FOAMING OR ALGAL BLOOM IN WATER BODIES OF INDIA: REMEDIAL MEASURES - RESTRICT PHOSPHATE (P) BASED DETERGENTS

T V Ramachandra **Durga Madhab Mahapatra**
Asulabha K S **Sincy Varghese**

Gautam and Vasantha Jagadisan endowment– Lake Research
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

ENVIS Technical Report: 108

March 2017

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

FOAMING OR ALGAL BLOOM IN WATER BODIES OF INDIA: REMEDIAL MEASURES - RESTRICT PHOSPHATE (P) BASED DETERGENTS

T V Ramachandra **Durga Madhab Mahapatra**
Asulabha K S **Sincy Varghese**

Gautam and Vasantha Jagadisan endowment– Lake Research
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

ENVIS Technical Report**: 108**
March 2017

Citation: 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

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

FOAMING OR ALGAL BLOOM IN WATER BODIES OF INDIA: REMEDIAL MEASURES - RESTRICT PHOSPHATE (P) BASED DETERGENTS

Citation: 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

Gautam and Vasantha Jagadisan endowment– Lake Research
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

ENVIS Technical Report 108

Foaming or Algal Bloom in Water bodies of India: Remedial Measures - Restrict Phosphate (P) based Detergents

Summary

Algal bloom or foaming is a consequence of nutrient enrichment (N and P) due to untreated sewage (mostly from human and household waste and detergents) and industrial effluents. The phosphorus from several sources reaching water bodies causes pollution leading to algal blooms, frothing, etc. Phosphorus represents both a scarce non-renewable resource and a pollutant for living systems.

Primary nutrient, such as carbon, nitrogen, phosphorus, etc. contribute to eutrophication. In fresh water ecosystem, primary producers are able to obtain N from the atmosphere and hence phosphorus is the primary agent of eutrophication. Moreover, elements carbon, nitrogen and phosphorus can generate its weight by 12, 71 and 500 times, and hence phosphorous is the limiting element in primary producers. Nutrients enrichment often leads to profuse growth of invasive species (water hyacinth, etc.), which forms thick mat hindering the sunlight penetration. In absence of sunlight, photosynthetic activities cease affecting the food chain. Absence of sunlight penetration leads to the decline of primary producers (algae) in the region below the macrophyte mat. Most part of nitrogen available in the sewage and industrial effluents is assimilated by producers, while phosphorous gets trapped in the sediment. During pre-monsoon with high intensity winds, churning of lake water happens, leading to the release of phosphorous from sediments forming froth. Foaming is the manifestation of interactions among air bubble, surfactant and hydrophobic particles. The hydrophobic particles congregate at the air-water interface and strengthen the water film between air bubbles. Meanwhile, the particles also serve as collector for surfactant which stabilizes the foam. Surfactants contain slowly biodegradable surfactants and hydrophobic particles are the filamentous bacteria with a long-chain structure and hydrophobic surface. Thus, frothing is due to the presence of slowly biodegradable surfactants (eg. household detergents) from industrial or municipal wastewater, excess production of extracellular polymeric substance (by microorganisms, proliferation of filamentous organisms) and air bubble (wind).

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

Constituents of Detergents: The surfactant nonylphenol ethoxylate (**NPE)**, an endocrine disruptor and estrogen mimic; phosphates, which help remove minerals and food bits but cause harmful algal blooms in waterway.

Chemical analyses of field samples reveal that, foams are enriched with particulate organic and inorganic compounds such as nutrients (Nitrogen, Phosphorus and Carbon), cations (Sodium, Potassium, Calcium and Magnesium). Foam generated is normally sticky and white in color. Most surfactants originate from the detergents, oil and grease that are used in households or industry. Surfactant could stabilize the foaming and allow foam to accumulate.

Physico-chemical parameters of water and foam samples from Varthur lake (01/05/2015)

Parameters	**V1**	**V2**	**Foam**
Water temperature (^{0}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

Algal Bloom: due to Nutrient enrichment in lentic ecosystem

Foam/Frothing: Nutrient enrichment in lotic ecosystems and in lentic ecosystem (with movement of water).

Fire associated with foam in Bellandur lake (@ Yamalur):

Flammability is the ability of a substance to burn or ignite, causing fire or combustion. Incidences of foam catching fire are due to compounds with high flammability i.e. (i) mostly hydrocarbons and organic polymers from nearby industries in the vicinity of Bellandur lake and (ii) phosphorous from detergents. 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 and phosphorous) with accidental fire (like throwing cigarettes, beedi) has led to the fire in the lake. Colour of the flame and subsequent analyses of black particles (burnt residues) confirms the source (long chain hydro carbons).

Phosphorus (P) is one of the nutrients essential to sustain biota on the Earth and is a non-renewable resource. The indiscriminate exploitation and abuse of this resource is threatening the sustenance and its availability for future generations is becoming obscure. There has been a series of events (frequent frothing, etc. in water bodies) and subsequent research have clearly highlighted the linkages of enhanced usage and influx of P with a phenomenal increase in P enrichment in surface and ground waters. Consequence of extensive phosphorus usage in contemporary urban societies is the nutrient enrichment or eutrophication of water bodies. Studies across the globe highlight of nearly 2.4–2.7-fold increase in nitrogen and phosphorus driven eutrophication of freshwater and marine ecosystems with the current level of human-induced stresses. The main sources of phosphate in aquatic environment, is through household sewage water containing detergents and cleaning preparations, agricultural run-off containing fertilizers, as well as, industrial effluents from fertilizer, detergent and soap industries.

The consumption of synthetic detergents is rapidly increasing with urbanisation and most of them contain phosphate as a ‘builder’, which has been increasing phosphate loading in water bodies. The estimated annual consumption of phosphate-containing laundry detergents for the current population in India is about 2.88 million tonnes and the total outflow of P is estimated to be 146 thousand tonnes per year. The environmental consequences necessitate immediate policy interventions for checking eutrophication of water bodies, through reduction in

Phosphate based detergents and hence P inputs to surface waters. All the detergent manufacturers need to adhere to minimise the use of P in the manufacture of detergents while the authorities need to restrict with stringent norms. Strict control with the vigilant and environmentally conscious public only could ensure that Indian water bodies remain safe and healthy.

During seventies and early eighties, 19^{th} 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 the 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 up to tertiary 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 field sample analyses, 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.

The study highlights the need for immediate intervention towards the reduction in the amount of sodium tripolyphosphate (STPP) used in detergent builders and switch to ‘alternative’ non-phosphate based builders, such as Zeolite A; and, improving wastewater treatment taking advantage of constructed wetlands in urban wastewater treatment.

Keywords: Lakes, water bodies, nutrient enrichment, eutrophication, detergents, phosphorous

Foaming or Algal Bloom in Water bodies of India: Remedial Measures - Restrict Phosphate (P) based Detergents

Introduction

Phosphorus is the most crucial nutrient in living systems and is a key component of the genetic make up 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, detergents, medicine, etc. 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. If no action is taken to quell misuse of phosphorous, demand is likely to increase exponentially. 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 of P are 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 diary 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).

Table 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

			Total Solid waste generation 28 tonnes
Output	Waste 21.8 tons Mine water Diesel exhaust gases	Waste water Tailings 6.5 tons Diesel exhaust gases	

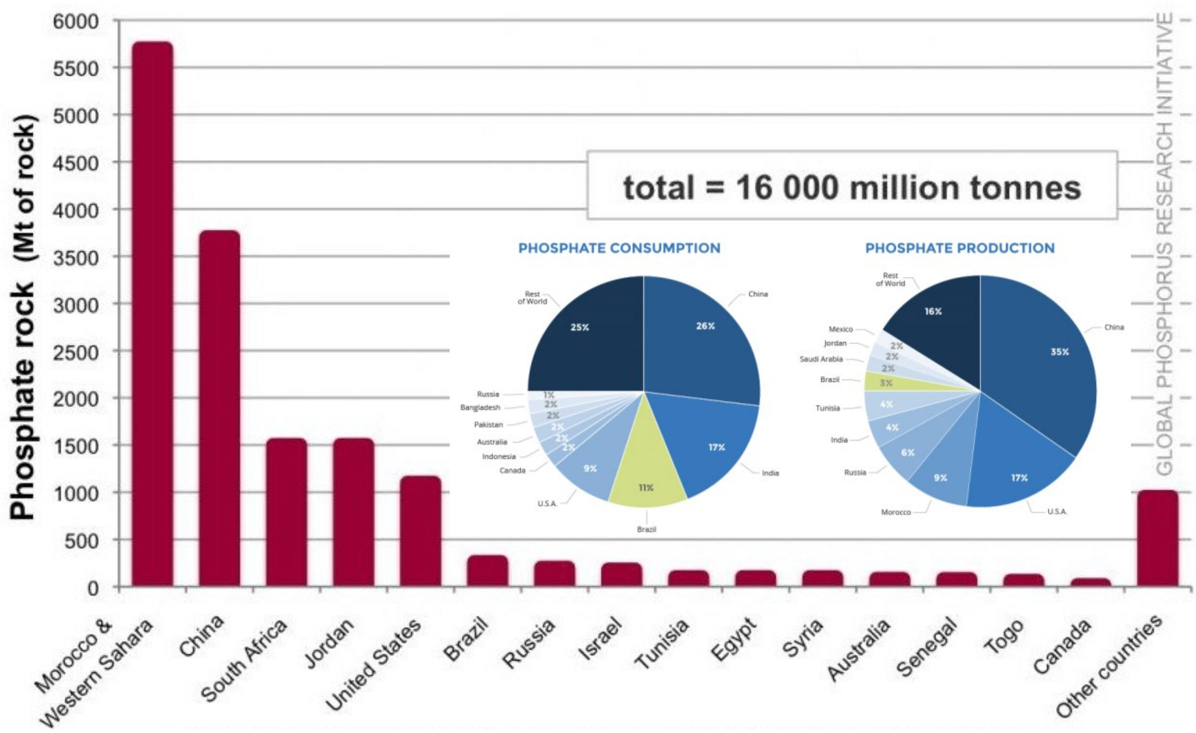


Figure 1. Rock Phosphate abundance and distribution, USGS (Jasinki, 2010)

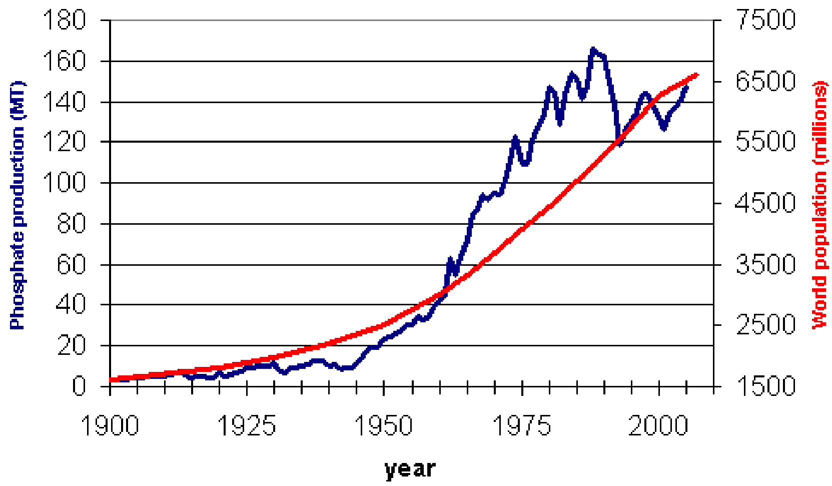


Figure 2. Increase in P production with increased population growth, USGS, 2010

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

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 is transported into surface water bodies from various non-point sources as agricultural runoff and from point sources like municipal and industrial wastewater discharges. In India 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 5 of the labile P (inorganic and soluble forms) present in municipal wastewaters are from these sources alone.

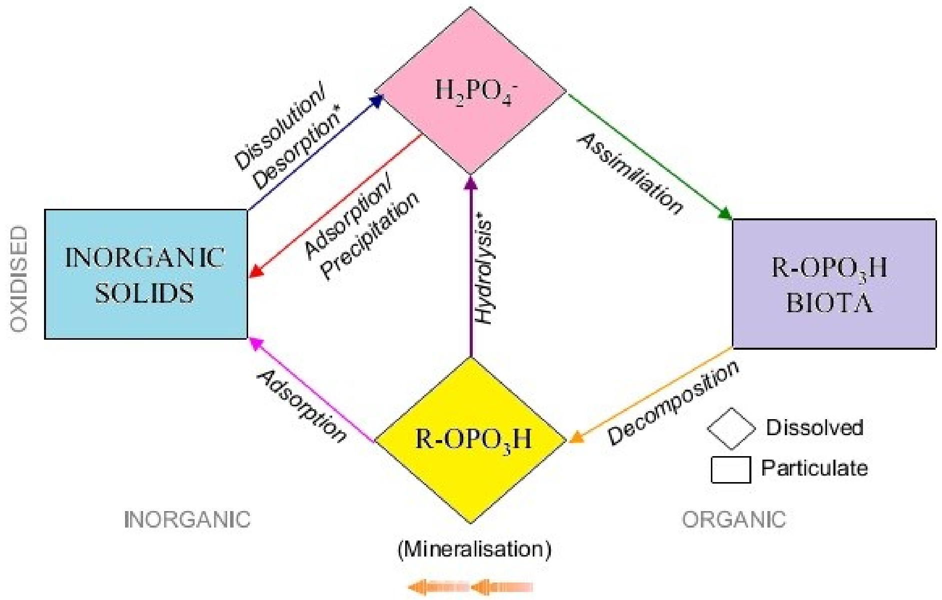


Figure 3. P biochemical Cycle (terrestrial and aquatic environments)

N and P are very basic nutrients trigger aquatic plant and algal growth and increase in the primary productivity in surface 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 enrichments 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 is 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 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 in 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 algal blooms and macrophytes invasion, the first step should be to minimise 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.

Soaps and 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 look 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. India realises the implication of detergents as a potential chemical pollutant on the surface and various receiving waters through the Environment protection act (1986) as in other nations. Despite norms, phosphorous is being used even today, evident from frothing in Yamuna river, Bellandur lake, Varthur lake, etc. Studies indicate 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). 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. This highlights grave situation due to misuse of phosphorous and consequent accumulation of P in aquatic systems, evident from frequent frothing episodes.

Today, the Nations action plan towards the control of nutrient enrichment is very meagre. Recent increased awareness among public, have led to the establishment of sewage treatment plants, but these plants treat water only up to secondary levels, and the issue of nutrient removal remains largely ignored. The Environment Protection policy (1986) and the Hazardous Waste Rules (1998) that clearly categorises the major forms of P as phosphine and phosphates as toxic chemicals and attempts to prohibit the usage of phosphates in the day to day chemicals is still weak and these rules are not yet applied in the manufacturing of the household laundry soaps and detergents. The Bureau of Indian Standards (BIS) has set up certain grades/standards for eco-labelling with the help of Ecomark in 1991. These eco-labelling necessitates the detergents to use surfactants that are biodegradable and packaging in recyclable and biodegradable materials. However, 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 (such as Zeolite) is required. European nations, the US and Canada had imposed restrictions on the sale of P-rich detergents (since 2010) and 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; dish wash 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 help in the rapid degradation/oxidation of the dirt/coloured/sticky materials ultimately removing the colour or the stain from the fabric. Other than these (surfactants, builders), various other constituents used in detergent are fragrance imparting agents, enzyme activators, bleach activators, fabric conditioners, alkali etc. Builders are one of the key components of detergents, which help in reducing water hardness, while 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 move 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 detrimental 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 3.

Table 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	Ethylenediamin otetracetic acid	Org.	EDTA	Poorly degradable. Dissolves metal ions
11	Carboxymethylo xysuccinate Carboxymethylt artronate	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

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. The STPP based conventional detergent powders generally have 15-30 % STPP with <5% PCA, where as 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 4.

Table 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 up to 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-release 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 witnessed 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. Restrictions of p based detergents can bring down the 40% of the P loads in aquatic systems that would contribute significantly towards safeguarding water resources. Furthermore, improved wastewater treatment facilities with effective N and P 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 waters. 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 hazardous 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 parallel 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 actins needs to be implemented

1. Immediate reduction, and eventual eradication of phosphates in detergents;
2. Awareness among consumers to select washing products with the least amount of polluting ingredients;
3. prompt promulgation of regulations requiring appropriate labelling of detergent packages listing of the ingredients and information about use of detergents in soft and hard water.
4. Enacting 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,
5. 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 documented.
6. More research and development on fate of P based ingredients in aquatic systems, from various sectors (Agricultural, Municipal etc.) has to be undertaken.
7. 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.

8. Seeking participation from the local communities in surface and ground water quality monitoring and management and strictly applying the “polluter pays principle” to the rapidly declining surface waters would ensure conservation and protection of the fresh water resources.

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 Sewage treatment does not remove P Intensive agriculture locally	Partial change to Zeolite based detergents Improvements in sewage treatment	~50% for the Seine Marginal for the Loire	Partial improvement
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	At an early stage	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
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	Detregents	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

2.0 Varthur–Bellandur–Yamalur Fiasco: Classic case of EUTROPICATION

Status	Contaminated water, sediment and air
Cause	1. Encroachment of lakebed, flood plains, and lake itself; 2. Loss in lake interconnectivity - Encroachment of rajakaluves / storm water drains and loss of interconnectivity; 3. Lake reclamation for infrastructure activities; 4. Topography alterations in lake catchment; 5. Unauthorised dumping of municipal solid waste and building debris; 6. Sustained inflow of untreated or partially treated sewage and industrial effluents; 7. Removal of shoreline riparian vegetation; and unabated construction activities in the valley zone has threatened these urban wetlands. 8. Pollution due to enhanced vehicular traffic; 9. Too many para-state agencies and lack of co-ordination among them. 10. Too many para-state agencies and too less governance
Solution	• 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) • 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 near to lakes after the survey based on reliable cadastral maps; • Effective judicial system for speedy disposal of conflicts related to encroachment; • Restriction of the entry of untreated sewage into lakes; • To make land grabbing cognizable non-bail offence; • Letting off only treated sewage into the lake (as in jakkur lake model); • Regular removal of macrophytes 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 • Ensure proper fencing of lakes • Restrictions on the diversion of lake for any other purposes; • Complete ban on construction activities in the valley zones.
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.	

Varthur – Bellandur – Yamalur Fiasco

Lakes in Bangalore are interconnected and there are three valleys and Kormangala-Challaghatta-Bellandur-Varthur Valley is one among them (Figure 2.1). Varthur Lake series belongs to Kormangala-Challaghatta Valley consisting of Byappanahalli, Harlur, Kasavanahalli, Kaikondanahalli, Doddanakundi, Vibuthipura, Kundalahalli, Chinnappanahalli, Bellandur, Agara and Varthur Lakes.

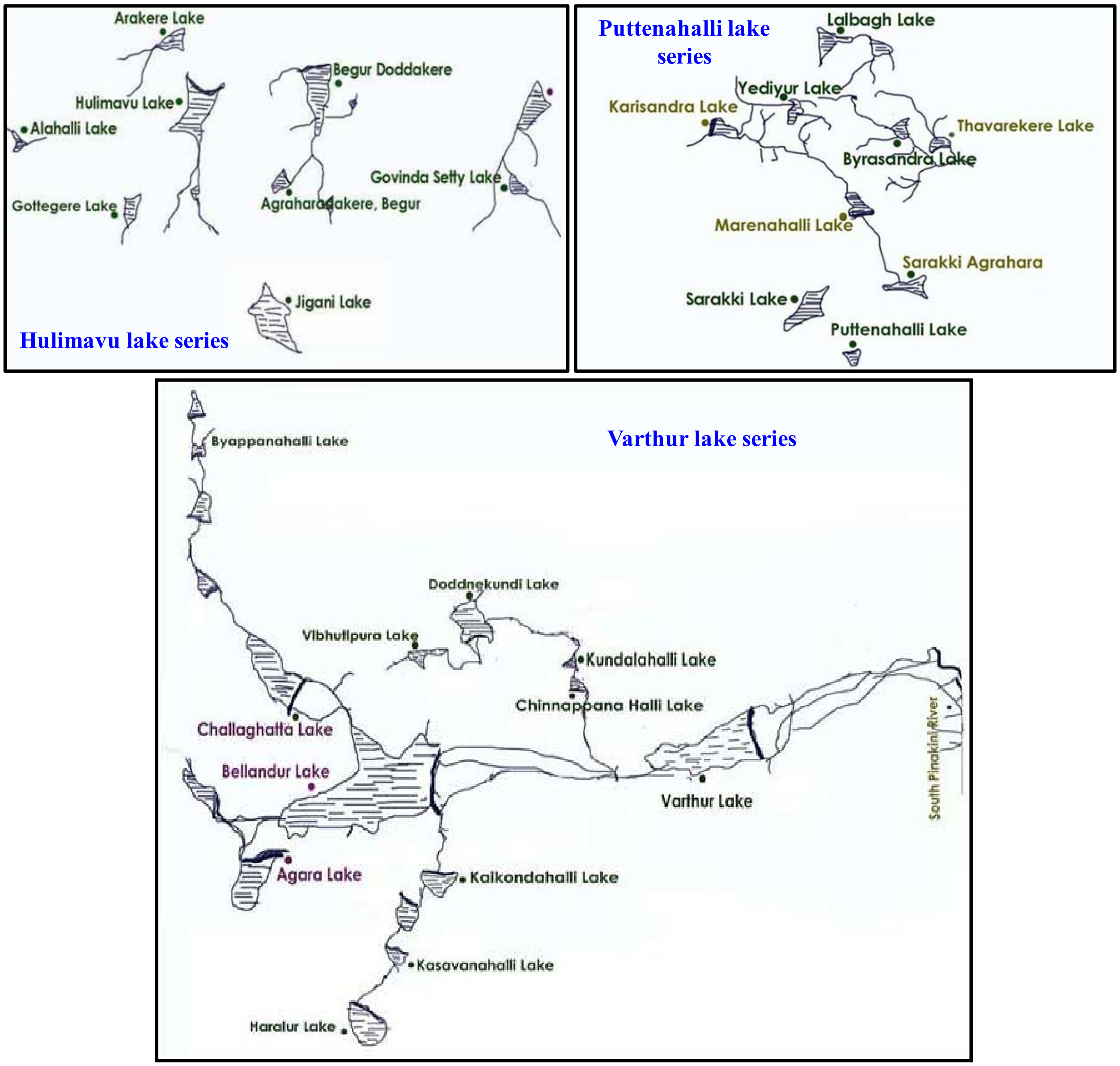


Figure 2.1: Lakes in Kormangala – Challaghatta Valley

(**Source:** http://parisaramahiti.kar.nic.in/vseries.html)

Varthur lake is the second largest lake in Bangalore. It is a part of a system of interconnected tanks and canals, i.e. three chain of lakes in the upstream joins Bellandur lake with a catchment area of about 148 square kilometres (14979 Hectares) and overflow of this lake gets into Varthur lake and from where it flows down the plateau and joins Pinakini river basin. Thus, Varthur lake receives all the surface runoff, wastewater and sewage from the Bangalore South taluk. The pollution levels had increased beyond the lake's assimilative capacity. Thus, nutrient enrichment and profuse growth of macrophytes and algae occurs, which leads to reduced oxygen levels and threats the aquatic life. A decline in ecosystem goods and services was also evident that affects economic growth and livelihood of local people. Thus, Varthur lake series has to be restored in order to maintain and improve the quality of life of local residents of the Varthur lake area.

The water quality analysis show that Varthur is heavily polluted/enriched with nutrients with high organic load, increased decomposition of organic matter, depletion of oxygen levels and macrophytes cover. The overgrowth of algae, bacteria and macrophytes had lowered nitrate level as it is required for their growth as well as reproduction, but orthophosphate levels were very high. The nutrients accumulated in Varthur lake due to sewage entry to the lake water daily (~500 million liters per day, MLD). Foam generated from Varthur lake (at Varthur Kodi junction) and spilled over to a road adjacent to the lake, causing hindrance to traffic movement and emanating a foul smell. It is normally sticky and white in colour. The physico-chemical characteristics of foam samples (collected from V2) of Varthur lake (Kodi junction) revealed that the foam had higher concentrations of ionic as well as organic components. Foams were enriched with particulate organic and inorganic compounds such as nutrients (Nitrogen, Phosphorus and Carbon) and cations (Sodium, Potassium, Calcium and Magnesium). These foams will cause an environmental problem. Varthur lake water has been contaminating groundwater sources. The nutrient enrichment in Varthur lake is evident from the overgrowth of macrophytes (85%) dominated mainly by *Eichhornia* sp., *Alternanthera* sp., *Typha* sp., and *Lemna* sp. The algae of Varthur lake was categorized mainly into four groups like Chlorophyceae, Bacillariophyceae, Cyanophyceae and Euglenophyceae.

This series receives about 500 MLD (million liters per day) of untreated and partially treated sewage daily. ***Sustained inflow of untreated sewage (due to BWSSB) and effluents (from industries) has contaminated the lake as the inflow of pollutants has surpassed the lake's assimilative capacity. Froth formation at outlets, profuse growth and spread of marcrophytes are all the indicators of nutrient enrichment. Nutrients in the form of N (nitrogen), carbon (C) and P (phosphorous) enters the lake through untreated sewage. Major part of N is up-taken by plants and algae while phosphorous and carbon gets trapped in sediments. Due to 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.***

Rejuvenation of Bellandur -Varthur lake involves:

1. De-silting: Due to sustained inflow of sewage and effluents, lake sediments are contaminated (with heavy metal, etc.). Needs de-silting and technological advancements allow wet dredging in a lake. Removal of accumulated silt will help in the storage of rain water and also recharging of ground water resources in the vicinity. This is essential as the groundwater table in the vicinity is as high as 1000-1500 feet.
2. Treatment of wastewater through constructed wetlands and algal ponds (similar to Jakkur lake). Constructed wetlands with shallow algal ponds helps in the removal of nutrients
3. Allowing only treated wastewater (sewage and effluents) to the lake.
4. Re-establishing interconnectivity among lakes. Removal of all encroachments (of storm water drains and Raja Kaluves). Encroachments of storm water drains has led to stagnation of water and flooding in Yamalur region.
5. Ban on alterations in the topography. Due to large scale land use changes and filling of low lying area, some of the new localities are now vulnerable to floods.
6. Removal of all encroachments in the lake bed. We need to show mercy to our next generation (not to land grabbers) and evict all types of encroachers.
7. Re-establishing wetlands at the inlets of these lakes. Bellandur lake on either side (inlet as well as at outlets) had large spatial extent wetlands, which have been and are being encroached by land mafia. These encroachments have to be evicted immediately to ensure the successful lake restoration and ensuring water security in the region.
8. Maintaining 30 m buffer around the lake (with regulated activities)
9. Stoppage of dumping of solid waste (and building debris in the lake bed and in the lake) and disposal of liquid waste by tankers.
10. Constituting lake conservation committee consisting of all stakeholders for regular monitoring and management.
11. Threshold on high raise building in the region. Need to protect valley zones considering ecological function and these regions are 'NO DEVELOPMENT ZONES' as per CDP 2005, 2015. No new projects in Bangalore unless carrying capacity assessment is done.
12. Rejuvenation is meaningful only when all interconnected lakes in the series are restored otherwise Bellandur and Varthur lake will continue to face contamination due to polluted lakes in the upstream.

INTRODUCTION

Wetlands constitute a transitional zone between terrestrial and aquatic habitats, which are influenced to varying degrees by both terrestrial and aquatic habitats. They differ widely in character due to regional and local differences in climate, soils, topography, hydrology, water chemistry, vegetation, and other factors (Ramachandra and Rajinikanth, 2005). Wetlands supports large biological diversity and provide a wide range of ecosystem services, such as food and fibre; waste assimilation; water purification; flood mitigation; erosion control; groundwater recharge; microclimate regulation; support many significant recreational, social and cultural activities, besides being a part of our cultural heritage (Ramachandra, 2012). Lakes have vanished due to adhoc approaches in planning leading to intense urbanization and urban sprawl. Some lakes are reduced to small pools of water, some are unauthorized encroached for illegal buildings, some have undergone unauthorised encroachment by slums and private parties, some have dried up and are leased out by the Government, many are sewage fed and are also used as dumping yards for either municipal solid waste or building debris (Ramachandra, 2010). Lack of proper management strategies will eventually lead to loss of lakes around Bangalore and depletion of ground water resources (Shivakumar, 2008). The failure to restore these ecosystems will result in extinction of species or ecosystem types and cause permanent ecological damage (Ramachandra, 2008).

Greater Bangalore (77°37'19.54'' E and 12°59'09.76'' N) is the principal administrative, cultural, commercial, industrial, and knowledge capital of the state of Karnataka with an area of 741 square kilometers and lies between the latitudes 12°39'00'' to 131°3'00''N and longitude 77°22'00'' to 77°52'00''E. Bangalore is located at an altitude of 920 metres above mean sea level, delineating three watersheds: Hebbal, Koramangala - Challaghatta and Vrishabhavathi watersheds. The undulating terrain in the region has facilitated creation of a large number of tanks for traditional uses such as irrigation, drinking, fishing, and washing (Ramachandra and Kumar, 2008). Bangalore has grown spatially more than ten times since 1949 (~69 square kilometers to 741) and is the fifth largest metropolis in India. The rapid urbanization process in Bangalore has led to the drastic changes in land use leading to imbalance in biological and social environment. There has been a % growth in built-up area during the last four decades with the decline of vegetation by 66% and water bodies by 74% (Ramachandra et al., 2012). The population has increased accounting for 45.68% growth in a decade. (Ramachandra et al., 2013).

Varthur lake is located in the south of Bangalore District in Karnataka. This lake is the second largest freshwater body in Bangalore built by the Ganga Kings over a thousand years ago for domestic and agricultural purposes. It covers a water-spread area of 190 ha (mean depth 1.1 m). It is a part of a system of interconnected tanks (figure 2.1, table 2.1) and canals that receive all the surface runoff, wastewater and sewage from the Bangalore South taluk and finally drains into the Dakshina Pinakini River (Mahapatra et al., 2011). The lake provides the local community with a pleasant microclimate and considerable aesthetic appeal. Varthur lake is surrounded by small farms that grow rice, ragi, coconut, flowers, and a variety of fruits and vegetables using the lake water (Ramachandra et al., 2006).

Lakes should maintain the physical, chemical and biological integrity for the survival, growth and reproduction of aquatic as well as riparian communities (Ramachandra, 2005). Most of the sewage and wastewater generated is discharged directly into storm water drains that are ultimately linked to water bodies which have contaminated the surface and ground waters. The deterioration and degradation of lake water quality occurs due to inflow of untreated sewage, dumping of domestic and municipal solid waste, silt and nutrient accumulation that allow profuse growth of algae and aquatic plants leading to depletion of aquatic biodiversity and other anthropogenic activities (like encroachments etc.). These activities in the lake would lead to the extinction or permanent ecological damages, so proper restoration measures and conservation strategies should be taken immediately

Pollution of aquatic ecosystems causes a decline in ecosystem goods and services that affects economic growth and livelihood of local people (Ramachandra et al., 2011). Rapid development and population expansion within Bangalore and its surrounding towns and villages, have polluted tanks and lakes in the area. . The sewage brings in large quantities of C, N and P that enables massive algal and macrophyte (water hyacinth, covering about 85% lake area) growth and malodour generation (Mahapatra et al., 2011).

Table 2.1: Lakes in Varthur series and their area (**Source:** http://parisaramahiti.kar.nic.in/vseries.html)

Sl. No.	Name of the Lake	Area (Hectares)
1	Byappanahalli Lake	3.23
2	Haralur Lake	5.16
3	Kasavanahalli Lake	8.91
4	Kaikondanahalli Lake	27.09
5	Doddanakundi Lake	47.08
6	Vibhuthipura Lake	30.20
7	Kundalahalli Lake	10.48
8	Chinnappanahalli Lake	56.80
9	Varthur Lake	180.40

Foam from Varthur lake has spilled over to a road adjacent to the lake, causing hindrance to traffic movement on the busy road and a foul smell was emanating from it at Varthur Kodi junction on 29/04/2015, in the morning. 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 biosurfactants. 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 (figure 2.2). 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 (Schilling and Zessner, 2011).

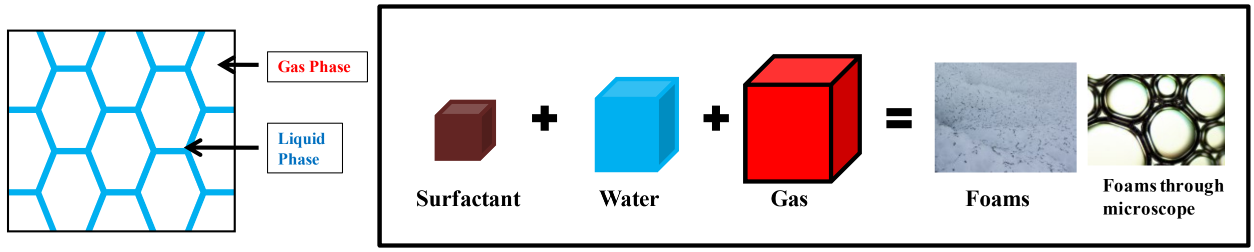


Figure 2.2: Structure and formation of foam in lakes

Foam accumulates compounds that are repelled by water (hydrophobic). Thus, foams are enriched with particulate organic and inorganic compounds such as nutrients (Nitrogen, Phosphorus, Carbon), cations (Sodium, Potassium, Calcium, Magnesium), heavy metals (Cadmium, Copper, Iron, Lead, Zinc) and chlorinated hydrocarbons. The organisms that inhabit the surface layer will be exposed to these contaminants and thus, affect the food web. These foams will cause an environmental problem, when it reaches drinking water supplies.

OBJECTIVE: The main objective of the study is to assess the present status of Varthur lake and to understand the causal factors of the foam emerging out of the lake and to suggest remedial measures for the protection of the lake.

MATERIALS AND METHODS

Study Area: Varthur lake (12°57 ′24.98″ to 12°56′31.24″ N, 77°43′03.02″ to 77°44′51.1″ E) is located in the Bangalore South taluk of the Bangalore District in Karnataka (figure 2.3). It covers a water-spread area of 190 ha and is the main irrigation source to the nearby agricultural fields and, supports a wide variety of flora and fauna. The average annual rainfall of Bangalore is 859 mm and temperatures vary from 14°C (December to January) to 33°C (maximum during March to May). There are two rainy periods, i.e. from June to September (south-west monsoon) and November to December (north-east monsoon).

Water Quality Analysis: The analysis of physico- chemical parameters like water temperature (WT); pH; total dissolved solids (TDS); electrical conductivity (EC); dissolved oxygen (DO); chemical oxygen demand (COD); total alkalinity (TA); chloride (Cl); total hardness (TH); calcium hardness (CaH); magnesium hardness (MgH); nitrate; orthophosphate (OP); sodium (Na) and potassium (K) of water and foam samples collected from Varthur lake were done according to the standard protocol (table 2.2; figure 2.4) as per APHA AWWA WEF (1998) and Trivedy Goel (1986).

Figure 2.3: Google Earth image of Varthur lake

Table 2.2: Standard methods followed for water quality analysis

Parameters	Methods (with Reference)
Onsite Measurements	
Water temperature (^{0}C)	Eutech: PCSTestr 35
pH	Eutech: PCSTestr 35
Total Dissolved Solids (TDS, mg/l)	Eutech: PCSTestr 35
Electrical conductivity (µS/cm)	Eutech: PCSTestr 35
Dissolved Oxygen (DO) (mg/l)	Winkler's Method (APHA, 1998: 4500-O)
Laboratory Measurements	
Hardness (mg/l)	EDTA titrimetric method (APHA, 1998: 2340-C)
Calcium hardness (mg/l)	EDTA titrimetric method (APHA, 1998: 3500-Ca B)
Magnesium hardness (mg/l)	Magnesium by calculation (APHA, 1998:3500-Mg)
Sodium (mg/l)	Flame emission photometric method (APHA, 1998:3500-Na B)
Potassium (mg/l)	Flame emission photometric method (APHA, 1998: 3500-K B)
Alkalinity (mg/l)	Titrimetric method (APHA, 1998: 2320 B)
Chloride (mg/l)	Argentometric method (APHA, 1998:4500-Cl^- B)
Biochemical Oxygen Demand (BOD) (mg/l)	5-Day BOD test (APHA, 5210 B, Trivedi&Goel, 1986, pp.53-55)
Chemical Oxygen Demand (COD) (mg/l)	Closed reflux, titrimetric method (APHA, 5220 C, Trivedi&Goel, 1986, pp.55-57)
Nitrates	Phenol Disulphonic acid method (Trivedy and Goel, 1986: pp 61)
Orthophosphates (mg/l)	Stannous chloride method (APHA, 4500-P)

Figure 2.4: Collection of water and foam from Varthur South (V1) and North (V2) outlets.

RESULTS AND DISCUSSIONS

The physico-chemical parameters of water (collected from V1 and V2) and foam samples (from V2) of Varthur lake (table 2.3) revealed that the foam had higher concentrations of all the parameters compared to that of water. Thus, foams are enriched with particulate organic and inorganic compounds such as nutrients (Nitrogen, Phosphorus and Carbon), cations (Sodium, Potassium, Calcium and Magnesium). Foam generated is normally sticky and white in color. Most surfactants originate from the detergents, oil and grease that are used in households or industry. Surfactant could stabilize the foaming and allow foam to accumulate. The organisms living at the surface layer of lake will be exposed to these contaminants and thus, these contaminants enter the food chain/web. These foams will cause an environmental problem. The use of Varthur lake water for domestic and irrigational purposes will be harmful and this is likely to contaminate groundwater.

Table 2.3: Physico-chemical parameters of water and foam samples from Varthur lake (01/05/2015)

Parameters	V1	V2	Foam
Water temperature (^{0}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

REVIEW OF VARTHUR LAKE WATER QUALITY (from 2001 – 2015)

The physico-chemical characteristics of Varthur lake from 2001 to 2015 (table 2.4, 2.5; figure 2.5) revealed that Varthur lake had received higher amounts of nutrients and ionic components over years. 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 as per CPCB standards (table 2.6).

Table 2.4: Physico-chemical parameters of Varthur lake at South outlet (V1)

	2015	2014	2013	2013	2009	2008	2002	2001	2001
WT (^{0}C)	27.1	32	24	24.4	30	26.3	22	26	23
TDS (mg/l)	448	596	500	532	749	840	1204	335	358
EC (µS)	749	1027	1030	1084	1075	1057	1470	460	474
pH	7.46	7.57	7.5	7.2	7.5	8.06	-	8	-
DO (mg/l)	2.6	0.24	0	0	8.16	0.81	2.2	2.8	5.5
COD (mg/l)	40	69.29	168	44	124	229.33	-	-	-
TA (mg/l)	336	520	317.33	377.33	400	300	-	-	348
Chloride (mg/l)	117.86	176.79	132.06	142	173.24	88.04	170	-	96
TH (mg/l)	206	253	198	210	236	420	251.1	383.7	218.4
Ca H (mg/l)	57.72	158.15	62.52	70.01	128	344.27	-	-	-
Mg H (mg/l)	36.03	23.05	32.92	34.02	26.24	102.4	-	-	-
OP (mg/l)	1.263	0.527	0.084	0.664	4.22	1.8	15.06	-	1
Nitrate (mg/l)	0.541	0.112	0.466	0.487	0.47	0.04	1.3	0.21	0.3
Na (mg/l)	169.5	178	41.2	208	174	23.2	-	1046	18.9
K (mg/l)	35	35.6	5.6	43.6	19	4.3	1.8	115	21.4
BOD (mg/l)	24.39	-	-	-	119.5	40.78	74.2	-	-

Note: 2013 – twice sampling was done

Table 2.5: Physico-chemical parameters of Varthur lake at North outlet (V2)

	2015	2013	2013	2011	2010	2010	2010	2010	2009	2008	2003	2003	2003	2002	2001	2001
WT (^{0}C)	26.9	24.4	25	-	29.5	27.5	26.5	26	26	25.6	27	27	23	23	27	26
TDS (mg/l)	454	489	532	-	636	700	-	-	849	849	-	-	-	1246	332	371
EC (µS)	764	1014	1075	1054	798	890	-	-	1224	1068	460	474	1420	1420	460	474
pH	7.35	7.7	7.2	7.61	7.84	7.58	8	8	7.5	9.03	7.61	7.55	7.68	-	7.75	-
DO (mg/l)	0	0	0	1.56	4.07	7.15	1.63	4.06	0	4.22	2	3	2.9	2.9	2	3
COD (mg/l)	88	184	52	98.2	192	298.67	-	234.66	188	325.33	-	-	82.2	-	-	-
TA (mg/l)	336	308	372	-	260	56	-	120	420	420	-	-	-	-	-	332
Cl (mg/l)	122.12	130.64	142	-	119.28	142	-	142	191.7	144.84	-	100	170	170	-	100
TH (mg/l)	224	198	214	-	264	236	292	420	288	436	213.6	209.3	232.5	232.5	213.6	209.3
Ca H (mg/l)	64.13	56.11	70.01	-	132	112	200	188.17	135	176.14	132	124	158.1	-	-	-
Mg H (mg/l)	38.85	34.48	34.99	-	85.39	124	92	48.76	37.18	106.38	19.83	20.73	18.08	-	-	-
OP (mg/l)	0.881	0.18	0.596	0.98	0.05	1.73	4.175	0.718	5	1.7	-	1	15.54	1.5	-	1
Nitrate (mg/l)	0.361	0.418	0.364	0.3	0.03	0.28	0.162	0.24	0.55	0.04	-	-	-	1.4	-	1.07
Na (mg/l)	161	48	202	-	34.6	31.5	-	18.93	180	19.4	-	-	-	9	907	32.8
K (mg/l)	34	12	43.2	-	6.7	6.3	0	0	19	3.5	-	-	-	2.2	130	20.2
BOD (mg/l)	60.98	-	-	89.7	46.28	55.28	44.7	-	140.8	41.68	-	-	74.2	74.2	-	-

Note: 2013 and 2001 – twice sampling was done, quarterly sampling in 2010 and 2003

Higher values of chemical parameters in Varthur lake is due to the sustained inflow of untreated daily (~500 million liters per day, MLD). The BOD and COD values reflected high pollution at Varthur with heavy organic load, decomposition of organic matter, depletion of oxygen levels and macrophytes cover. Water temperature (22-32°C) showed seasonal variations, while pH was found to be alkaline (7.2- 9.03). The nutrient like nitrate (0.03-1.4 mg/l) was lower in the system due to the uptake of nutrients by algae, bacteria and macrophytes for growth as well as reproduction. The orthophosphate (0.05-15.54 mg/l) levels were high.

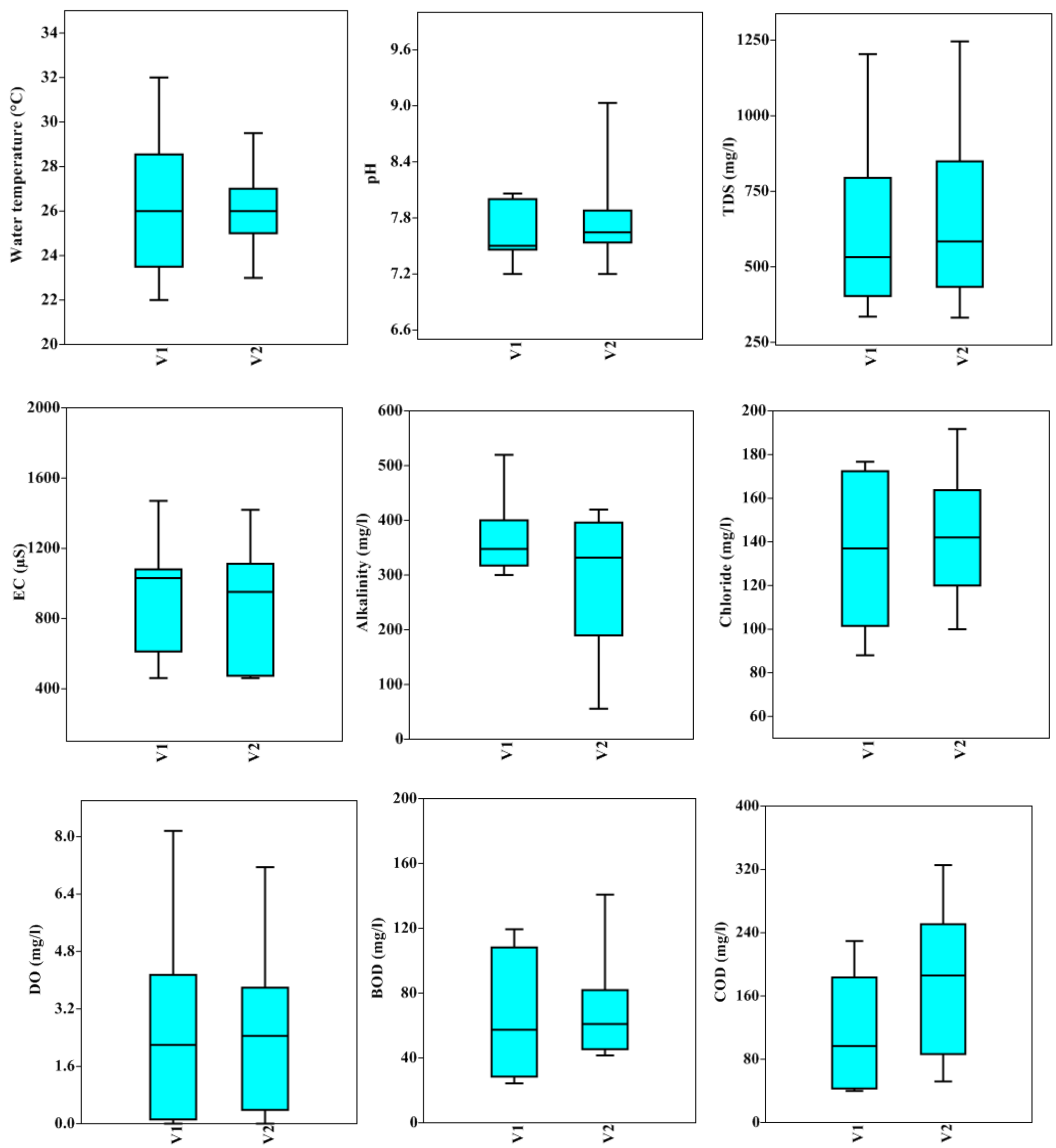
Table 2.6: Classification of Inland Surface Water (CPCB)

As per ISI-IS: 2296-1982	
Classification	**Type of use**
Class A	Drinking water source without conventional treatment but after disinfection
Class B	Outdoor bathing
Class C	Drinking water source with conventional treatment followed by disinfection.
Class D	Fish culture and wild life propagation
Class E	Irrigation, industrial cooling or controlled waste disposal

Characteristic	**A**	**B**	**C**	**D**	**E**
pH	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.0 - 8.5
DO (mg/L)	6	5	4	4	-
BOD (mg/L)	2	3	3	-	-
TDS, mg/l, Max	500	-	1500	-	2100
Electrical Conductance at 25 °C, µS, Max	-	-	-	1000	2250
Total Hardness (as $CaCO_3$), mg/l, Max	300	-	-	-	-
Calcium Hardness (as $CaCO_3$), mg/l, Max	200	-	-	-	-
Magnesium Hardness (as $CaCO_3$), mg/l, Max	100	-	-	-	-
Chlorides (as Cl), mg/l, Max	250	-	600	-	600
Nitrates (as NO_2), mg/1, Max	20	-	50	-	-

The continuous entry of sewage water and rainwater runoff to Varthur lake had reduced the depth of the lake (due to sedimentation with silt transport from the catchment due to large scale construction activities), reduction of ground water recharge (sedimentation has formed semi-paved surface, reducing the groundwater recharge potential) and contamination of ground water (due to sustained inflow of untreated sewage from household and untreated effluents from industries). The solid waste dumping and discharge of municipal wastewater had caused nutrient enrichment in Varthur lake, which is evident from the overgrowth of macrophytes (85%)

dominated mainly by *Eichhornia* sp., *Alternanthera* sp., *Typha* sp., and *Lemna* sp. The algae of Varthur lake was categorized mainly into 4 groups: Chlorophyceae (*Chlamydomonas* sp., *Chlorogonium* sp., *Scenedesmus* sp., *Ankistrodesmus* sp., *Chlorella* sp., *Oedogonium* sp.); Cyanophyceae (*Cylindrospermopsis* sp., *Arthrospira* sp., *Microcystis* sp., *Oscillatoria* sp., *Anabaena* sp., *Merismopedia* sp., *Lyngbya* sp.); Bacillariophyceae (*Gomphonema* sp., *Cymbella* sp., *Navicula* sp., *Pinnularia* sp., *Nitzschia* sp., *Synedra* sp., *Fragilaria* sp., *Cocconeis* sp., *Melosira* sp.); Euglenophyceae (*Phacus* sp., *Euglena* sp., *Trachelomonas* sp., *Lepocinclis* sp.).



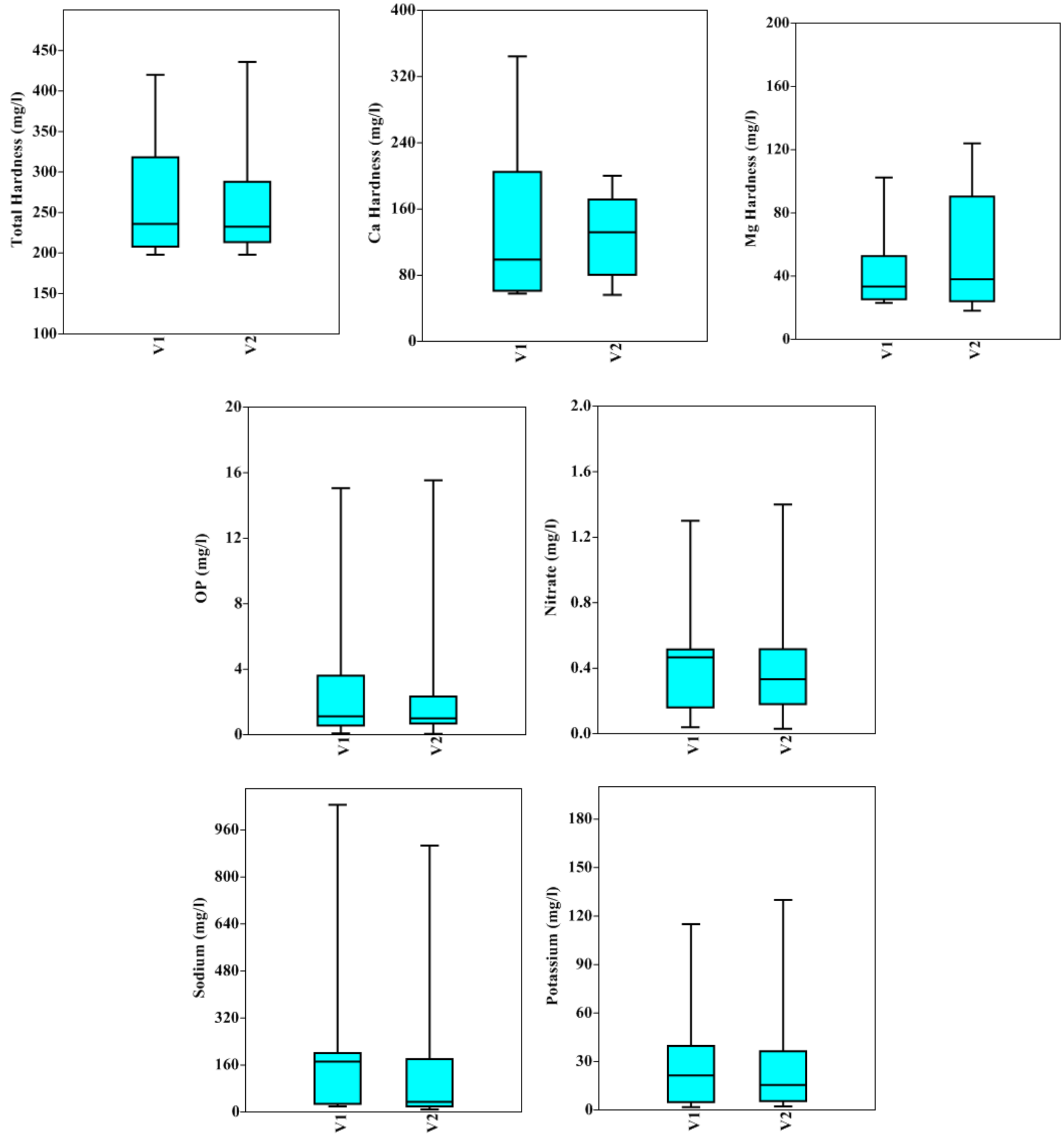


Figure 2.5: Temporal variation of physico-chemical parameters in Varthur lake water samples (2001 to 2015).

WATER QUALITY AND PHYTOPLANKTON STUDIES ON VARTHUR LAKE

Table 2.7: Water quality studies on Varthur lake (2001 – 2013)

Influence of Catchment Land Cover Dynamics on the Physical, Chemical and Biological Integrity of Wetlands LULC changes in the wetland catchment that alters the physical and chemical integrity of the system are the direct and indirect consequence of anthropogenic activities leading to loss of biodiversity, water and soil pollution and climatic changes. Varthur wetland with high percent of built-up and being densely populated is in stressed condition with high pollution due to inflow of sewage and industrial wastes. During the study, hypoxic and even anoxic condition prevailed due to low dissolved oxygen levels that attributed to the presence of water hyacinth covering the water surface, with heavy domestic organic load and decomposition of organic matter. Thus, the concentration of both BOD and COD exceeded the permissible limits at all sampling sites and across months. Total hardness (236-420 mg/l), alkalinity (55-440 mg/l) and chlorides (119.28-153.36 mg/l) were recorded very high due to sewage inflow. Thus, the plans for conservation of wetlands should be done at catchment scale. Diatom community comprised of pollution tolerant species reflecting trophic status. Pollution tolerant diatoms dominated the wetlands with eutrophic water quality condition. The species such as *Gomphonema parvulum, Cyclotella meneghiniana, Nitzschia palea* and *Nitzschia umbonata* are tolerant to high electrolyte and organic rich condition inhabited Varthur wetland. This clearly signifies that the wetland is polluted and eutrophic in condition. Thus, catchment characteristics are critical in determining biota of freshwater bodies, thus plans for conservation of wetlands should also be seen at catchment scale, rather than looking wetlands as isolated ecosystem. **Recommendation**: The restoration and conservation measures should be taken based on the LULC changes in the catchment area of wetlands. **Reference**: Ramachandra T.V, Meera D.S. and Alakananda B., 2013, Influence of Catchment Land Cover Dynamics on the Physical, Chemical and Biological Integrity of Wetlands, *Environment & We -International Journal of Science & Technology - (EWIJST)*, 8(1): 37-54.	**2013**
Biomonitoring to Assess the Efficacy of Restoration and Management of Urban Water Bodies The Varthur lake categorized under polluted wetlands was characterized by high ionic contents with high EC (1245.5 µS), BOD (34.27 mg/l) and COD (81.3 mg/l) but low DO levels (2.96 mg/l), indicating the presence of high organic matter. Varthur lake had about 91.7% of eutrophic algal species with a Shannon diversity of 1.28 and Dominance index of 0.37. The abundance of *Cyclotella meneghiniana*, *Nitzschia palea*, *Fallacia pygmaea* and *Staurosirella pinnata* were evident. **Reference**: Alakananda B., Mahesh M.K and Ramachandra T.V., 2013, Biomonitoring to assess the efficacy of restoration and management of urban water bodies, *International Journal of Environmental Sciences*, Vol 2 (3), pp: 165-178.	**2013**

Role of Macrophytes in a Sewage Fed Urban Lake Macrophytes help in maintaining the nutrient levels in urban lakes. The analysis of seasonal data of Varthur lake reveals that dissolved oxygen concentration and redox condition is dependent on the extent of macrophyte spread. The increase in nutrient content (32 t N/d) due to sustained inflow of sewage has resulted in the prolific growth of invasive species like water hyacinth (*Eichhornia crassipes*). This hinders aerobic functioning of the lake by restricting sunlight penetration and hence, reducing algal photosynthesis. This in turn, results in anoxic environment due to blockage of air-water interface, influencing oxygen diffusion. The roots of these floating macrophytes provide a good substratum for the attachment of bacteria, increasing bacterial activity in the system that leads to reduced DO levels. The increased amount of plant litter decomposition also contributes to higher autochthonous organic load and hence higher BOD levels. In Varthur lake (with 85% macrophytes cover), highly anaerobic conditions (-235 mV), low DO level (0 mg/l) and high BOD load (180 mg/l) persisted during summer. Varthur lake behaves as an aerobic lagoon in monsoon, aerobic-anaerobic lagoon in pre-monsoon and as anaerobic–aerobic system in post-monsoon. The overgrowth, ageing, and subsequent decay of macrophytes creates anoxic conditions and devours the lake from oxygen, which in turn, affects the food chain and interferes with the ecological integrity of the system. This necessitates the regular removal of macrophytes from the lake, which allows the growth of primary producers and other aquatic organisms. **Recommendation**: Regular removal of macrophytes from the lake. **Reference**: Durga Madhab Mahapatra, Chanakya H.N., Ramachandra. T.V., 2011, Role of macrophytes in a sewage fed urban lake. *Institute of Integrative Omics and Applied Biotechnology Journal (IIOABJ)*, Vol. 2, Issue 8, pp. 1-9.	**2011**
Ecological and Socio-Economic Assessment of Varthur Wetland, Bengaluru (India) The socio-economic survey and water quality analysis showed a decline of ecosystem goods and services with the decline in water quality affecting the livelihood of dependent population and local economy. Varthur had a total economic value of only Rs 118.9/ha/d, which is lower than unpolluted lakes. The main effects of pollutants entering Varthur lake are disappearance of native species, dominance of invasive exotic species (African catfish), in addition to profuse breeding of disease vectors and pathogens. This necessitates the implementation of sustainable management strategies to recover the lost wetland benefits or to enhance the use-value of Varthur lake. The strategies include restoration of wetlands, letting of treated sewage into the wetlands, letting treated water through series of wetlands for further improvement of water quality, removal of excess growth of macrophytes and exotic fish species, regular monitoring of wetlands, public awareness and enhanced co-operation among government agencies. Also, water treatment plant for Varthur wetland will improve the water quality and the massive sludge can be used for agricultural fields as fertilizers.	**2011**

Reference: Ramachandra T. V., Alakananda B, Ali Rani and Khan M. A, 2011, Ecological and socio-economic assessment of Varthur wetland, Bengaluru (India), *Journal of Environment Science & Engineering*, Vol 53. No 1. p 101-108, January 2011.	
C:N Ratio of Sediments in a Sewage Fed Urban Lake The analysis of C:N ratio of surficial sediments collected from Varthur lake was done as the sludge/sediments act as a major sink for C and N. The C and N values were found to be significantly higher in the deeper areas than the shallow inlet regions due to the accumulation of autochthonous organic material. About 60% of the nutrients were terrestrial in origin. The quantity of C and N stored on the sediments in a daily basis was large which accounts to 9 t C and 2.9 t N. The north side of the lake had higher C content compared to the other regions, which attributed to higher anthropogenic effects and terrestrial C sources like sewage from the urbanized pocket. A lower C value in the southern side is attributable to suburb type habitations with more agricultural fields in the immediate vicinity. The lake has a higher organic matter at the centre and near the outlets, due to rapid decay and settling of the autochthonous organic matter. The N content was very low (below 5% of the dry wt.) in the sediment/sludge sample of Varthur lake, indicating an N deficient system. The N limitation is due to uptake by micro and macro-biota or rapid volatilization, denitrification and leaching in water. The organic N in the sediments will be transformed to various inorganic forms as nitrites, ammonia, nitrous oxide or molecular nitrogen. The source of organic matter (OM) in sediments of Varthur lake is essentially autochthonous macrophytes near the outlets and terrestrial N near the inlet zones, whereas the middle part OM is phycogenic in origin. The C/N ratios indicate that run-off water from the catchment can increase the terrestrial OM component. This lake surrounded by agricultural and horticultural lands (67%) can increase OM content. Therefore, proper wastewater management strategies have to be taken to minimize sewage inflow and prevent agricultural run-off into the lake systems. **Reference**: Durga Madhab Mahapatra, Chanakya H. N. and T. V. Ramachandra, 2011, C:N ratio of Sediments in a sewage fed Urban Lake. *International Journal of Geology*, Issue 3, Vol. 5, pp. 86 - 92.	**2011**
Assessment of Treatment Capabilities of Varthur Lake, Bangalore, India This study includes the physico-chemical and biological analysis of sewage-fed Varthur lake and assessment of its treatment capabilities in terms of BOD removal, nutrient assimilation and self-remediation. Varthur lake with an average water depth of 1.1m, water spread area of 220 ha, and receiving about 500 MLD of wastewater per day has a water retention time of 4.84d. Anaerobic conditions (0 mg/L) prevailed at the inlet but at the middle and outlets DO were higher due to algal photosynthetic activities. About >50% BOD removal was achieved in the monsoon season but the extensive coverage of macrophytes during February - May lowered the organic decomposition, and BOD removal. Alkalinity, TDS, conductivity and hardness values were higher than earlier studies due to continuous influx of untreated sewage.	**2011**

The lake behaved as an anaerobic - aerobic lagoon. The primary producers (phytoplankton) treated the water to nearly standard water quality levels. The macrophytes and the algae together with wetland vegetation have an important role in regulating the amount of nutrients. The role of macrophytes and phytoplankton in removing nutrients in sewage-enriched systems varies with the nature of the effluent and age of the wetland, in addition to other environmental factors like sunlight. **Reference**: Mahapatra, D.M., Chanakya, H.N. and Ramachandra, T.V. 2011, Assessment of Treatment capabilities of Varthur Lake, Bangalore, India. *International Journal of Environment, Technology and Management*, Vol. 14, Nos. 1/2/3/4, pp. 84-102.	
Biofuel Prospects of Microalgal Community in Urban Wetlands Varthur lake showed moderate water quality. The class Bacillariophyta (diatoms) and Chlorophyta dominated at Varthur lake as well as agricultural sample with *Achnanthidium* sp., *Gomphonema* sp., *Nitzschia* sp., *Navicula* sp., *Chlamydomonas* sp., *Scenedesmus* sp. and *Anabaena* sp. accounting more in number (occurrence number in microscopic field). The Varthur lake and agriculture field samples had diatoms that are lipid-rich were suggested as an important source for biodiesel. **Reference**: Ramachandra, T.V., Alakananda, B. and Supriya G., 2011, Biofuel prospects of microalgal community in urban wetlands. *International Journal of Environmental Protection (IJEP)*, Vol.1 No. 2, PP.54-61.	**2011**
Algal Photosynthetic Dynamics in Urban Lakes Under Stress Conditions Varthur lake is undergoing a high nutrient stress resulting in anaerobic conditions with prolonged sewage inflow. Thus, deprivation of oxygen (hypoxic conditions at the inflow region and 4.22 mg/l at the outlets of Varthur lake) is an indicator of the present trophic status of the lake, which is rich in inorganic and organic matter making the conditions increasingly eutrophied. The biochemical oxygen demand levels in Varthur lake (BOD level: 40.78 - 99.95 mg/l) indicate higher levels of biodegradable organic matter, high oxygen consumption by heterotrophic organisms and a high rate of organic matter remineralization. The phosphate content in Varthur lake (1.3-2.1 mg/l) was well beyond the eutrophic levels due the inflow of sewage, sediment resuspension during high turbulence period, anaerobic conditions at the lake bottom and agricultural runoff from the cultivated lands nearby. The nitrate content in Varthur (0.03 – 0.05 mg/l) was very low due to the growth of aquatic weeds, persistence of anaerobic conditions and scant oxidation. The Day net productivity values indicates lower productivities in Varthur lake which can be attributed to decreased transparency and hence, lesser sunlight penetration due to microalgal bloom (*Chlorella* sp.). The productivity of the lake directly linked to the type and the abundance of the algal community. In Varthur lake, the algal community dominated by *Chlorella* sp. (member of Chlorophyceae) that comprised of *C. vulgaris*, *C. pyrenoidosa* and *C.minutissima*, followed by members of Bacillariophyceae (18%) as *Nitzschia palea* and *Gomphonema parvulum. Microcystis aeruginosa* (Cyanophyceae) occured in minor proportions (1%). The abundance of Chlorophyceae and Cyanophyceae	**2010**

members in Varthur lake is an indicator of organic pollution and nutrient accumulation. The turbidity values shows very high algal abundance in Varthur lake, which is attributing to algal bloom, coincides with the high inorganic nutrients and high BOD values. Chlorophyceae growth depends upon the nutrient load and is an indicator of trophic status of the lake. **Reference**: Durga Madhab Mahapatra, Supriya Guruprasad, Chanakya H. N. and Ramachandra T. V., 2010, Algal Photosynthetic Dynamics in Urban Lakes under Stress Conditions. Proceedings of the Conference on Infrastructure, Sustainable Transportation and Urban Planning CiSTUP@CiSTUP 2010, 18th - 20th October 2010, C*i*STUP, IISc, Bangalore.	
Status of Varthur Lake: Opportunities for Restoration and Sustainable Management This study focuses on restoration aspects of Varthur lake based on hydrological, morphometric, physical-chemical and socio-economic aspects. The results of the water quality analysis showed that the lake is eutrophic with high concentrations of phosphorous and organic matter. The results of the morphometric analysis reveal that Varthur is a shallow lake, with a very large surface area in relation to its depth. The total area of the lake was estimated 1,478,000 m^2. The bathymetric map of Varthur lake shows that the lake has an estimated maximum depth of approximately 2.0 meters with the mean depth of 1.05 m. The lake bottom exhibits a very gradual downward slope from west to east, with maximum observed depth occurring near the dam wall. The presence of bacterium *Escherichia coli* in Varthur indicates faecal contamination. The water quality analysis of groundwater revealed that the parameters (ammonia, chloride, electrical conductivity, fluoride, nitrate, and pH) were within the limits set by Indian Standards Specification for Drinking Water. The lake water has not contaminated the groundwater in the vicinity. The socio-economic aspects of Varthur lake showed that local residents relied heavily on the lake for cattle fodder and irrigation. The total land area irrigated using Varthur lake water was 622.27 hectares and the total number of farmers dependent on the lake water for irrigational purposes was1159. The crops grown in Varthur village include paddy, coconut, banana, beetle leaf, arecanut and floriculture. Thus, the lake has to be restored in order to maintain and improve the quality of life of local residents of the Varthur lake area. **Recommendations:** Pollution impediment, harvesting of macrophytes, desiltation, rain water harvesting, watershed management and the adoption of restoration programmes with an ecosystem approach through Best Management Practices (BMPs) which will help in correcting point and non-point sources of pollution. **Reference**: Ramachandra T .V., Ahalya N. and Payne, M., 2006, Status of Varthur Lake: Opportunities for Restoration and Sustainable Management. Technical Report: 102, Centre for Ecological Sciences, Bangalore.	**2003**
Conservation of Bellandur Wetlands: Obligation of Decision Makers to Ensure Intergenerational Equity The Mixed Use Development Project - SEZ is proposed by Karnataka	**2013**

Industrial Areas Development Board (KIADB) along Sarjapur Road in a wetland between Bellandur and Agara Lake, with an area of 33 hectare. The proposal of the project is to construct residential areas, offices, and retail and hotel buildings in this area, which is contrary to sustainable development as the natural resources (lakes, wetlands) will be affected. This violates Hon'ble High Court of Karnataka's verdict to protect, conserve, rehabilitate and wisely use lakes and their watersheds in Bangalore, all lakes in Karnataka and their canal networks, and also violates CDP 2015 as the valley zone is supposed to be protected as the region is "No Development Zone". The SEZ will affect the ecological functioning, enhances flooding in the vicinity (due to encroachment of drains/rajakaluves; alterations in topography; encroachment of lakebed and encroachment of lake itself by dumping debris and land filling), traffic congestion due to additional vehicle movement (SEZ has a capacity of over 14000 Car units); enhances levels of vehicular pollutants that causes health problems (increase in respiratory diseases) and brings shortage in drinking water in Bangalore (SEZ requires 4587 Kilo Liters per day (4.58 MLD – Million liters per day)). **Reference:** Ramachandra, T. V., Aithal, B. H., Vinay, S., and Lone, A. A., Conservation of Bellandur wetlands: Obligation of decision makers to ensure intergenerational equity. ENVIS Technical Report: 55, Environmental Information System, Centre for Ecological Sciences, Bangalore, 2013.	

DISCUSSIONS: The major problems faced by Varthur lake (table 2.8) are (i) encroachment, (ii) sustained inflow of untreated sewage and industrial effluents and (iii) dumping of municipal solid wastes and building debris and (iv) irresponsible para-state agencies (with fragmented governance) – KLCDA, BDA, BBMP, BWSSB…..

Table 2.8: Threats to lakes and its effects

Sl.No	Problems faced by lakes	Effects on lakes
1.	Discharge of untreated domestic sewage and industrial effluents	▪ Degradation of water quality ▪ Odour problems ▪ Dissolved oxygen depletion ▪ Nutrient accumulation ▪ Heavy metal contamination ▪ Over growth of algae and aquatic macrophytes ▪ Accumulation of silt and organic matter ▪ Reduction in depth of lake ▪ Contamination of ground water. ▪ Loss of aesthetic value
2.	Encroachment of lake and construction activities in the lake catchment	▪ Reduction of catchment area of lakes ▪ Reduction of ground water table as water recharge capacity goes down

		▪ Increased discharge of domestic sewage ▪ Generation of building debris and solid wastes ▪ Soil erosion, sedminentation ▪ Cutting down of trees in that location ▪ Affects fauna population ▪ Loss of interconnectivity among lakes
3.	Land use change	▪ Reduction of catchment area ▪ Affected the hydrological regime ▪ Affected micro climatic conditions
4.	Unplanned urbanization	▪ Loss of wetlands and green spaces ▪ Increased frequency of floods ▪ Decline in groundwater table ▪ Heat island ▪ Increased carbon footprint
5.	Threat to ecological balance	▪ Aquatic biodiversity is affected (fish, birds, flora and fauna that are dependent on lake system)
6.	Decline of Ecosystem goods and services	▪ Affects economic growth and livelihood of local people
7.	Removal of shoreline riparian vegetation	▪ Causes soil erosion ▪ Effests the habitat of aquatic organisms
8.	Dumping of municipal solid waste and building debris	▪ Affects human health ▪ Breeding of disease vectors and pathogens

SOLUTIONS:

1) Mapping of water body (identification of flood plain and buffer zone)
2) Remove encroachments near to lakes after surveying the lake area
3) Apply 'polluter pays principle' in true spirit - Restrict the entry of untreated sewage into lakes
4) Let only treated sewage through constructed wetlands and shallow algae pond into the lake (as in Jakkur lake)
5) Regular maintenance of floating macrophytes
6) Planting of native species of macrophytes in open spaces of lake catchment area (for retaining water in the lake)
7) Avoid dumping of solid wastes into lakes
8) Ensure proper fencing of lakes
9) Lake area cannot be diverted for any other purpose
10) Make local residents environmentally literate

SUGGESTIONS

Table 2.9: Suggestions to be implemented in lakes

Desilting of lakes	Silt has accumulated during last 50 years and with sustained inflow of sewage, the accumulated silt had contaminated which has to be removed on priority. Lake has become a shallow lake with a maximum depth of 2m. Desilting of the lake was done by local people in mid 70's. Removal of silt also helps in ground water recharge in the region as the accumulated silt in the lake over a period has become non-permeable, which had prevented the vertical and lateral flow of water. Bangalore is facing a severe water crisis and removal of silt will help in harvesting of rain water efficiently.
Letting only treated sewage into lake	Model similar to Jakkur lake with constructed wetland and algal pond will help in removal of nutrients **(Annexure 11).**
Restoration and treatment of lake in the entire basin	Varthur lake, being located in the downstream of Agaram and Madivala lake series, will get rejuvenated only when the connected and interconnected lakes are restored and treated in similar way.
Protection of riparian and buffer zone vegetation	Any clearances of riparian vegetation and buffer zone vegetation (around lakes) have to be prohibited.
Management of polluted lakes	• The highly polluted lakes should be fenced off to prevent fishing, cattle grazing, washing, bathing and collection of edible or medicinal plants to prevent health hazards • Warning boards should be displayed around water bodies • Implementation of bioremediation method for detoxification of polluted water bodies • Based on the concept of **polluter pays,** a mechanism be evolved to set up efficient effluent treatment plants [ETP], individual or collective, to reduce the pollution load
Environment Education	• Public education and outreach should include all components of aquatic ecosystem restoration, management and conservation • Lake associations and citizen monitoring groups have proved helpful in educating the general public • Environmental education program should be more proactive, field oriented and experimental (with real time examples) for effective learning • Environmental education should be made mandatory at all levels – schools, colleges, universities, professional courses, teachers and teacher educators at the teachers' training institutes (Tch, B Ed, D Ed)

The important recommendations suggested through Lakshman Rau committee report, emphasizing the preservation and restoration of existing tanks in Bangalore in 1988 are applicable for Varthur lake also.

This includes:

- Efforts should be made to ensure that these tanks are not polluted by discharge of wastes.
- Off shore development by large scale planting of trees and also removal of encroachments to prevent silting
- Existing tanks should be deweeded and aquatic life must be developed
- The Bangalore Development Authority / Bangalore City Corporation / Minor Irrigation Department must remove encroachments in the tank areas
- The Forest Department, Bangalore Development Authority, Bruhat Bengaluru Mahanagara Palike, Minor Irrigation Department, Bangalore Water Supply and Sewerage Board, and Town Planning Department should play an active role in the implementation of recommendations and these recommendations should be reviewed periodically
- Mosquito control measures are to be entrusted to BBMP or any other suitable agency
- The responsibility of maintenance of water bodies in a clean and safe condition should be with Bangalore Water Supply and Sewerage Board

The aquatic conservation strategy (Ramachandra et al., 2005) focuses on conservation and maintainence of ecological health of aquatic ecosystems so as to maintain the aquatic biodiversity in the region, maintain 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 waterbodies involving students at school, college and research institutions, and also public awareness will help in developing appropriate conservation and management strategies.

REFERENCES

1. Alakananda, B., Mahesh, M. K., and Ramachandra, T. V., 2013, Biomonitoring to assess the efficacy of restoration and management of urban water bodies. *International Journal of Environmental Sciences*, Vol 2(3), pp: 165-178.
2. APHA, Standard Methods (20 Ed.) for the examination of water and waste water, APHA, AWWA, WPCE, Washington DC, 1998.
3. Mahapatra, D. M., Chanakya, H. N., and Ramachandra, T. V., 2011, C:N ratio of sediments in a sewage fed urban lake. *International Journal of Geology*, Vol. 5(3), pp. 86 - 92.
4. Mahapatra, D. M., Chanakya, H. N., and Ramachandra, T. V., 2011, Role of macrophytes in a sewage fed urban lake. *Institute of Integrative Omics and Applied Biotechnology Journal (IIOABJ)*, Vol. 2(8), pp. 1-9.
5. Mahapatra, D. M., Chanakya, H. N., and Ramachandra, T. V., 2011, Assessment of treatment capabilities of Varthur Lake, Bangalore, India. *International Journal of Environmental Technology and Management*, Vol. 14, pp. 84-102.
6. Mahapatra, D. M., Supriya, G., Chanakya, H. N., and Ramachandra, T. V., 2010, Algal photosynthetic dynamics in urban lakes under stress conditions. Proceedings of the Conference on

Infrastructure, Sustainable Transportation and Urban Planning CiSTUP@CiSTUP 2010. 18th - 20th October 2010, C*i*STUP, IISc, Bangalore.
7. Ramachandra, T. V., 2012, Conservation and Management of Wetlands: Requisite Strategies. LAKE 2012**:**National Conference on Conservation and Management of Wetland Ecosystems.
8. Ramachandra, T. V., Conservation and management of urban wetlands: Strategies and challenges, ENVIS Technical Report: 32, Environmental Information System, Centre for Ecological Sciences, Bangalore, 2009.
9. Ramachandra, T. V., Conservation, restoration and management of aquatic ecosystems, In *Aquatic Ecosystems - Conservation, Restoration and Management*, Ramachandra, Ahalya N. and Rajasekara Murthy (ed.), Capital Publishing Company, New Delhi, 2005.
10. Ramachandra, T. V., Ahalya N., and Payne, M., Status of Varthur Lake: opportunities for restoration and sustainable management. Technical report 102, Centre for Ecological Sciences, Indian Institute of Science, Bangalore, 2003.
11. Ramachandra, T. V., Aithal, B. H., and Durgappa, D. S., 2012, Insights to urban dynamics through landscape spatial pattern analysis. *International Journal of Applied Earth Observation and Geoinformation*, Vol.18, pp. 329-343.
12. Ramachandra, T. V., Aithal, B. H., and Kumar, U., 2012, Conservation of wetlands to mitigate urban floods. *Resources, Energy, and Development*. Vol. 9(1), pp. 1-22.
13. Ramachandra, T. V., Aithal, B. H., Vinay, S., Setturu, B., Asulabha, K. S., Sincy, V., and Bhat, S. P., Vanishing lakes interconnectivity and violations in valley zone: Lack of co-ordination among para-state agencies, ENVIS Technical Report 85, CES, Indian Institute of Science, Bangalore, 2015.
14. Ramachandra, T. V., Aithal, B. H., Vinay, S., and Lone, A. A., Conservation of Bellandur wetlands: Obligation of decision makers to ensure intergenerational equity. ENVIS Technical Report: 55, Environmental Information System, Centre for Ecological Sciences, Bangalore, 2013.
15. Ramachandra, T. V., Alakananda, B., Ali Rani and Khan, M. A., 2011, Ecological and socio-economic assessment of Varthur wetland, Bengaluru (India). *Journal of Environmental Science and Engineering*, Vol. 53(1), pp. 101-108.
16. Ramachandra, T. V., Alakananda, B., and Supriya, G., 2011, Biofuel prospects of microalgal community in urban wetlands. *International Journal of Environmental Protection (IJEP),* Vol.1(2), pp. 54-61.
17. Ramachandra, T. V., and Ahalya, N., Essentials of Limnology and Geographical Information System (GIS). Energy and Wetlands Research Group, Center for Ecological Sciences, Indian Institute of Science, Bangalore, 2001.
18. Ramachandra, T. V., and Kumar, U., 2008, Wetlands of Greater Bangalore, India: Automatic delineation through pattern classifiers, *The Greendisk Environmental Journal*. Issue 26 (http://egj.lib.uidaho.edu/index.php/egj/article/view/3171).
19. Ramachandra, T. V., Mahapatra, D. M., Bhat, S. P., Asulabha, K. S., Sincy, V., and Aithal, B. H., Integrated wetlands ecosystem: Sustainable model to mitigate water crisis in Bangalore. ENVIS Technical Report 76, Environmental Information System, CES, Indian Institute of Science, Bangalore, 2014.
20. Ramachandra, T. V, Meera, D. S., and Alakananda, B., 2013, Influence of catchment land cover dynamics on the physical, chemical and biological integrity of wetlands. *Environment and We - International Journal of Science and Technology - (EWIJST)*, Vol. 8(1), pp. 37-54.

21. Ramachandra, T. V., and Rajinikanth, R., 2005, Economic valuation of wetlands. *Journal of Environmental Biology*, Vol. 26(3), pp. 439-447.
22. Rau, L., 1988, Report of the expert committee for preservation, restoration or otherwise of the existing tanks in Bangalore metropolitan area.
23. Schilling, K., and Zessner, M., 2011, Foam in the aquatic environment, *Water Research*, Vol. 45, pp. 4355 – 4366.
24. Shivakumar, K. V., 2008, Water quality monitoring of lakes in Bangalore-Laborattory Central Laborattory KSPCB. Proceedings of Taal 2007: The 12th World Lake Conference, pp. 1908 – 1915.
25. Trivedi, R. K., and Goel, P. K., Chemical and biological methods for water pollution studies. Published by Environmental Publications, Post Box 60, Karad, 1986.
26. http://esrd.alberta.ca/water/programs-and-services/surface-water-quality-program/documents/FoamSurfaceWaters
27. http://nhlakes.mylaketown.com/uploads/tinymce/nhlakes/NewsArticles/LakeConcerns/5-3 Lake Foam
28. http://www.deccanchronicle.com/150430/nation-current-affairs/article/filthy-foam-varthur-lake-spills-bengaluru-road
29. http://www.in.gov/idem/files/wqsurvey_025surfacefoam
30. http://parisaramahiti.kar.nic.in/vseries.html
31 http://wgbis.ces.iisc.ernet.in/energy/water/paper/researchpaper2.html

Foam and Fire: Indicator of contaminants in Varthur & Bellandur Lakes

Cause	Sustained inflow of untreated sewage (due to BWSSB) and effluents (from industries) due to dereliction of duties by regulatory agencies (KSPCB, CPCB) has contaminated the lake as the inflow of pollutants has surpassed the lake's assimilative capacity. Froth formation at outlets, profuse growth and spread of marcrophytes are all the indicators of nutrient enrichment. Nutrients in the form of N (nitrogen), carbon (C) and P (phosphorous) enters the lake through untreated sewage. Major part of N is up-taken by plants and algae while phosphorous and carbon gets trapped in sediments. Due to 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.
Solution	1) Decentralised treatment of municipality waste water preferably at ward levels (similar to Jakkur lake) 2) Apply 'polluter pays principle' in true spirit - Restrict the entry of untreated sewage and industrial effluents into lakes. Agency responsible for sustained inflow of untreated sewage need to restore the lake. Similarly industries responsible for polluting water bodies should be made to pay (this also entails penalising regulatory agency for dereliction of duties by not applying 'polluter pays' principle as per Water Act, 1974) 3) Let only treated sewage through constructed wetlands and shallow algae pond into the lake (as in Jakkur lake) 4) Regular maintenance of floating macrophytes 5) Mapping of water body (identification of flood plain and buffer zone) 6) Remove encroachments near to lakes after surveying the lake area 7) Re-establish interconnectivity among lakes (by removing all encroachers of storm water drains/raja kaluves without any humanity considerations – encroacher or polluter needs to pay for arrogance of encroachments) 8) Planting of native species of macrophytes in open spaces of lake catchment area (for retaining water in the lake) 9) Avoid dumping of solid wastes into lakes 10) Ensure proper fencing of lakes 11) Lake area should not be diverted for any other purposes 12) Make local residents environmentally literate 13) Restrictions / product ban – detergents using phosphorous (which is a limited, non-renewable resource)

Foam and Fire: Varthur - Bellandur Lakes

Cause: Sustained inflow of sewage (500 MLD) into Bellandur and Varthur lakes comprises of many natural and synthetic dissolved organic compounds, such as soaps and detergents. These are surface-active agents or surfactants that reduce the surface tension of water, allowing air bubbles to persist at the water's surface. These detergents essentially consist of phosphates, and a portion of which is up-taken by aquatic plants while the balance gets trapped in the sediments.

Figure 3.1: 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

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 3.1 a-c). 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: Also, 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. 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.

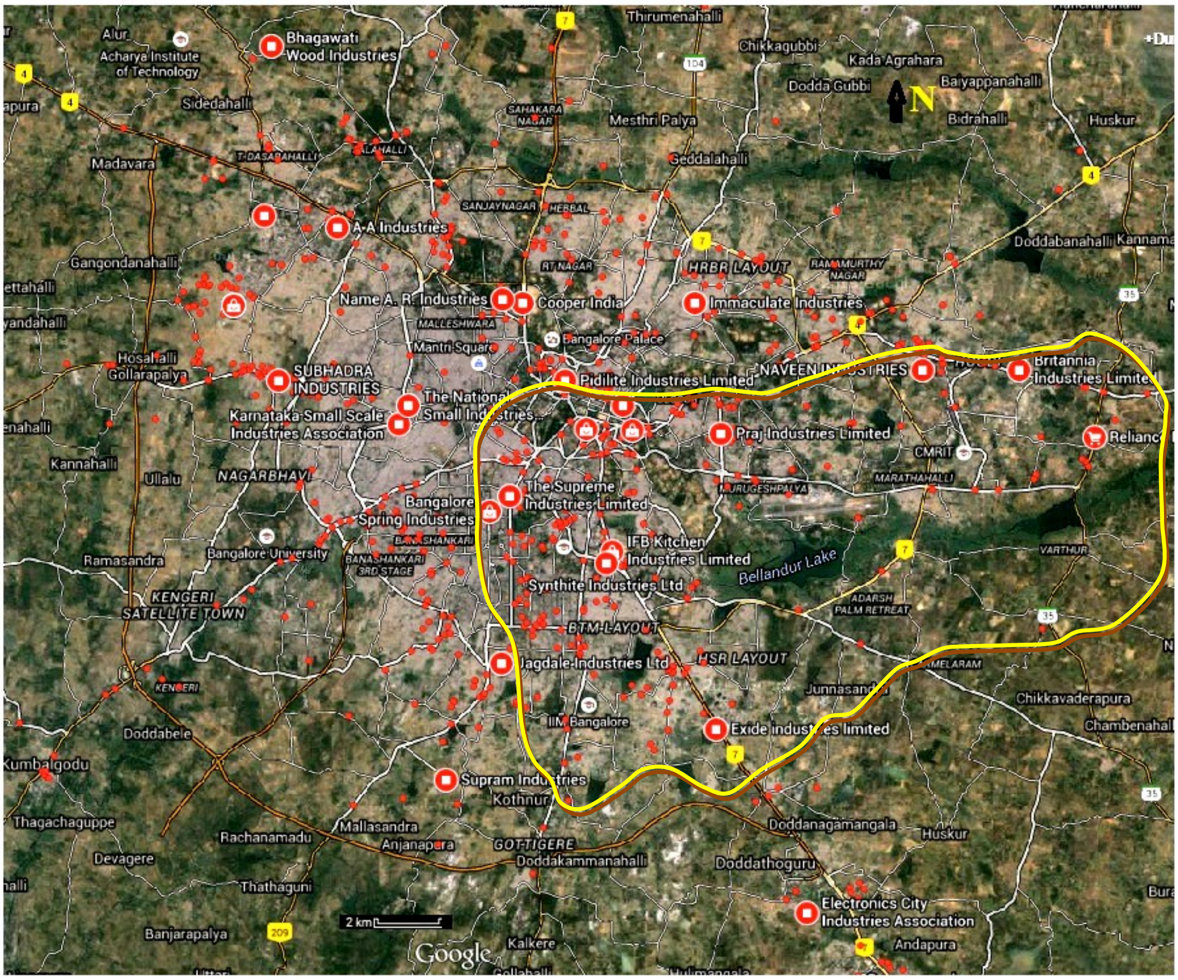


Figure 3.2: Distribution of industries in the vicinity of Bellandur and Varthur lake and also industries scattered in the city (overlaid on Google earth image http://earth.google.com)

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 (Figure 3.2 and 3.3) 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.

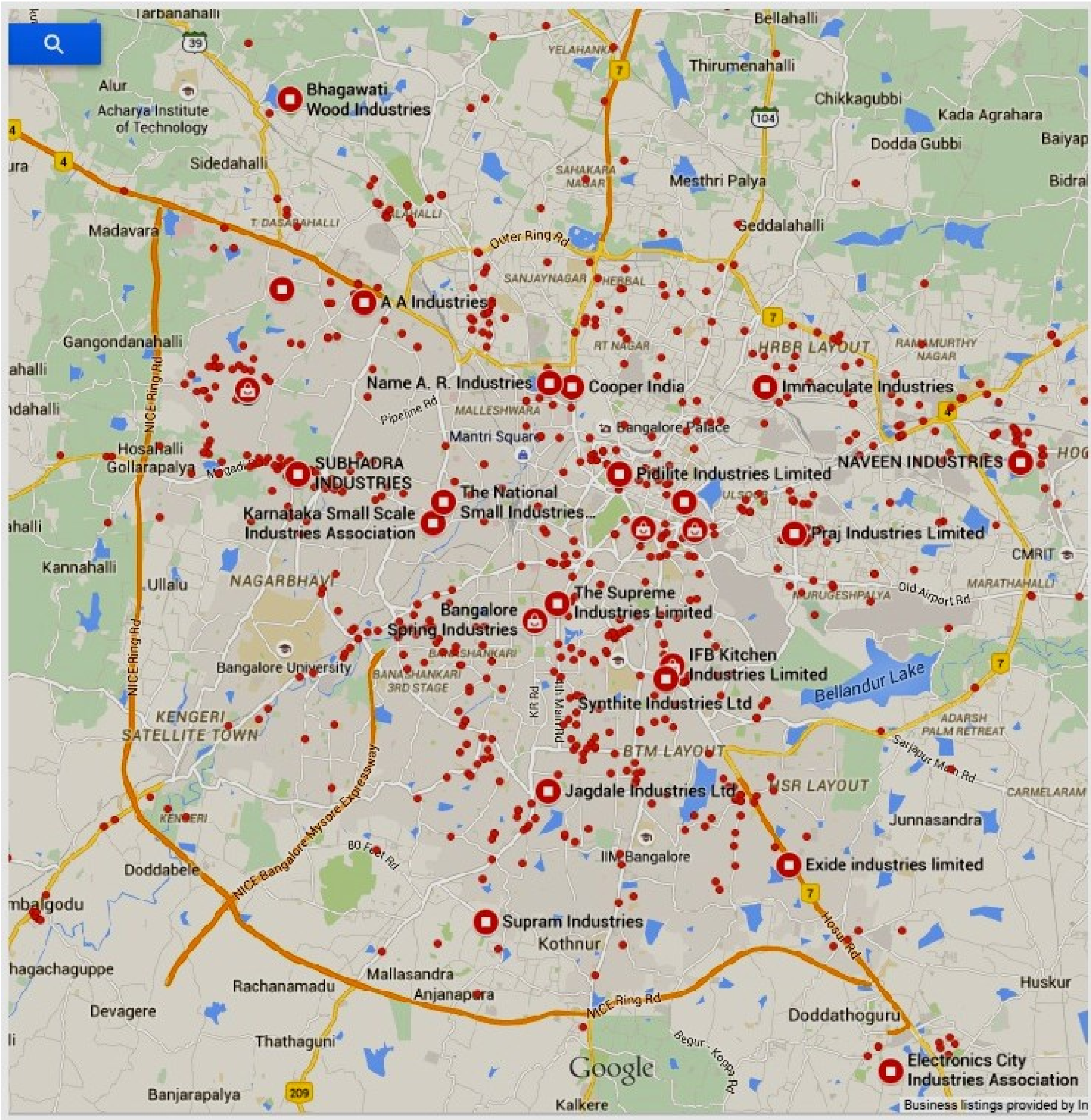
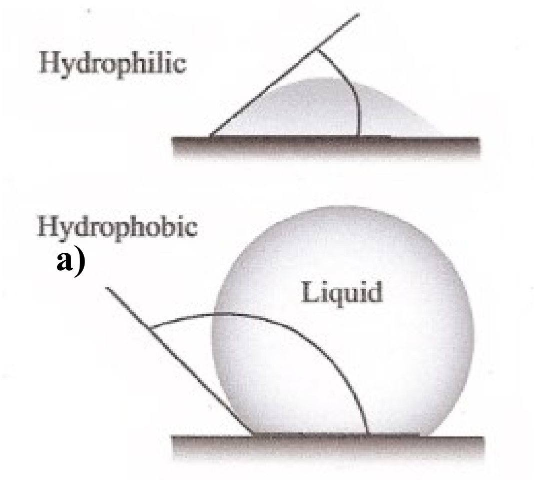


Figure 3.3: City map showing the distribution of various industries scattered in the city

Many industries that are present (Figures 3.2 and 3.3) 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.

Surfactants influence on the surface tension of water: 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 (Figure 3.4 a). In this manner, surfactants reduce the overall attraction between water molecules, thus diminishing surface tension (Figure 3.4b). Lower surface tension causes water to become more 'fluid' or elastic, and when air gets in the resulting bubbles can persist for some time.



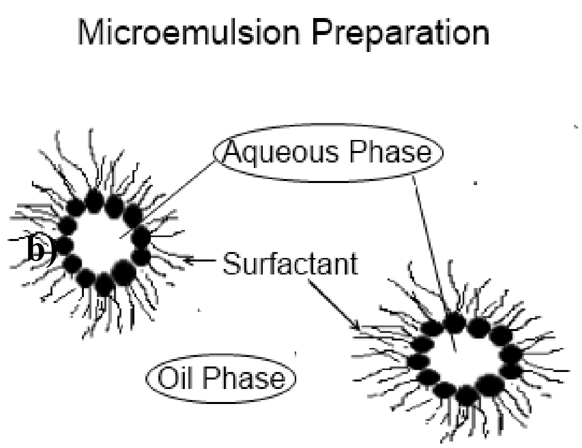


Figure 3.4a) Surface tension in case of hydrophobic and hydrophilic molecules

Figure 3.4b) Action of a surfactant in reducing the surface tension with polar heads binding to aqueous phase and hydrophobic tails that binds to oil/dirt phase

b)

Figure 3.5: Foam formation at the a) Varthur North (Kodi) outfalls, b) South outfalls

Foam / Froth formation: 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. Figure 3.6 illustrates hydrophobic oil and aqueous phases.

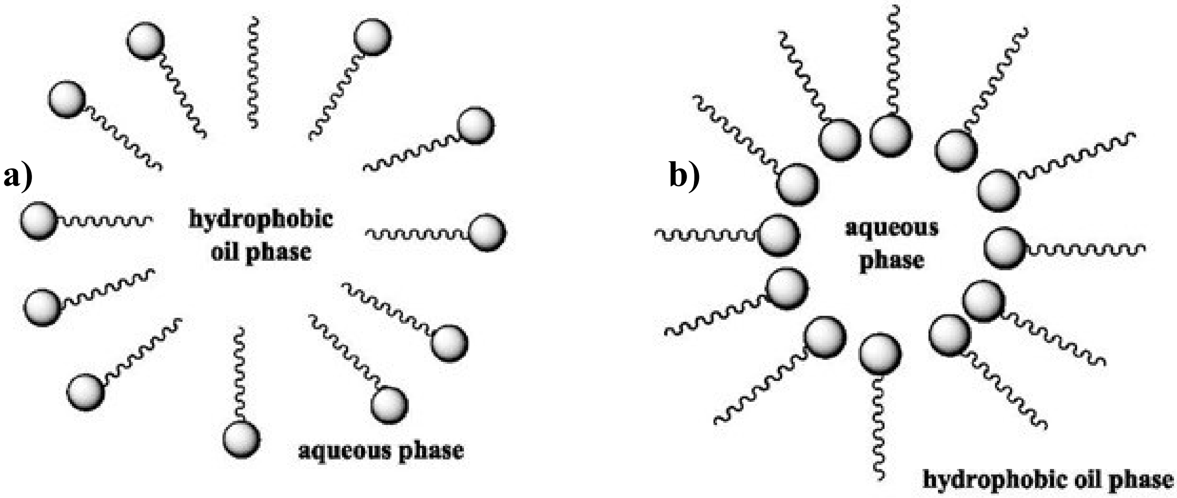


Figure 3.6 a) Hydrophobic oil phase (non polar tails towards the centre) b) Aqueous phase (polar heads to wards the centre)

Characteristics of foam: 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 (Figure 3.7). The foam had a pungent odour with sulphide smell unlike the natural foam that has an earthy or fishy aroma. 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 (Figure 3.8).

Figure 3.7: Foam sample collection from Varthur north outfalls

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 (Figure 3.9). Moreover, the foam volumes were observed to be higher during the 2nd and 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 (Hug, 2006 and Ganidi et al., 2009). 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 groups during 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.

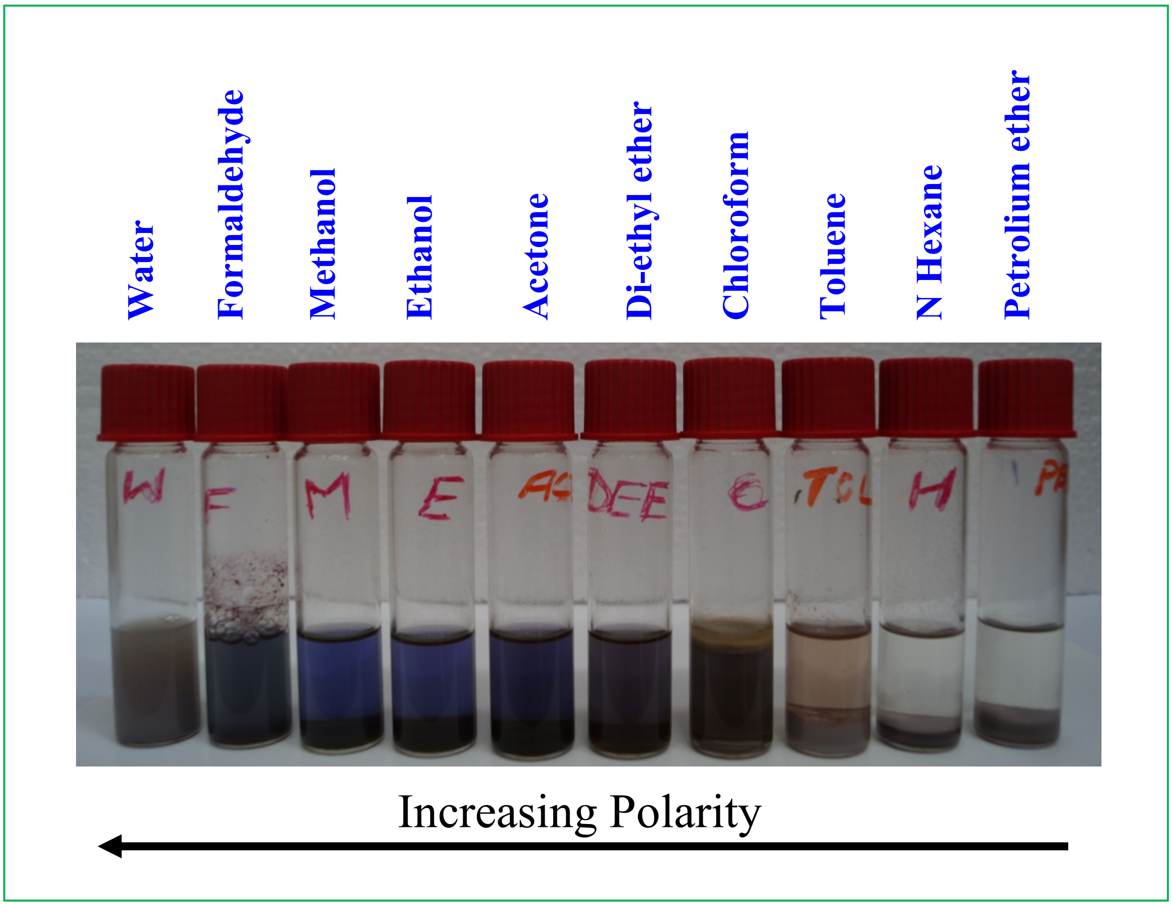


Figure 3.8: Analysis of Elution of the liquid phase of the foam in different solvents in the order of increasing polarity

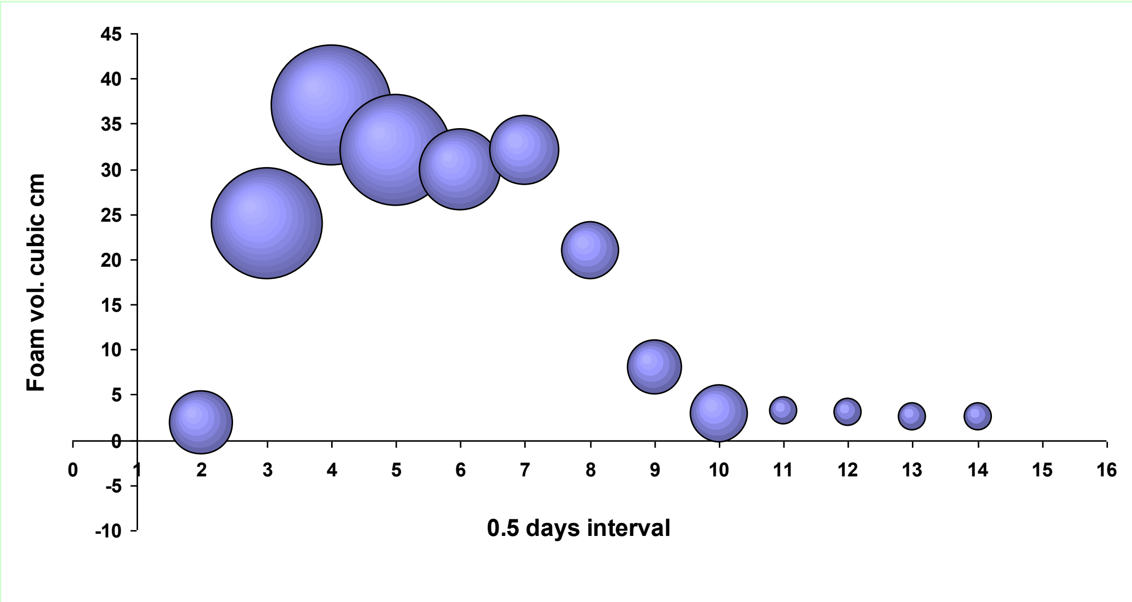


Figure 3.9: Foaming coefficients– foam volume and mean bubble size variation with time (note 1-12 indicates 6 days' interval)

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 poly phosphates (27-34 %) and 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 were grey in colour with higher particulate matter arising from sludge.

Influence of water hardness on foaming: Water hardness influences the amount of foam that results from water turbulence. Water hardness is a result of the presence of certain minerals in water, principally calcium and magnesium (and iron and manganese, to a lesser extent). Dissolved in water, calcium and magnesium exist as positively charged ions. These out-compete water molecules for binding to negatively charged surfactants (carboxylic fatty acids for example). The harder the water, the more likely the surfactant will be bound up by calcium or magnesium and, consequently, the less likely surface tension will be reduced. 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) 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 Yamalur- Bellandur lake

Flammability is the ability of a substance to burn or ignite, causing fire or combustion. Incidence of foam catching fire (Fig ure 3.10a and b) are due to compounds with high flammability i.e. mostly 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.

Figure 3.10 a) Flames over the surface of the froth during the night observed at the Yamalur-Bellandur lake outfalls b) 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 (Mahapatra et al., 2013a). 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 a here 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.

References:

1. Barber, W.P. (2005). Anaerobic digester foaming: causes and solutions. Water 21, 45–49. Available from: http://www-uk1.csa.com/ids70/results.php?SID=4oo9hnkld4c223a8lr72q3vbb1&id=2
2. Ganidi, N., Tyrrel, S., Cartmell, E. (2009). Anaerobic digestion foaming causes – a review. Bioresource Technol. 100, 5546–5554.
3. Hug, T. (2006). Characterisation and controlling of foam and scum in activated sludge systems. Swiss Federal Institute of Technology, Zurich.

4. Mahapatra D.M., Chanakya H.N., Ramachandra T.V. (2011c). C:N ratio of Sediments in a sewage fed Urban Lake. International Journal of Geology. 5,3:86-92.
5. Mahapatra D.M., Chanakya H.N., Ramachandra T.V. (2011a). Assessment of Treatment capabilities of Varthur Lake, Bangalore. International Journal for Environment, Technology & Management. 14, 1-4:84-102.
6. Mahapatra D.M., Chanakya H.N., Ramachandra T.V. (2013a), Bioenergy generation from components of a Continuous Algal Bioreactor: Analysis of Lipids, Spectroscopic and Thermal properties. Proceedings of 10th IEEE INDICON Conference on Impact of Engineering on Global Sustainability, pp. 183-184, IIT Bombay, India 12th – 15th Dec, 2013.
7. Mahapatra D.M., Chanakya H.N., Ramachandra T.V. (2014a), Bioremediation and Lipid Synthesis of Myxotrophic Algal Consortia in municipal wastewater. Bioresource Technology. 168: 142-150.
8. Mahapatra D.M., Chanakya H.N., Ramachandra T.V. (2014b), Novel Algal Bioreactor for Wastewater Treatment and Biofuel (lipid) Production. GYTI Technological Innovations, SRISTI pp. 60, GYTI Exhibition, IIM Ahmedabad. India 29th March, 2014.
9. Mahapatra D.M., Chanakya H.N., Ramachandra T.V., (2011b). Role of Macrophytes in urban sewage fed lakes. Institute of Integrative Omics and Applied Biotechnology. 2, 7: 1-9.
10. Mahapatra, D.M., Chanakya, H.N, Ramachandra, T.V. (2013b). *Euglena* sp. as a Suitable Source of Lipids for Potential use as Biofuel and Sustainable Wastewater Treatment. Journal of Applied Phycology. 25:855-865.
11. Mahapatra, D.M., Chanakya, H.N., Ramachandra, T.V. (2013c). Treatment efficacy of Algae based sewage treatment plants. Environmental Monitoring and Assessment. 185:7145-7164.
12. Mahapatra, D.M., Ramachandra, T.V. (2013). Algal Biofuel: Bountiful Lipid from *Chlorococcum* sp. proliferating in Municipal Wastewater. Current Science. 105:47-55.
13. Ramachandra T.V., Solanki, M. (2007). Ecological assessment of Lentic Waterbodies of Bangalore, ENVIS Technical Report 25, Environmental Information System, Centre for Ecological Sciences, Bangalore.
14. Ramachandra T.V. and Murthy R. (2000). Restoration and management strategies for wetlands, Lake Symposium 2000.
15. Ramachandra, T.V., Mahapatra, D.M., Karthick B., Gordon, R. (2009). Milking diatoms for sustainable energy: biochemical engineering vs. gasoline secreting diatom solar panels. Industrial & Engineering Chemistry Research. 48, 19:8769-8788.
16. Ramachandra, T.V., Mahapatra, D.M., Samantray, S., Joshi, N.V. (2013). Biofuel from Urban Wastewater: Scope and Challenges. Renewable and Sustainable Energy Reviews. 21:767-777.

Foam and Fire (and encroachments) in Varthur & Bellandur Lakes: Highlights the level of irresponsibility of para-state agencies handling sewage and industrial effluents in the city.

GIVE CITIZEN OF BANGALORE CLEAN AIR, WATER and ENVIRONMENT

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/Welcome.html

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 Ballandur 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

Annexures
(compiled from literatures)

PHOSPHORUS: CHEMISTRY and USES

P	Melting point	44.1° C
	Boiling point	280° C
Density		1.8 g/cm³
Appearance		Phosphorus occurs in more than one form. One of these is waxy and white, and another is a dark, red powder.
Other physical properties		The waxy, white form of phosphorus glows in the dark.
Chemical properties		Phosphorus is insoluable in water. The waxy, white form is very reactive and can explode in air. (It burns at 35 °C.) It is also very poisonous. The powdery form is less reactive, although it burns in air. It is not very toxic.
Compounds		Calcium phosphate, a natural rock used to make phosphate fertilizers, is one compound of phosphorus.
Uses		Phosphorus is alloyed with bronze. It is also used in incendiary bombs and match heads.
Notes		Phosphorus compounds play an important role in the use of energy in living things.
SOURCE		Properties of Matter http://www.propertiesofmatter.si.edu/Phosphorus.html
White Phosphorous		*White phosphorus* is a soft, waxy, flammable substance, consisting of tetrahedral P_4 molecules; it is often slightly yellowish because of the presence of impurities (hence, it is sometimes imaginatively known as *yellow phosphorus*). White phosphorus is highly reactive, and spontaneously ignites at about 30°C in moist air. It is usually stored under water, to prevent exposure to the air. It is also extremely toxic, even in very small quantities.

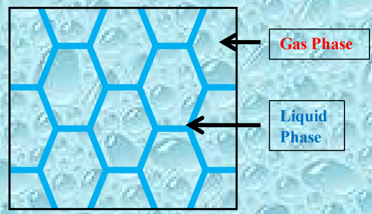
Hazards: White phosphorus is toxic (the approximate fatal dose is about 50 to 100 mg. Even in very small quantities, it produces severe gastrointestinal irritation, diarrhea, and liver damage. It also causes burns when it comes in contact with skin. Chronic exposure to white phosphorus causes bony necrosis (especially of the jaw, a condition called "phossy-jaw") and anemia.

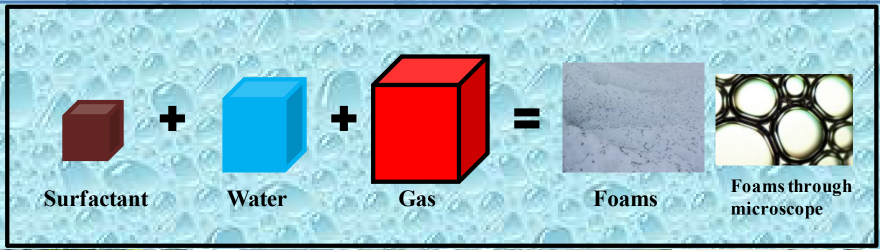
https://www.angelo.edu/faculty/kboudrea/demos/burning_phosphorus/burning_phosphorus.htm
http://chandrasekaran.tripod.com/uses.htm

Use values of Phosphorous	
HEALTH:	In living beings, phosphorus is found in bones, teeth, nucleic acids (DNA and RNA), in the energy carriers (such as ATP), lipids, proteins and enzymes. This highlights that phosphorus is vital for biological organisms.
Initiates Fire	Phosphorus catches fire readily, it is used in match sticks; red phosphorus is used in "safety matches" and is less volatile and less poisonous.
Flame retardants	Phosphorus in its elemental form is used to make fire, while in the form of derived chemicals it is used to stop or reduce the hazards of fire.
Uses	• Surfactants, Cleaners: • Phosphorus compounds (small molecules or polymer) are very useful in the synthetic polymers, paints and protective coatings for wood, the plasticizer/flame-retardant (and fire-resistance). • Organo phosphates with good lubrication, thermal stablility and fire-resistant properties are used as high temperature lubricants. • Metal Treating, Electroplating of copper or zinc, their pyrophosphate is used as electrolyte (along with potassium pyrophosphate). • Water Treatment - to convert hard water to soft water by removing the metal ions as insoluble metal phosphates. • tooth pastes (cavity protection or tartar control), in shampoos and many more commonly used items.

ELEMENT ANALYSIS

Description	Units	Slush	Sediment
Bulk Density	kg/cum	500	1700
Organic Carbon	%	18	8
Nitrogen	%	3	0.35
Phosphorous	%	2.5	0.28
Cadmium	mg/kg	7	2.4
Cobalt	mg/kg	8	5
Copper	mg/kg	68	30
Iron	mg/kg	20935	13580
Manganese	mg/kg	140	98
Nickle	mg/kg	26	20
Lead	mg/kg	7	6.5
Zinc	mg/kg	106	45
Sodium	mg/kg	2175	2075
Potassium	mg/kg	7750	6025
Calcium	mg/kg	581	608
Magnesium	mg/kg	433	1452





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