20'	20'	20'	25'	25'	25'	30'	30'	30'	33'	33'	33'	35'	35'	40'	40'
60W LED Lights	8	8	8	8	8	8	9	9	9	10	10	10	11	11	11	11
Total Watts	480	480	480	480	480	480	540	540	540	600	600	600	660	660	660	660
AMP Draw	4	4	4	4	4	4	4.5	4.5	4.5	5	5	5	5.5	5.5	5.5	5.5

Figure 1: Floating fountain and technical details

Table 1: various Scenarios for fountain placement

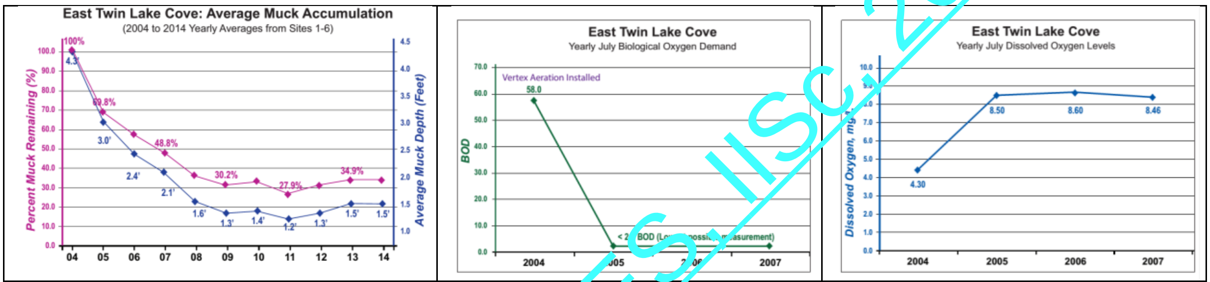
distance c/c in meters	~900 acres	Number of fountains [~551 acre (excluding 0.5 m depth regions – pre de-siltation/current depth)]
150	165	75
200	95	***40***
250	60	25

Diffused Aerators

East twin lake of Michigan of USA has an area of 900 acres. At the inlet of the lake **eight Vertex Air 3 XL systems**, i.e., about 24 diffusers with 8 aerators were used covering an area of 160 acres (Fig 2). Source: http://www.vertexwaterfeatures.com/sites/default/files/PDF-Case-Study-East-Twin-Lake-10y-Update-051016_0.pdf

Figure 2: Location of installation and Aerators

Results of installing the aerator is as depicted in Fig 3, indicating increase in oxygen, decreased DO and muck level with time.



Reduction of muck level	Reduction in BOD	Increase in DO

Figure 3: observations in quality of lake

Similar to Michigan Twin lake, Bellandur lake has an area over 900 acres (but sustained inflow of untreated sewage), if aerators are used to cover the entire area, about 45 aerators with 135 diffusers are necessary. Considering current conditions and a minimum depth of over 0.5 meters, area of lake is 551 acres, 28 aerator units with 84 diffusers would be necessary.

Proposed combination of Surface (Fountain) aerators and Deep (Diffused) aerators, where in the diffused aerators are placed at the inlets, and fountains at the centre as shown in Fig 4.

About 25 diffusers with 10 air flow systems at the inlets A, B, C and D and about 40 fountains at 200 m center to center would be necessary to cover the lake (Table 2).

Table 2: Number of aerators and fountain necessary to cover Bellandur lake

Aerators/Fountains		Area in Acres	# of diffusers	air flow system
Diffused Aeration system*	inlet A	86	13.0	5.0
	inlet B	58	9.0	3.0
	Inlet C	3	1.0	1.0
	Inlet D	11	2.0	1.0
Fountain Aeration Systems	Center	393	Fountains 40.0	@ 200m center to center

*Note: if sewage is treated through integrated wetlands system, diffused aeration system is not required.

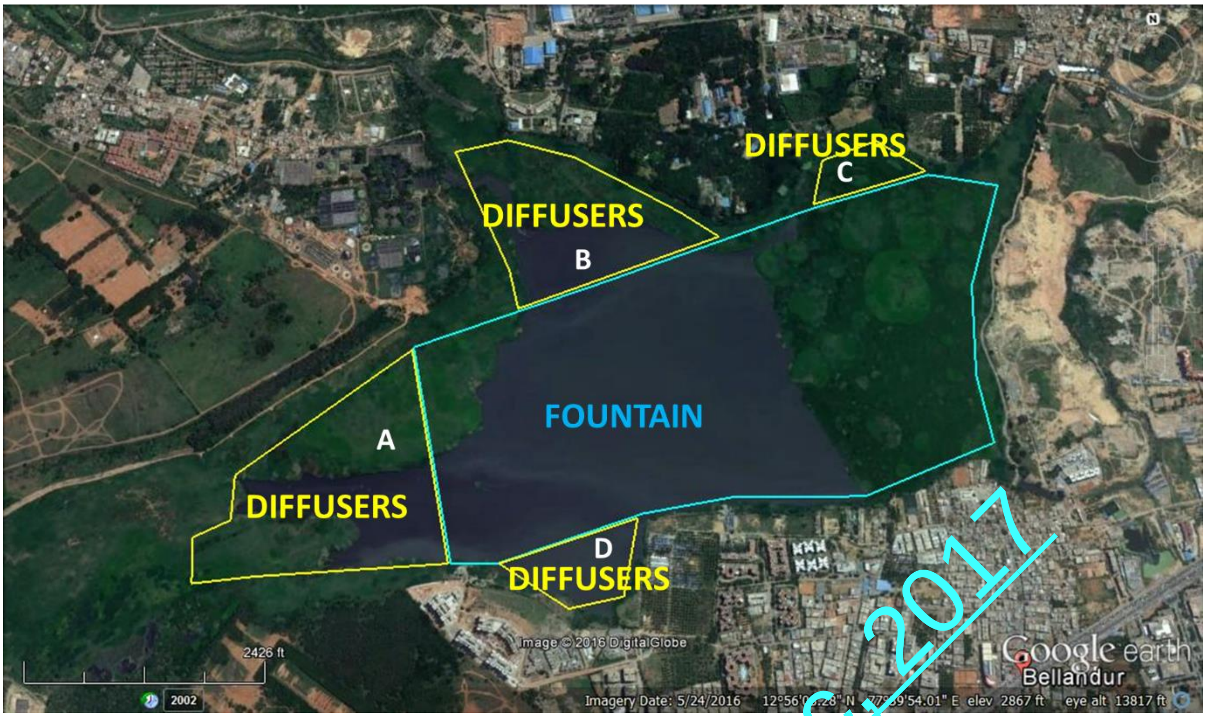
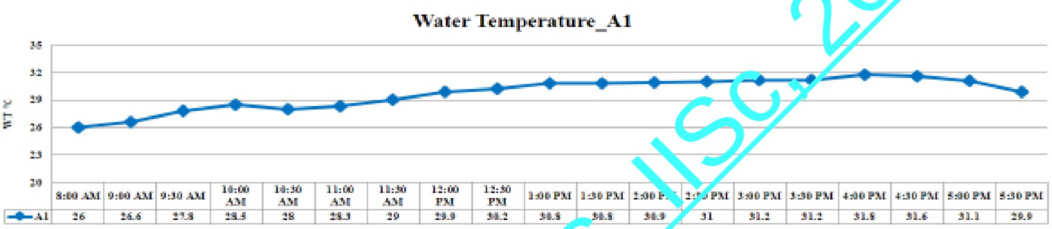


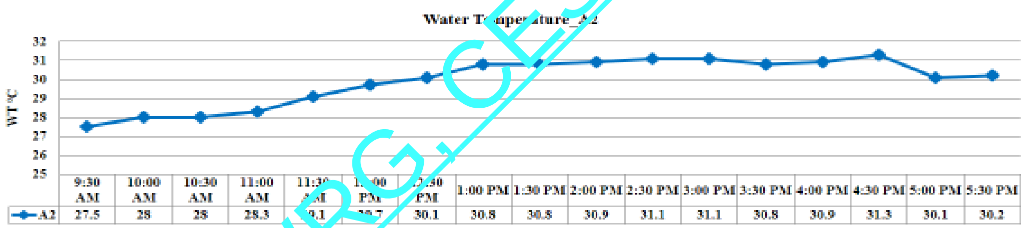
Figure 4: Combined proposal of diffusers (not required after sewage treatment) and fountain aerators.

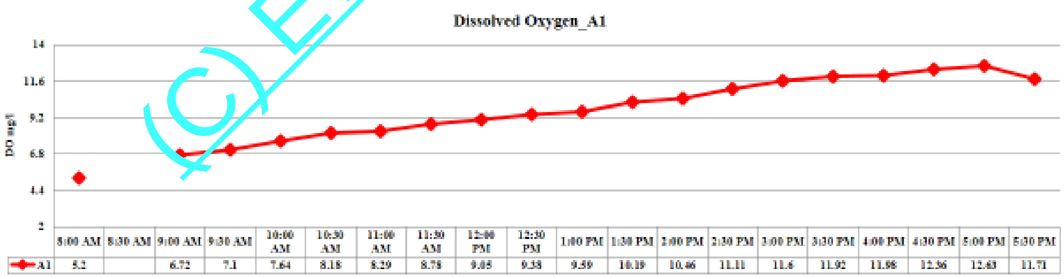
Fountains at Sankey Lake - Advantages of Aeration: Improvements in dissolved oxygen (refer details provided next) and aesthetic beauty and enhanced recreation value is observed after installation of fountains. Even algae such as *Microcystis* infestation has reduced considerably after installing fountains in the lake.

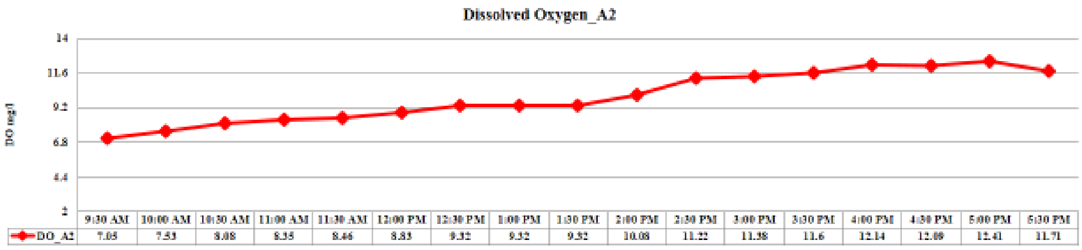
Fountains at Sankey Lake

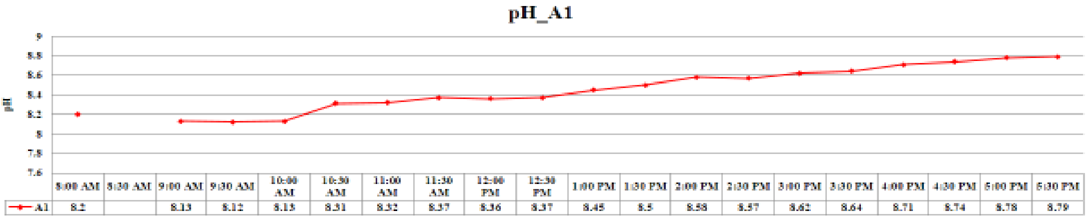
Water quality Monitoring region in Sankey lake (19th March 2017, 7 am to 6 pm)

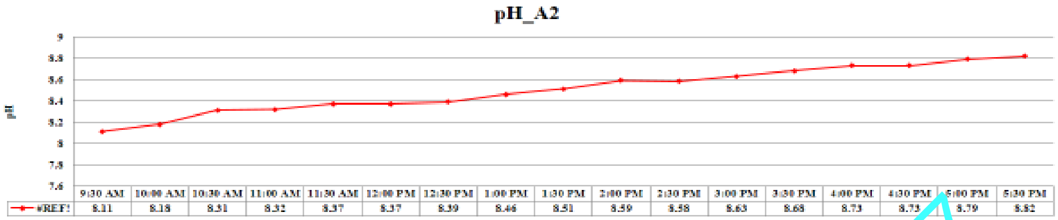


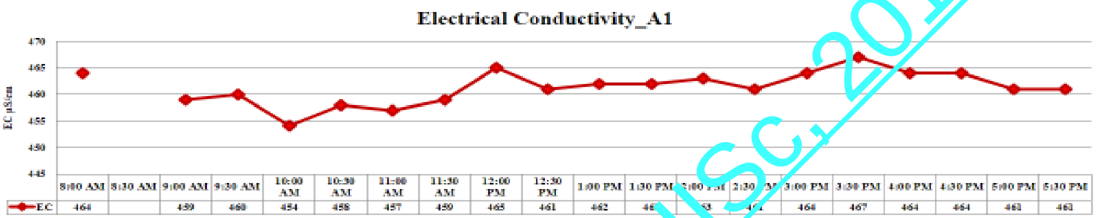


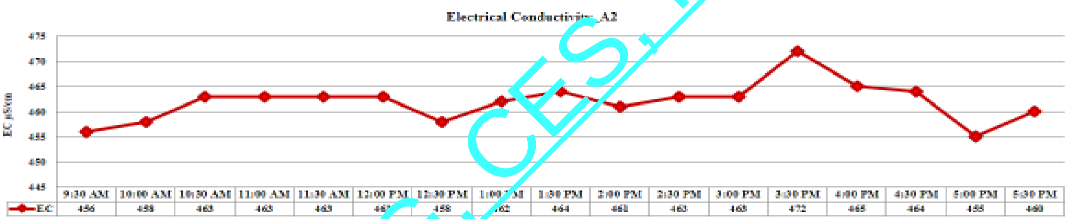


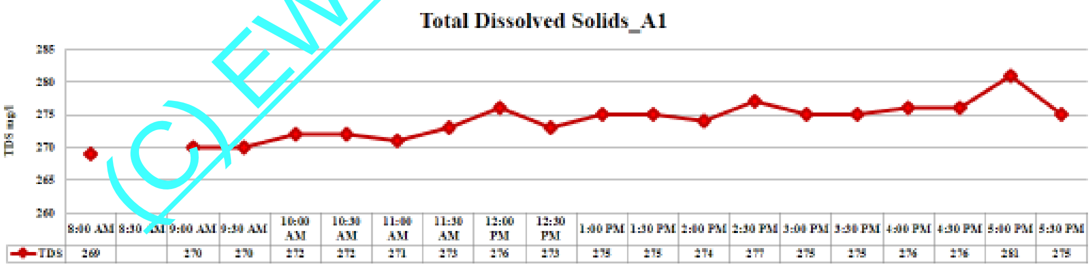


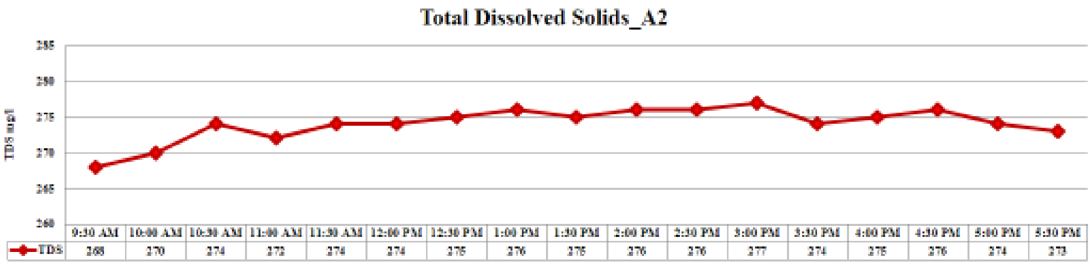












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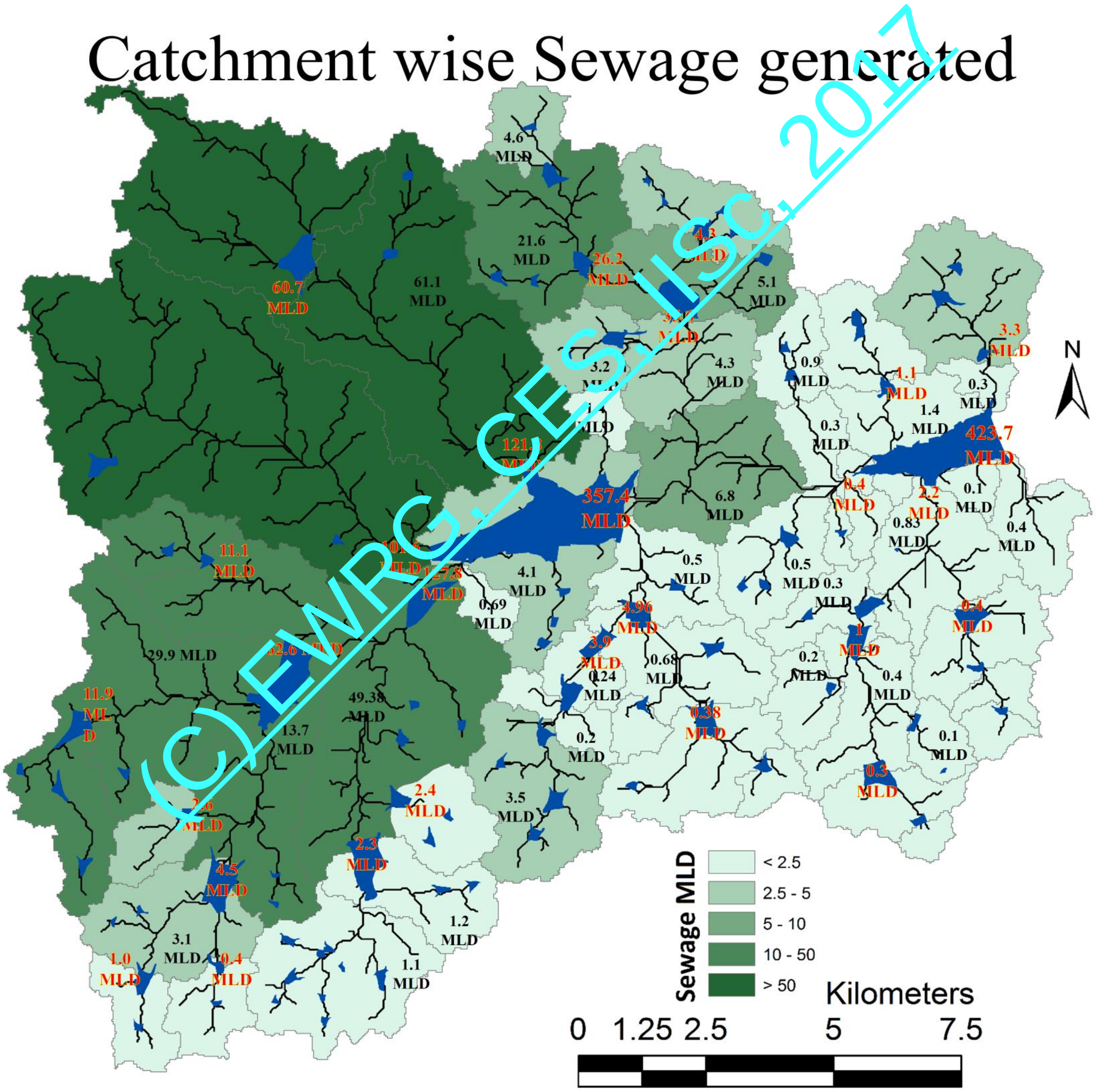
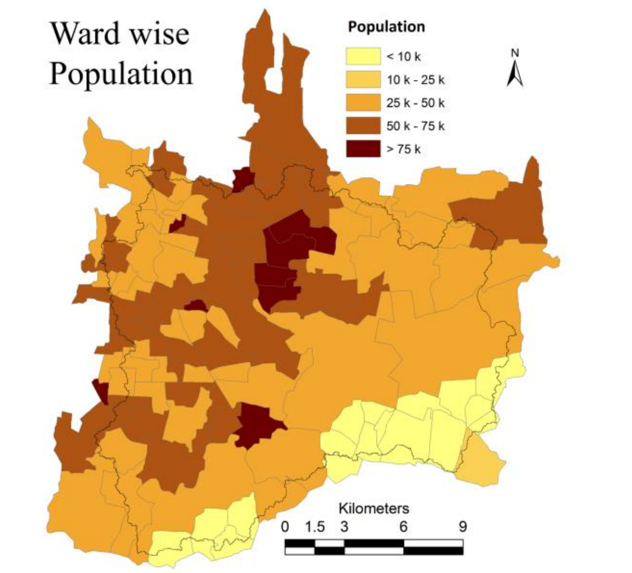
ANNEXURE III

Quantification of Sewage Generated (based on the population projection 2017)

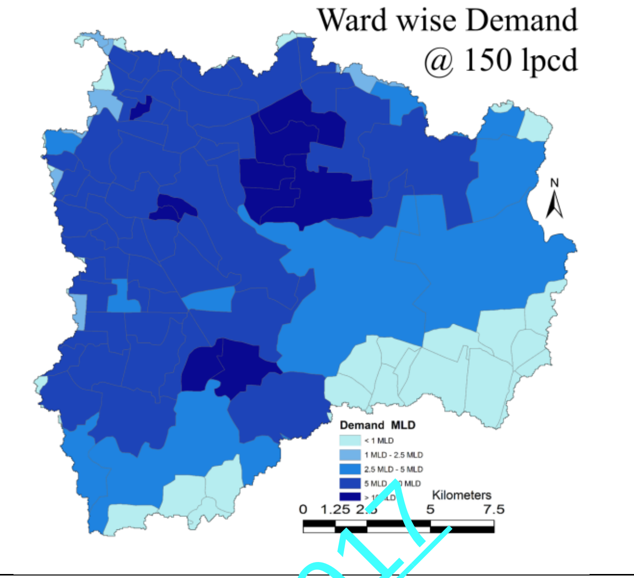
Method	Reference	Population - Varthur	Demand MLD		Sewage MLD	
		Population 2017	150 lpcd	135 lpcd	150 lpcd	135 lpcd
I	$P_n=P_0*e^{rt}$ P_0= present population r = Growth rate, t= decades	3474725	521.21	469.09	416.97	375.27
II	**$P_n=P(1+nr)$** **r=Growth rate** **n=No. of decades**	3538848	530.83	477.74	424.66	382.20
III	Pn= P_0 + n.C Pn = Future population C=population growth per decade	3286050	492.91	443.62	394.33	354.89



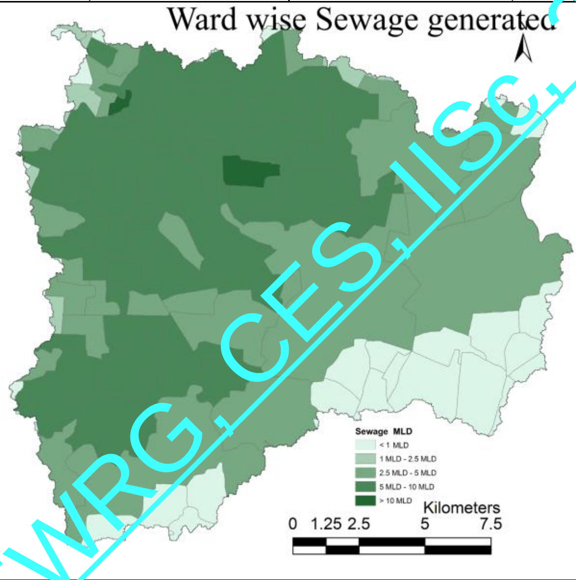
Note : text in black indicates sub catchment sewage generates and text in yellow and red represents cumulative at the outlet, considering upstream discharges



Population 2017 (as per Method 2)



Water Demand (2017)



Sewage – 2017

Table 1: Population, Water Demand and Sewage discharge (as per Method I)

Method I_Population 2017						
LOCATION (VILLAGES/wards)	Growth Rate	Population - Varthur	Water Demand in MLD		Sewage Generated in MLD	
			Demand in 150 lpcd - Varthur	Demand in 135 lpcd - Varthur	Sewage in 150 lpcd - Varthur	Sewage in 135 lpcd - Varthur
HEGGONDAHALLI	28.8%	497	0.07	0.07	0.06	0.05
KODATHI	26.2%	1608	0.24	0.22	0.19	0.17
HADOSIDDAPURA	26.4%	536	0.08	0.07	0.06	0.06
CHIKKAVADERAPURA	158.0%	519	0.08	0.07	0.06	0.06
SULIKUNTE	26.3%	2359	0.35	0.32	0.28	0.25
CHIKKA NAYAKANAHALLI	26.3%	361	0.05	0.05	0.04	0.04
DOMMASANDRA	26.2%	1448	0.22	0.20	0.17	0.16

CHOKKASANDRA	0.8%	1	0.00	0.00	0.00	0.00
BETTADASANAPURA	33.4%	1017	0.15	0.14	0.12	0.11
HOMMADEVANAHALLI	52.8%	1452	0.22	0.20	0.17	0.16
MYLASANDRA	15.2%	2027	0.30	0.27	0.24	0.22
VITASANDRA	16.2%	1094	0.16	0.15	0.13	0.12
RAYASANDRA	55.5%	164	0.02	0.02	0.02	0.02
CHOODASANDRA	42.6%	1284	0.19	0.17	0.15	0.14
CHIKKAKANAHALLI	28.8%	24	0.00	0.00	0.00	0.00
HALNAYAKANAHALLI	26.3%	1419	0.21	0.19	0.17	0.15
MULLURU	26.2%	1907	0.29	0.26	0.23	0.21
KACHAMARANHALLI	26.3%	1090	0.16	0.15	0.13	0.12
HALASAHALLI THIPPASANDRA	10.0%	457	0.07	0.06	0.05	0.05
Gottigere	46.9%	23487	3.52	3.17	2.82	2.54
Anjanapura	43.1%	172	0.03	0.02	0.02	0.02
Arakere	53.2%	58539	8.78	7.90	7.02	6.32
Begur	35.7%	29598	4.44	4.00	3.55	3.20
Singasandra	45.5%	39507	5.93	5.33	4.74	4.27
Konankunte	51.6%	44507	6.68	6.01	5.34	4.81
Vasanthpura	49.3%	2512	0.38	0.34	0.30	0.27
Puttenahalli	56.8%	51009	7.65	6.89	6.12	5.51
Jaraganahalli	46.3%	34922	5.24	4.71	4.19	3.77
Hongasandra	64.2%	64422	9.66	8.70	7.73	6.96
Mangammanapalya	64.4%	76791	11.52	10.37	9.21	8.29
Sarakki	61.3%	47877	7.18	6.46	5.75	5.17
Bilekhalli	46.7%	47496	7.12	6.41	5.70	5.13
J P Nagar	13.0%	35092	5.26	4.74	4.21	3.79
BTM Layout	24.2%	50712	7.61	6.85	6.09	5.48
Bommanahalli	56.1%	59678	8.95	8.06	7.16	6.45
Shakambari Nagar	24.2%	11524	1.73	1.56	1.38	1.24
Madivala	6.7%	39127	5.87	5.28	4.70	4.23
Jakkasandra	12.0%	29601	4.44	4.00	3.55	3.20
Gurappanapalya	37.3%	65104	9.77	8.79	7.81	7.03
Jayanagar East	0.8%	31268	4.69	4.22	3.75	3.38
Karisandra	26.0%	636	0.10	0.09	0.08	0.07
HSR Layout	31.3%	40849	6.13	5.51	4.90	4.41
Pattabhiram Nagar	24.2%	40480	6.07	5.46	4.86	4.37
Byrasandra	15.7%	36912	5.54	4.98	4.43	3.99
Suddagunte Palya	24.2%	52881	7.93	7.14	6.35	5.71
Yediyur	24.2%	1372	0.21	0.19	0.16	0.15
Koramangala	24.2%	52070	7.81	7.03	6.25	5.62
Jayanagar	24.2%	48337	7.25	6.53	5.80	5.22
Siddapura	41.9%	62948	9.44	8.50	7.55	6.80
Adugodi	24.2%	44098	6.61	5.95	5.29	4.76

Lakkasandra	24.2%	41679	6.25	5.63	5.00	4.50
Ejipura	15.8%	37491	5.62	5.06	4.50	4.05
Nilasandra	49.7%	80340	12.05	10.85	9.64	8.68
Bellandur	18.8%	27720	4.16	3.74	3.33	2.99
Vishveshwara Puram	24.2%	39847	5.98	5.38	4.78	4.30
Vannarpet	39.4%	66693	10.00	9.00	8.00	7.20
Chamarajapet	26.4%	1096	0.16	0.15	0.13	0.12
Konena Agrahara	56.4%	72396	10.86	9.77	8.69	7.82
Sudham Nagara	20.4%	44635	6.70	6.03	5.36	4.82
Varthur	16.4%	26915	4.04	3.63	3.23	2.91
Shanthi Nagar	24.2%	53641	8.05	7.24	6.44	5.79
Marathahalli	62.3%	60983	9.15	8.23	7.32	6.59
K R Market	29.6%	15013	2.25	2.03	1.80	1.62
Dharmaraya Swamy Temple Ward	18.6%	44249	6.64	5.97	5.31	4.78
Jeevanbhima Nagar	55.6%	87999	13.20	11.88	10.56	9.50
H A L Airport	46.9%	70077	10.51	9.46	8.41	7.57
Chickpete	38.5%	59427	8.91	8.02	7.13	6.42
Domlur	24.2%	51105	7.67	6.90	6.13	5.52
Agaram	24.2%	52472	7.87	7.08	6.30	5.67
Cottonpete	41.2%	4995	0.75	0.67	0.60	0.54
Jogupalya	36.8%	62323	9.35	8.41	7.48	6.73
Shantala Nagar	24.2%	44509	6.68	6.01	5.34	4.81
Hagadur	25.0%	21942	3.29	2.96	2.63	2.37
Hoysala Nagar	24.2%	52853	7.93	7.14	6.34	5.71
New Tippasandra	52.0%	79483	11.92	10.73	9.54	8.58
Sampangiram Nagar	24.2%	48734	7.31	6.58	5.85	5.26
Halsoor	24.2%	52854	7.93	7.14	6.34	5.71
Dodda Nekkundi	31.6%	34916	5.24	4.71	4.19	3.77
Bharathi Nagar	38.5%	60372	9.06	8.15	7.24	6.52
Gandhinagar	24.2%	31113	4.67	4.20	3.73	3.36
Shivaji Nagar	53.3%	84489	12.67	11.41	10.14	9.12
C V Raman Nagar	55.9%	72770	10.92	9.82	8.73	7.86
Subhash Nagar	8.1%	1177	0.18	0.16	0.14	0.13
Vijnana Nagar	42.1%	48519	7.28	6.55	5.82	5.24
Vasanth Nagar	24.2%	14138	2.12	1.91	1.70	1.53
Sarvagna Nagar	24.2%	51459	7.72	6.95	6.18	5.56
Garudacharpalya	46.3%	21571	3.24	2.91	2.59	2.33
A Narayanapura	41.2%	56730	8.51	7.66	6.81	6.13
Pulikeshinagar	24.2%	41468	6.22	5.60	4.98	4.48
Jayamahal	24.2%	35340	5.30	4.77	4.24	3.82
Maruthi Seva Nagar	24.2%	44523	6.68	6.01	5.34	4.81
Ramaswamy Palya	35.3%	55954	8.39	7.55	6.71	6.04
Devasandra	30.6%	9326	1.40	1.26	1.12	1.01

S K Garden	17.6%	34916	5.24	4.71	4.19	3.77
Benniganahalli	33.8%	45948	6.89	6.20	5.51	4.96
Vijnanapura	37.4%	35597	5.34	4.81	4.27	3.84
Kammanahalli	49.9%	4260	0.64	0.58	0.51	0.46
Hudi	40.3%	912	0.14	0.12	0.11	0.10
Sagayarapuram	43.2%	50924	7.64	6.87	6.11	5.50
Kadugodi	53.5%	5386	0.81	0.73	0.65	0.58
Kushal nagar	16.5%	219	0.03	0.03	0.03	0.02
Devara Jeevanahalli	27.7%	6533	0.98	0.88	0.78	0.71
Gangenahalli	24.2%	9400	1.41	1.27	1.13	1.02
Banasavadi	37.9%	4807	0.72	0.65	0.58	0.52
Jayachamarajendra Nagar	30.5%	9940	1.49	1.34	1.19	1.07
Aramane Nagara	24.2%	3818	0.57	0.52	0.46	0.41
Horamavu	42.6%	203	0.03	0.03	0.02	0.02
Hombegowda Nagara	24.2%	53684	8.05	7.25	6.44	5.80
CHIKKAKANAHALLI	28.8%	24	0.00	0.00	0.00	0.00
CHIKKAKANAHALLI	28.8%	25	0.00	0.00	0.00	0.00
Total		3474725	521.21	469.09	416.97	375.27

Table 2: Population, Water Demand and Sewage discharge (as per Method II)

Method II__Population 2017						
LOCATION (village/ward)	Growth Rate	Population - Varthur	Water Demand in MLD		Sewage Generated in MLD	
			Demand in 150 lpcd - Varthur	Demand in 135 lpcd - Varthur	Sewage in 150 lpcd - Varthur	Sewage in 135 lpcd - Varthur
HEGGONDAHALLI	0.333	502	0.08	0.07	0.06	0.05
KODATHI	0.3	1621	0.24	0.22	0.19	0.18
HADOSIDDAPURA	0.302	540	0.08	0.07	0.06	0.06
CHIKKAVADERAPURA	3.857	667	0.1	0.09	0.08	0.07
SULIKUNTE	0.3	2378	0.36	0.32	0.29	0.26
CHIKKA NAYAKANAHALLI	0.301	364	0.05	0.05	0.04	0.04
DOMMASANDRA	0.3	1459	0.22	0.2	0.18	0.16
CHOKKASANDRA	0.008	1	0	0	0	0
BETTADASANAPURA	0.397	1031	0.15	0.14	0.12	0.11
HOMMADEVANAHALLI	0.695	1499	0.22	0.2	0.18	0.16
MYLASANDRA	0.164	2032	0.3	0.27	0.24	0.22
VITASANDRA	0.176	1098	0.16	0.15	0.13	0.12
RAYASANDRA	0.742	170	0.03	0.02	0.02	0.02
CHOODASANDRA	0.531	1311	0.2	0.18	0.16	0.14
CHIKKAKANAHALLI	0.333	24	0	0	0	0
HALNAYAKANAHALLI	0.3	1431	0.21	0.19	0.17	0.15
MULLURU	0.3	1923	0.29	0.26	0.23	0.21
KACHAMARANHALLI	0.3	1099	0.16	0.15	0.13	0.12

HALASAHALLI THIPPASANDRA	0.105	457	0.07	0.06	0.05	0.05
Gottigere	0.598	24091	3.61	3.25	2.89	2.6
Anjanapura	0.539	175	0.03	0.02	0.02	0.02
Arakere	0.702	60467	9.07	8.16	7.26	6.53
Begur	0.429	30040	4.51	4.06	3.6	3.24
Singasandra	0.577	40465	6.07	5.46	4.86	4.37
Konankunte	0.675	45886	6.88	6.19	5.51	4.96
Vasanthpura	0.638	2584	0.39	0.35	0.31	0.28
Puttenahalli	0.765	52926	7.94	7.15	6.35	5.72
Jaraganahalli	0.589	35797	5.37	4.83	4.3	3.87
Hongasandra	0.901	67503	10.13	9.11	8.1	7.29
Mangammanapalya	0.905	80488	12.07	10.87	9.66	8.69
Sarakki	0.845	49964	7.49	6.75	6	5.4
Bilekhalli	0.595	48704	7.31	6.58	5.84	5.26
J P Nagar	0.139	35164	5.27	4.75	4.22	3.8
BTM Layout	0.274	51062	7.66	6.89	6.13	5.51
Bommanahalli	0.753	61867	9.28	8.35	7.42	6.68
Shakambari Nagar	0.274	11604	1.74	1.57	1.39	1.25
Madivala	0.069	39148	5.87	5.28	4.7	4.23
Jakkasandra	0.137	29659	4.45	4	3.56	3.2
Gurappanapalya	0.452	66169	9.93	8.93	7.94	7.15
Jayanagar East	0.009	31269	4.69	4.22	3.75	3.38
Karisandra	0.297	641	0.1	0.09	0.08	0.07
HSR Layout	0.368	41321	6.2	5.58	4.96	4.46
Pattabhiram Nagar	0.274	40761	6.11	5.5	4.89	4.4
Byrasandra	0.17	37020	5.55	5	4.44	4
Suddagunte Palya	0.274	53247	7.99	7.19	6.39	5.75
Yediyur	0.274	1382	0.21	0.19	0.17	0.15
Koramangala	0.274	52430	7.86	7.08	6.29	5.66
Jayanagar	0.274	48672	7.3	6.57	5.84	5.26
Siddapura	0.521	64243	9.64	8.67	7.71	6.94
Adugodi	0.274	44403	6.66	5.99	5.33	4.8
Lakkasandra	0.274	41967	6.3	5.67	5.04	4.53
Ejipura	0.171	37603	5.64	5.08	4.51	4.06
Nilasandra	0.644	82654	12.4	11.16	9.92	8.93
Bellandur	0.207	27836	4.18	3.76	3.34	3.01
Vishveshwara Puram	0.274	40122	6.02	5.42	4.81	4.33
Vannarpet	0.482	67904	10.19	9.17	8.15	7.33
Chamarajapet	0.303	1105	0.17	0.15	0.13	0.12
Konena Agrahara	0.758	75080	11.26	10.14	9.01	8.11
Sudham Nagara	0.226	44855	6.73	6.06	5.38	4.84
Varthur	0.178	27001	4.05	3.65	3.24	2.92
Shanthi Nagar	0.274	54012	8.1	7.29	6.48	5.83

Marathahalli	0.865	63734	9.56	8.6	7.65	6.88
K R Market	0.345	15168	2.28	2.05	1.82	1.64
Dharmaraya Swamy Temple Ward	0.204	44430	6.66	6	5.33	4.8
Jeevanbhima Nagar	0.744	91165	13.67	12.31	10.94	9.85
H A L Airport	0.599	71881	10.78	9.7	8.63	7.76
Chickpete	0.47	60461	9.07	8.16	7.26	6.53
Domlur	0.274	51458	7.72	6.95	6.17	5.56
Agaram	0.274	52835	7.93	7.13	6.34	5.71
Cottonpete	0.509	5094	0.76	0.69	0.61	0.55
Jogupalya	0.444	63312	9.5	8.55	7.6	6.84
Shantala Nagar	0.274	44817	6.72	6.05	5.38	4.84
Hagadur	0.284	22103	3.32	2.98	2.65	2.39
Hoysala Nagar	0.274	53218	7.98	7.18	6.39	5.75
New Tippasandra	0.682	81990	12.3	11.07	9.84	8.85
Sampangiram Nagar	0.274	49071	7.36	6.62	5.89	5.3
Halsoor	0.274	53219	7.98	7.18	6.39	5.75
Dodda Nekkundi	0.371	35326	5.3	4.77	4.24	3.82
Bharathi Nagar	0.469	61419	9.21	8.29	7.37	6.63
Gandhinagar	0.274	31329	4.7	4.23	3.76	3.38
Shivaji Nagar	0.712	87334	13.1	11.79	10.48	9.43
C V Raman Nagar	0.749	75414	11.31	10.18	9.05	8.14
Subhash Nagar	0.084	1178	0.18	0.16	0.14	0.13
Vijnana Nagar	0.523	49524	7.43	6.69	5.94	5.35
Vasanth Nagar	0.274	14236	2.14	1.92	1.71	1.54
Sarvagna Nagar	0.274	51815	7.77	7	6.22	5.6
Garudacharpalya	0.589	22111	3.32	2.98	2.65	2.39
A Narayanapura	0.509	57857	8.68	7.81	6.94	6.25
Pulikeshinagar	0.274	41754	6.26	5.64	5.01	4.51
Jayamahal	0.274	35585	5.34	4.8	4.27	3.84
Maruthi Seva Nagar	0.274	44831	6.72	6.05	5.38	4.84
Ramaswamy Palya	0.423	56773	8.52	7.66	6.81	6.13
Devasandra	0.358	9429	1.41	1.27	1.13	1.02
S K Garden	0.192	35044	5.26	4.73	4.21	3.78
Benniganahalli	0.403	46568	6.99	6.29	5.59	5.03
Vijnanapura	0.453	36181	5.43	4.88	4.34	3.91
Kammanahalli	0.648	4384	0.66	0.59	0.53	0.47
Hudi	0.496	929	0.14	0.13	0.11	0.1
Sagayarapuram	0.541	52038	7.81	7.03	6.24	5.62
Kadugodi	0.708	5565	0.83	0.75	0.67	0.6
Kushal nagar	0.18	220	0.03	0.03	0.03	0.02
Devara Jeevanahalli	0.319	6592	0.99	0.89	0.79	0.71
Gangenahalli	0.274	9465	1.42	1.28	1.14	1.02
Banasavadi	0.461	4888	0.73	0.66	0.59	0.53

Jayachamarajendra Nagar	0.357	10049	1.51	1.36	1.21	1.09
Aramane Nagara	0.274	3845	0.58	0.52	0.46	0.42
Horamavu	0.532	207	0.03	0.03	0.02	0.02
Hombegowda Nagara	0.274	54055	8.11	7.3	6.49	5.84
CHIKKAKANAHALLI	0.333	24	0	0	0	0
CHIKKAKANAHALLI	0.333	25	0	0	0	0
Total		3538848	530.83	477.74	424.66	382.2

Table 3: Population, Water Demand and Sewage discharge (as per Method III)

Method III - Population 2017					
LOCATION (villages/wards)	Population - Varthur	Water Demand in MLD		Sewage Generated in MLD	
		Demand in 150lpcd - Varthur	Demand in 135 lpcd - Varthur	Sewage in 150lpcd - Varthur	Sewage in 135 lpcd - Varthur
HEGGONDAHALLI	482	0.07	0.07	0.06	0.05
KODATHI	1564	0.23	0.21	0.19	0.17
HADOSIDDAPURA	521	0.08	0.07	0.06	0.06
CHIKKAVADERAPURA	297	0.04	0.04	0.04	0.03
SULIKUNTE	2294	0.34	0.31	0.28	0.25
CHIKKA NAYAKANAHALLI	351	0.05	0.05	0.04	0.04
DOMMASANDRA	1408	0.21	0.19	0.17	0.15
CHOKKASANDRA	1	0.00	0.00	0.00	0.00
BETTADASANAPURA	974	0.15	0.13	0.12	0.11
HOMMADEVANAHALLI	1318	0.20	0.18	0.16	0.14
MYLASANDRA	2006	0.30	0.27	0.24	0.22
VITASANDRA	1082	0.16	0.15	0.13	0.12
RAYASANDRA	143	0.02	0.02	0.02	0.02
CHOODASANDRA	1202	0.18	0.16	0.14	0.13
CHIKKAKANAHALLI	23	0.00	0.00	0.00	0.00
HALNAYAKANAHALLI	1380	0.21	0.19	0.17	0.15
MULLURU	1855	0.28	0.25	0.22	0.20
KACHAMARANAHALLI	1060	0.16	0.14	0.13	0.11
HALASAHALLI THIPPASANDRA	455	0.07	0.06	0.05	0.05
Gottigere	21708	3.26	2.93	2.60	2.34
Anjanapura	160	0.02	0.02	0.02	0.02
Arakere	53079	7.96	7.17	6.37	5.73
Begur	28196	4.23	3.81	3.38	3.05
Singasandra	36659	5.50	4.95	4.40	3.96
Konankunte	40559	6.08	5.48	4.87	4.38
Vasanthpura	2305	0.35	0.31	0.28	0.25
Puttenahalli	45704	6.86	6.17	5.48	4.94
Jaraganahalli	32332	4.85	4.36	3.88	3.49
Hongasandra	56282	8.44	7.60	6.75	6.08

Mangammanapalya	67038	10.06	9.05	8.04	7.24
Sarakki	42260	6.34	5.71	5.07	4.56
Bilekhalli	43928	6.59	5.93	5.27	4.74
J P Nagar	34835	5.23	4.70	4.18	3.76
BTM Layout	49515	7.43	6.68	5.94	5.35
Bommanahalli	53595	8.04	7.24	6.43	5.79
Shakambari Nagar	11252	1.69	1.52	1.35	1.22
Madivala	39047	5.86	5.27	4.69	4.22
Jakkasandra	29386	4.41	3.97	3.53	3.17
Gurappanapalya	61768	9.27	8.34	7.41	6.67
Jayanagar East	31267	4.69	4.22	3.75	3.38
Karisandra	619	0.09	0.08	0.07	0.07
HSR Layout	39313	5.90	5.31	4.72	4.25
Pattabhiram Nagar	39525	5.93	5.34	4.74	4.27
Byrasandra	36524	5.48	4.93	4.38	3.94
Suddagunte Palya	51634	7.75	6.97	6.20	5.58
Yediyur	1340	0.20	0.18	0.16	0.14
Koramangala	50841	7.63	6.86	6.10	5.49
Jayanagar	47197	7.08	6.37	5.66	5.10
Siddapura	59009	8.85	7.97	7.08	6.37
Adugodi	43057	6.46	5.81	5.17	4.65
Lakkasandra	40695	6.10	5.49	4.88	4.40
Ejipura	37089	5.56	5.01	4.45	4.01
Nilasandra	73638	11.05	9.94	8.84	7.95
Bellandur	27310	4.10	3.69	3.28	2.95
Vishveshwara Puram	38906	5.84	5.25	4.67	4.20
Vannarpet	62947	9.44	8.50	7.55	6.80
Chamarajapet	1060	0.16	0.14	0.13	0.12
Konena Agrahara	64952	9.74	8.77	7.79	7.01
Sudham Nagara	43865	6.58	5.92	5.26	4.74
Varthur	26606	3.99	3.59	3.19	2.87
Shanthi Nagar	52375	7.86	7.07	6.29	5.66
Marathahalli	53629	8.04	7.24	6.44	5.79
K R Market	14502	2.18	1.96	1.74	1.57
Dharmaraya Swamy Temple Ward	43609	6.54	5.89	5.23	4.71
Jeevanbhima Nagar	79168	11.88	10.69	9.50	8.55
H A L Airport	64761	9.71	8.74	7.77	6.99
Chickpete	56214	8.43	7.59	6.75	6.07
Domlur	49899	7.48	6.74	5.99	5.39
Agaram	51234	7.69	6.92	6.15	5.53
Cottonpete	4692	0.70	0.63	0.56	0.51
Jogupalya	59213	8.88	7.99	7.11	6.40
Shantala Nagar	43459	6.52	5.87	5.22	4.69

Hagadur	21394	3.21	2.89	2.57	2.31
Hoysala Nagar	51606	7.74	6.97	6.19	5.57
New Tippasandra	72329	10.85	9.76	8.68	7.81
Sampangiram Nagar	47584	7.14	6.42	5.71	5.14
Halsoor	51607	7.74	6.97	6.19	5.57
Dodda Nekkundi	33584	5.04	4.53	4.03	3.63
Bharathi Nagar	57114	8.57	7.71	6.85	6.17
Gandhinagar	30379	4.56	4.10	3.65	3.28
Shivaji Nagar	76460	11.47	10.32	9.18	8.26
C V Raman Nagar	65407	9.81	8.83	7.85	7.06
Subhash Nagar	1174	0.18	0.16	0.14	0.13
Vijnana Nagar	45465	6.82	6.14	5.46	4.91
Vasanth Nagar	13805	2.07	1.86	1.66	1.49
Sarvagna Nagar	50244	7.54	6.78	6.03	5.43
Garudacharpalya	19973	3.00	2.70	2.40	2.16
A Narayanapura	53287	7.99	7.19	6.39	5.75
Pulikeshinagar	40489	6.07	5.47	4.86	4.37
Jayamahal	34506	5.18	4.66	4.14	3.73
Maruthi Seva Nagar	43472	6.52	5.87	5.22	4.69
Ramaswamy Palya	53353	8.00	7.20	6.40	5.76
Devasandra	8989	1.35	1.21	1.08	0.97
S K Garden	34461	5.17	4.65	4.14	3.72
Benniganahalli	43965	6.59	5.94	5.28	4.75
Vijnanapura	33767	5.07	4.56	4.05	3.65
Kammanahalli	3901	0.59	0.53	0.47	0.42
Hudi	859	0.13	0.12	0.10	0.09
Sagayarapuram	47565	7.13	6.42	5.71	5.14
Kadugodi	4878	0.73	0.66	0.59	0.53
Kushal nagar	216	0.03	0.03	0.03	0.02
Devara Jeevanahalli	6336	0.95	0.86	0.76	0.68
Gangenahalli	9178	1.38	1.24	1.10	0.99
Banasavadi	4554	0.68	0.61	0.55	0.49
Jayachamarajendra Nagar	9583	1.44	1.29	1.15	1.03
Aramane Nagara	3728	0.56	0.50	0.45	0.40
Horamavu	190	0.03	0.03	0.02	0.02
Hombegowda Nagara	52417	7.86	7.08	6.29	5.66
CHIKKAKANAHALLI	23	0.00	0.00	0.00	0.00
CHIKKAKANAHALLI	24	0.00	0.00	0.00	0.00
Total	**3286050**	**492.91**	**443.62**	**394.33**	**354.89**

Annexure IV

CENTRE FOR ECOLOGICAL SCIENCES
INDIAN INSTITUTE OF SCIENCE
BANGALORE 560 012, INDIA
Telephone: 91-080-23600985 / 2293 3099/ 2293 2506
Telefax: 91-080-23601428 / 23600085 / 23601683 (attn: CES/TVR)
E Mail: cestvr@ces.iisc.ernet.in; energy@ces.iisc.ernet.in
Web URL http://ces.iisc.ernet.in/energy
https://www.researchgate.net/profile/T_V_Ramachandra/publications

Dr. T.V. Ramachandra
Co-ordinator
Energy & Wetlands Research Group

CES/TVR/BDA/10422/2017
21- February- 2017

To
Excutive Engineer (East Division)
BDA
Bangalore

Dear Sir

Subject: Fire in Bellandur lake on 16th February 2017
Ref: your letter BDA/Chairman/AS/297/2016-17 dated 18th Feb 2017

Thank you for your letter cited above, regarding the fire incident in Bellandur lake (Southern Side, near Iblur Lake (about 140 m), behind Sun city apartment complex) on 16th February 2017 evening. Our research group members visited the location and collected samples, etc. Fire is due to igniting debris of dry plants, solid waste (consisting of predominantly waste plastics, etc.) and aggravated by methane generation in the lake, based on the sample chemical analyses and field investigation. Details are:

Indicator	Causal factors
Fire	Burning of combustible matter (dry biomass, solid waste, etc.), aggravated by the methane enriched environment. Igniting dry biomass could be accidental (due to throwing cigarette / beedi) or by desperate residents– to prevent mosquito menace.
Dry biomass (plant matter)	The lake has been receiving about 400-450 MLD untreated sewage (rich in N, P, etc.) daily in addition to about 20-30 MLD from the nearby apartments. The availability of nutrients (nitrogen and Phosphorous) in the lake has led to the profuse growth of macrophytes [water hyacinth, (*Eichhornia crassipes*), Alligator weed (*Alternanthera philoxeroides* Alternentra), etc.). These weeds by their abundance of leaves, dense vegetation and innumerable rootlets in tertiary manner form a thick mat. These weeds have started

	drying with increasing temperature and also due to senescence (biological aging)
Dumping of solid waste	• Solid waste collected in the city are being dumped in the lake since the existence of inefficient regulatory and monitoring mechanism in the city administration. • Illegal Bangladeshi immigrants (residing in the immediate vicinity of the lake) recover materials, which has economic value and dump the remaining waste materials into the lake. This is happening over five years in the locality, which was brought to the notice of all responsible decision makers, but no action has been taken to either stop these illegal activities or evict illegal immigrants. Continuation of these activities not only hampers lake environment but also threaten the social harmony in the city. • Throwing household garbage (in the polythene bags) by the residents from the nearby localities. It is observed that many residents while travelling in a vehicle throwing the plythene bags (with solid waste) directly into the lake
Methane generation (with anaerobic environment below macrophytes mat)	Water hyacinth provides suitable breeding places for mosquitoes and other disease-carrying insects and makes the region (below the mat) anaerobic, leading to the generation of methane.
Presence of long chain hydrocarbon residues (along with dry biomass)	In addition to the sewage, untreated industrial effluents from the industries in the catchment has contributed to the favorable environment. Water sample analyses also highlight the contamination due to industrial discharges.

Implementation of recommendations of the expert committee within reasonable time would bring down such unfortunate instances as well as impending catastrophe due to high level of pollutants in the environment.

Thank you

best wishes and regards

T.V. Ramachandra

Dr. T V Ramachandra

Dr. T.V. RAMACHANDRA
Co-ordinator
Energy & Wetlands Research Group (CES)
Centre For Ecological Sciences
Indian Institute of Science
BANGALORE-560 012, INDIA

ENCRAOACHMENT

FIRE (2016)

FIRE (2017)

MESH BARRICADES (but froth crosses over), PIPES (SHIFTING PROBLEMSTO THE DOWNSTREAM)

MITIGATING FROTH – IRRESPONSIBLE AD-HOC REACTIONARY APPROACHES OF 21st Century ADMINISTRATORS (than addressing the pollution at the source)

ENERGY AND WETLANDS RESEARCH GROUP
SAHYADRI: ENVIRONMENTAL INFORMATION SYSTEM (ENVIS)
CENTRE FOR ECOLOGICAL SCIENCES
NEW BIOSCIENCE BUILDING, III FLOOR, E-WING, LAB: TE15
Indian Institute of Science, 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