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ROLE OF MACROPHYTES IN A SEWAGE FED URBAN LAKE

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ABSTRACT

Macrophytes play a major role in maintaining the nutrient levels in urban aquatic systems. However their prolific growth result in spread of invasive species such as water hyacinth (Eichhornia crassipes) due to the availability of higher nutrient concentrations. This hinders aerobic functioning of the lake by restricting sunlight penetration and also affecting algal photosynthesis. This also results in anoxic environment due to blockage of air-water interface, influencing oxygen diffusivity. Reduction in DO (0 mg/l) impacts the viability of aquatic biota and result in the disappearance of biodiversity. This communication evaluates the influence of the invasive macrophytes in the functioning of lake across the seasons. Significant seasonal changes in water quality were noticed due to changes in the redox conditions (- 235 mV) and dissolved oxygen levels at various locations depending on the extent and location of macrophyte spread based on the nutrient levels coupled with wind regime prevailing during the season. The analysis of seasonal data reveals that dissolved oxygen concentration and redox condition is dependent on the extent of macrophyte spread. N content in Lemna and Alternanthera species (of 4 g/100 g dry weight) is significant compared to other species (p<0.005). During monsoon, lake functions in the absence of macrophytes, predominantly as aerobic lagoon; and functions as aerobic-anaerobic lagoon (pre-monsoon) and as anaerobic–aerobic system (post-monsoon). Anaerobic conditions are mainly due to the interference of macrophytes in lake functioning and inefficient handling of nutrients in the absence of algae. This necessitates the regular removal of macrophytes from the lake. Provision to allow the growth of primary producers will help in nutrient management.

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KEY WORDS

macrophytes; wastewater; nutrients; eutrophication; lagoon; sewage; urban lakes

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[I] INTRODUCTION

Macrophytes grow in or near water and are emergent, submergent, or floating, forming a vital component of lake ecosystems. However, the introduction of invasive-exotic species such as water hyacinth (*Eichhornia crassipes*), alligator weed (*Alternanthera phyloxiroides*), water lettuce (*Pistia stratiotes*) etc. have changed the lake dynamics significantly. In recent times the urban waterbodies are being used for the disposal of sewage, etc. Sustained inflow beyond the assimilative capacity of waterbodies has lead to eutrophication, resulting in the profuse growth and spread of invasive species. Influx of partially treated and untreated sewage has resulted in overgrowth, ageing, and subsequent decay of macrophytes creating anoxic conditions and devouring the system from life giving oxygen. This has impacted the food chain and hence the ecological integrity of the system.

Water hyacinth (*Eichhornia crassipes*) native to Brazil has been introduced to tropical and subtropical region, [1] is amongst the fastest growing, free floating freshwater invasive weed species which derives required nutrients directly from water. Its distribution and dispersal is aided by water currents and wind. It consists of 5% dry matter with 50% silica, 30% potassium, 15% nitrogen and 5%protein[2]. Its potential negative characteristics pose a threat for the habitat quality of waterbodies. The average growth rate of water hyacinth is 10-12 $g/m^2/d$ and the maximum is 45-50 $g/m^2/d$ [3, 4, 5]. During growth, water hyacinth can store N up to 909 g/m^2 [6]. These invasive aquatic plants form a thick 'mat' that restricts the exchange of oxygen across the air/water interface and also hampers algal photosynthesis resulting in reduced dissolved oxygen. The anoxic conditions under water hyacinth mats also favour the release of nitrogen and phosphorous (N and P) from sediments which may further aid the rapid growth of macrophytes [7, 8, 9]. In addition, it influences the wind-driven water movement, impeding circulation of oxygen-rich surface water [10]. Bank side grasses grow over the water hyacinth mats, anchoring the mats to the bank edges. Varieties of grasses and sedges as *Cyperus* sp. and in some instances, plants like *Colocasia esculenta* (taro) etc. have established themselves on these mats. Once established, very large flows are required to break them up and disperse.

The southwest monsoon winds tend to push the floating macrophytes over spillways of lakes situated on their south-eastern, eastern and southwestern edges, thereby ridding the water surface free of macrophytes each year. This natural flushing of macrophytes during monsoon associated with the

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phenological events was considered to be the most important short-term process for cleaning urban lakes. The macrophytes in their matured stage are infested by the mottled water hyacinth weevil and caterpillar that reduces about 75% of the leaf surface areas in 2-3 weeks, consequently resulting in loss of the major photosynthesizing machinery i.e. the leaves and greatly helps in compacting the water hyacinth mass, as they also disrupt the long, spongy and bulbous stalk tissues, the plants lose their buoyancy and settles faster which is followed by leaching of plant nutrients and subsequently rapid bacterial degradation takes place which reduces the DO levels significantly and creates anaerobic conditions throughout the lake. Thus this process submerges a large quantity of organic matter which ultimately decomposes, increasing the biochemical oxygen demand (BOD) that deteriorates water quality. Dissolved oxygen falls to such low level that leads to massive fish kills [11].

Oxygen is amongst the most important of several dissolved gases vital to aquatic life. It is a principal and direct indicator of water quality in surface waters. Primary source of oxygen in surface water is from photosynthesis of aquatic plants, algae and diffusion of atmospheric oxygen across the air water interface. The dissolved oxygen content of natural water varies with the temperature, photosynthetic activities and respiration or decomposition of plants and animals [12]. On a daily basis they maintain equilibrium as per the consumption and production. The diurnal oxygen cycle varies in a sinusoidal manner with minimum values observed early in the morning and maximum concentrations at midday [13]. A decline in DO has serious implications on the health of the aquatic system, as hypoxic and anoxic conditions reduce or eliminate sensitive native fish and invertebrate species.

During aerobic decomposition, cellulosic materials are converted into carbon dioxide and water by the bacterial action. CO_2 in the dissolved form maintains equilibrium with its carbonate and bicarbonate forms and decides the C supply for the algae and aids in photosynthesis bringing manifold increase in the primary productivity of the system. Oxygen level of the waterbodies are reduced by continuous inflow of sewage, containing large loads of organic carbon, phosphates and nitrates that finally lead to profuse growth and spread of aquatic biota. Under such circumstances, aquatic plants and algae proliferate incredibly and when they die they form food for bacteria, which in turn multiply and use large quantities of dissolved oxygen. In addition to this, when plant biomass increases at the surface of the water (pelagic zone) they block transmittance of sunlight into deeper layers and diffusion of oxygen from the atmosphere into the water, thereby, reducing photosynthetic potential of submerged plants and algal species. In addition to this, their extensive root system in the water provides a large surface area for the growth of microbes which rapidly consume DO [14]. These microbes render the system more anoxic by carrying out the anaerobic digestion on a myriad of substrates. Moreover, under anoxic conditions, ammonia, iron, manganese and hydrogen sulphide concentrations can rise to levels deleterious to biota. In addition, phosphate and ammonium are released into the water from anoxic sediments further enriching the ecosystem [15].

Varthur lake, situated in the south of Bangalore, was built to store water for drinking and irrigation purposes [16]. However, over the last five decades, due to sustained influx of sewage, nutrients in the lake are now well over safe limits. Sewage brings in large quantities of C, N and P which are trapped within the system. This lake receives about 40% of the city sewage (c.500million liters per day, MLD) resulting in eutrophication. There have been substantial algal blooms, dissolved oxygen depletion and malodour generation, apart from extensive growth and spread of water hyacinth that covers about 85% of the lake during the dry season.

Water hyacinth mats greatly reduces DO content in water under the mats [17, 8, 9] affecting aquatic diversity and productivity. Decomposition of macrophytes happens due to ageing, over-crowding, wind driven compaction, pest damage, etc. During oxidation, microflora utilize detritus C as an energy source and reduces electron acceptors such as oxygen, nitrate and sulphate [18]. Water hyacinth litter breaks down as a result of aerobic, anaerobic and facultative anaerobic microbial activity [19]. Bacteria accentuate degradation process and fungal decomposition under such conditions is negligible [20]. O_2 concentrations in water play an important role in the release and transformations of nutrients [21].

This paper focuses on the impact of wind induced drift of macrophytes, its removal during monsoon, and its rapid growth which governs the aerobic-anaerobic status of the lake and thereby brings out its relation with the water quality. The objectives of the study were to:

i. Determine the major contributor of the BOD load that disrupts the lake's functioning,
ii. Map oxic, hypoxic and anoxic zones based on DO levels and to understand the influence of wind induced drift of macrophytes on seasonal water quality changes and
iii. Quantify nutrient loads (C and N) and their uptake by macrophytes.

[II] MATERIALS AND METHODS

The field study was conducted in Varthur lake (12°57'24.98" - 12°56'31.24" N, 77°43'03.02" - 77°44'51.1"E) situated in the south of Bangalore, **[Figure-1]** which is the second largest lake in the city. It covers a water-spread area of 220 ha (maximum depth 2 m) and has a varying extent of floating macrophytes during different seasons. It is a part of a series of interconnected and cascading waterbodies. The Varthur lake catchment has seen large scale land use changes after 2000, following rapid urbanization.

Water samples were collected at 10-15 cm from the surface (to avoid floatables and macrophyte debris), every month over a

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period of twelve months and analyzed for various physico-chemical parameters-pH, water and air temperature, conductivity, turbidity, redox potential and dissolved oxygen (DO), BOD, COD and inorganic nutrient as per standard protocol of APHA [22]. The biomass/macrophyte coverage over the lake surface was also monitored with the help of GPS and remote sensing data. For macrophyte biomass estimation, 1 m^2 quadrate sampling method was adopted [23]. C and N contents were determined using CHN analyzer. The algal community structures at various sampling sites were also investigated. The nutrient content in water and biomass were analyzed. The pattern of the wind induced drift resulting in the movement of macrophyte population and the accumulation at different extremes of the lake was studied. Changes in the dissolved oxygen concentration and other water quality parameters were investigated with the macrophyte cover and resultant oxidizing or reducing environment.

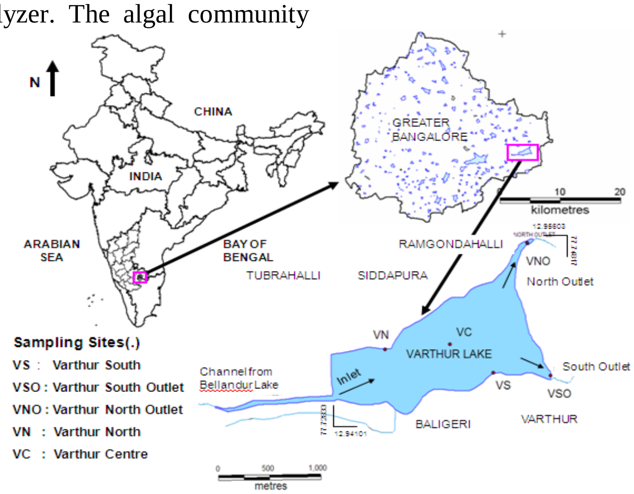

Fig: 1. Varthur lake, Greater Bangalore, India with sampling locations

[III] RESULTS AND DISCUSSION

3.1. Monthly variations of dissolved oxygen (DO) concentrations

Water quality parameters were monitored on monthly basis **[Table-1]**. Significant variations in mean monthly values of DO were observed **[Figure-2]**. DO ranged from 0-5 mg/l depending on the extent and density of macrophytes during the morning. In anthropogenically modified, weed-infested streams from upper reaches, deoxygenated water (DO = 0-0.3 ppm) arrives for most part of the day, due to high flow rates of water through extensive weed mats. The influx of hypoxic, nutrient rich wastewaters during the mid day is more stressful to aquatic biota as fish and invertebrates that undergo higher metabolic rates during the day require a higher DO than in the night.

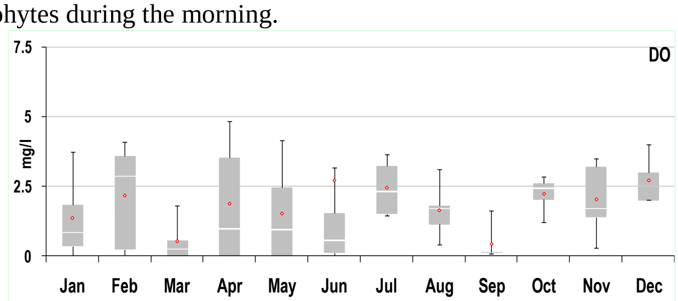

Fig: 2. Month-wise variations in Dissolved Oxygen

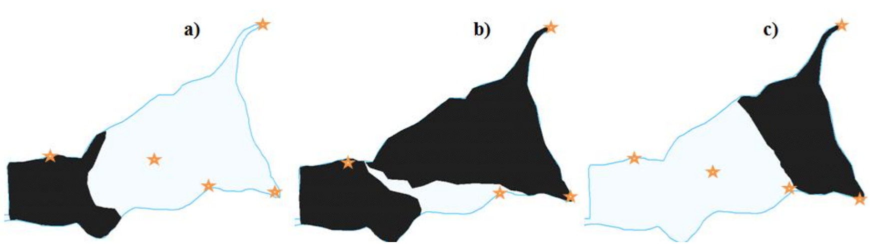

Fig: 3. Extent of macrophyte spread across seasons (extracted from satellite data)
Note: a) Winter b) Summer and c) Monsoon.

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According to BIS (IS 10500-1991) and CPCB standards, the oxygen saturation for surface waters should be around 75% (6 ppm), yet it is the minimum that decides the aptness of habitat for various species (rather than average-based guidelines). Most of the DO data for urban Indian lakes are spot one time measurements during daylight hours, when DO would be substantially above its minimum and in many cases, even approaching its maximum level. Such approaches are inadequate for determining the DO status of these urban waterbodies. Spot readings are used when oxygen levels are typically at their lowest and potentially most stressful for aquatic biota when there is an absence of continuous data [24].

Parameters	Units	μ	σ	Min	Max
Nitrates	ppm	0.304	0.219	0.1	0.96
Ammonium	ppm	15.06	7.6	3.93	30.73
Phosphates	ppm	0.98	0.7	0.14	3.5
Total Phosphates	ppm	7.86	2.44	3.14	9.87
BOD	ppm	89.65	38.54	44	186.1
COD	ppm	98.2	21.24	52	197.3
pH	units	7.61	0.64	6.2	8.22
EC	μS/cm	1054.4	158.64	751	1420
DO	ppm	1.56	0.67	0	13
Transparency	cm	23	3.16	18	28
Turbidity	NTU	78.5	25.6	29	224
ORP	mV	-9.33	129.29	-235	135

Table: 1. Physico-chemical parameters of Varthur lake.
Note: μ: mean; σ: standard deviation; Min: minimum, Max: maximum.

Field investigations reveal that DO is correlated to temperature (r = 0.79). Higher DO levels during the mid-day are due to enhanced algal photosynthetic activities with higher insolation. However during the night due to respiration of aquatic biota, DO levels drop to zero. Furthermore, higher variability in DO was observed during summer. In stagnant systems, which are not light limited, minima is typically around dawn, but in flowing conditions, upstream conditions, flow rates and mass loading make this less predictable.

3.2. Spatial analysis and seasonal effects on wind-induced macrophyte drift and consequent deposition

Varthur is a shallow, wind-influenced hypereutrophic lake characterized by consistent phytoplankton blooms and having higher deposits of unconsolidated organic sediment. The lake receives about 500 MLD sewage (measured) which undergoes anaerobic stage in the upper reaches of the lake. BOD at the inlet is about 120-200 mg/L, Algae driven oxidative BOD reduction facilitate the water to be oxic and brings down the BOD to about 30mg/L at outlets when the lake is not infested with exotic weeds. The algal population plays a pivotal role in maintaining the oxic condition's of the water. Preponderance of ammonia (~40 ppm; **[Table-1]**) at critical levels when the lake is infested with macrophytes poses a threat to the lake's aquatic biological food chain and its activities. The wind regime plays a decisive role in the spread and location of macrophytes mats in the lake. A study conducted to understand the DO levels in various locations of the lakes, reveals significant differences in the dissolved oxygen depending on presence or absence of macrophytes cover. The DO values were monitored in various seasons during the study period to address seasonal variability's. **[Table-2]**.

During the pre-monsoon summer period, the macrophytes grows luxuriously all over the surface of the lake **[Figure-3b]** thus creating anoxic zones (Oxidation reduction potentials ORP -65 to -225 mV), along with enhanced bacterial activities under higher reigning temperatures. Roots of the floating macrophytes provide a good substratum for the attachment of bacteria, drastically reducing the DO levels and resulting in hypoxia and anoxia. DO varies depending on the extent and density of macrophyte mats, evident from the significant difference ($p=0.00006<0.001$) **[Table-3]** in regions with or without macrophytes. This emphasize that lake functioned as anaerobic lagoon. The floating mat of macrophytes gets compacted with an anoxic environment just beneath it. With the increased amount of plant litter decomposition, it significantly contributes to higher autochthonous organic load and hence BOD. The DO values reveal consistent anoxic zones associated with the macrophytes and thus the seasonal changes in the pattern of oxygenation at various extremes of the lake.

During June, gusty westerly winds (4.7 m/s) drifts water hyacinth towards outlets **[Figure-3c]** and subsequent drifts compact water hyacinth which forms thick mat in the region. This compaction is aided by the pest infestation and ageing, which further helps in compacting and also reducing the biomass. This aids in rapid settling while decomposition often creates an anoxic environment near the outlets. The regions near the outlets were highly anaerobic (ORP -180 to -218 mV) with DO values 0 mg/l, compared to the upper reaches which were free from macrophytes (ORP +70 to +85) with DO values from 6.5 to 11.5 mg/l. DO concentrations at outlets were significantly different ($p=1.1 \times 10^{-12} <0.0001$) **[Table-3]** from the regions free of macrophyte cover (inlet and middle regions).

During monsoon, higher catchment run-off into the lake pushes macrophytes including decomposed, semi-decomposed plant litter to the downstream. This exposes water surface to air and sunlight allowing photosynthetic activities in the lake aiding algal growth **[Figure-3a]**. This process rejuvenates the system to aerobic status. Furthurmore higher inflow help in cleansing the system from superficial sludge accumulated at outlets which improves the system's performance. The sludge up-welled by wind turbulence comprises of semi-degraded macrophyte biomass (C: N = 50.05:3.02) showing that most of the C forms are intact. However lower values of N indicates uptake by micro organisms, algae and macrophytes.

Table: 2. DO concentrations at the mid-day at various sites in all seasons

Sampling Location	DO Concentration at Mid-Day (ppm) Pre-monsoon	Monsoon	Post-monsoon
Inlet	8	2.5	3.73
Centre	9.5	6.5	0.13
Outlet North	0	1.3	0.0
Outlet South	0	12.6	0.48
South	12	8.2	1.2

Table: 3. One way ANOVA for DO concentrations in all four studied seasons

Dependent Parameter	Source	Degree of Freedom	F value	p-value at < 0.00001
Summer DO	A	1	23.56	6×10^{-5}
	B	24		
	C	25		
Winter DO	A	2	24.99	4.16×10^{-5}
	B	24		
	C	25		
Monsoon DO	A	1	29.02	6.04×10^{-5}
	B	16		
	C	17		
Spring DO	A	1	396.93	1.1×10^{-12}
	B	16		
	C	17		

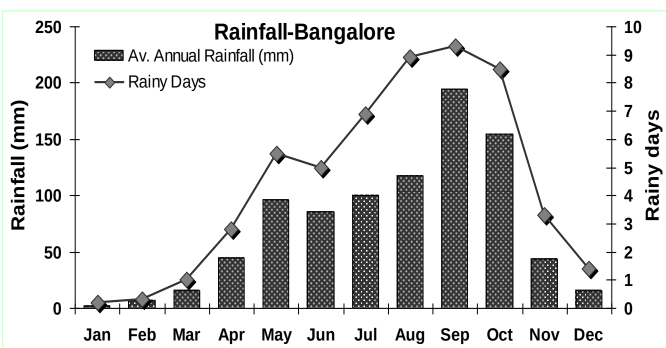

Fig: 4. Monthly rainfall variations near the Study area

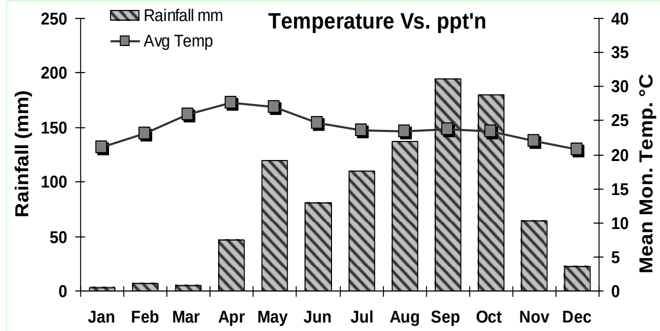

Fig: 5. Comparison between Mean monthly temperatures with the precipitation.

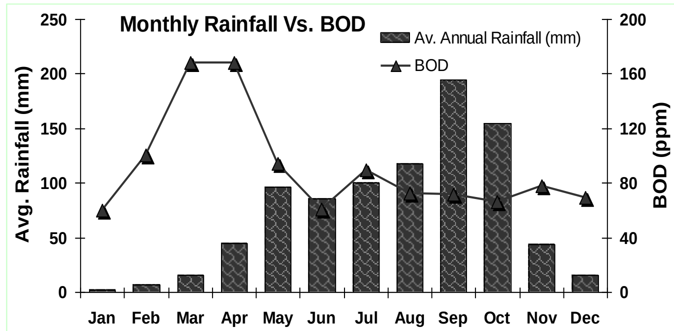

Fig: 6. Relation between the precipitation and mean BOD values

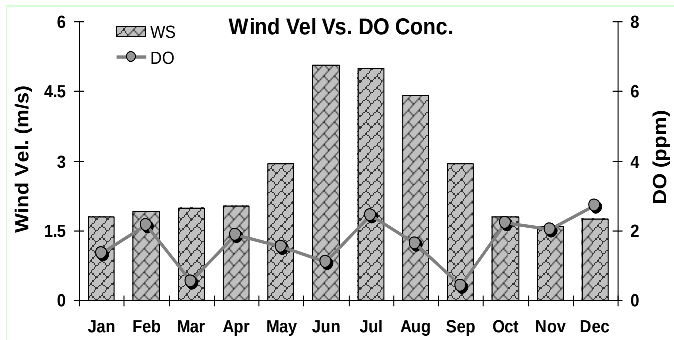

Fig: 7. Relation between the monthly wind velocities with avg. monthly DO level

3.3. Algal seasonal dynamics in the lake and role in supplementing DO level

Algal communities identified upto the genus levels shows algal species from four different families [Table-4]. During summer *Scenedesmus* sp., *Anabaena* sp. and *Anaycstis* sp. were dominant while enormous *Chlorella* sp. was observed during monsoon season (80 %). Micro-algal sampling studies also revealed a greater dominance of diatoms especially *Nitszchia* sp. near the inlet reaches during the summer and

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euglenophycean members like *Euglena* sp. and *Trichellomonas* sp. dominated in the monsoon. Filamentous algae's like *Oedogonium* sp. and *Oscillatoria* sp. were observed near outlets. Comparative analysis of algal populations in biofilms showed a marked difference in the community structures in various zones of the lake. Diatom species such as *Gomphonema* sp. and *Nitszchia* sp. at the inlet and chlorophytes and euglenoides were observed at the outlets. Field investigations reveal that there is a periodic transition from an anaerobic-aerobic (in monsoon) to anaerobic (in summer) and aerobic-anaerobic system (winter/pre monsoon) as algae play a vital role in oxygenating the system that lowers BOD. This depends upon the wind direction and the extent of growth and movement of the macrophytes together with the nutrient influx.

Table: 4. Algae communities identified upto genus level

Chlorophyceae	Cyanophyceae	Bacillariophyceae	Euglenophyceae
Chlamydomonas	*Cylindrospermo*	*Gomphonema*	*Phacus*
Chlorogonium	*-psis*	*Cymbella*	*Euglena*
Scenedesmus	*Arthrospira*	*Navicula*	*Trachelomonas*
Ankistrodermus	*Microcystis*	*Pinnularia*	*Lepocinclis*
Chlorella	*Oscillatoria*	*Nitzschia*	
Oedogonium	*Anabaena*	*Synedra*	
	Merismopedia	*Fragillaria*	
	Lyngbya	*Cocconeis*	
		Melosira	

3.4. Characteristic change in water quality and its improvement after flushing out of macrophytes by wind and water flow

The rainfall pattern shows an increase in the intensity mostly during August, September and October **[Figure-4]**. During pre-monsoon period dense mats of water hyacinth and other weeds covering 85% of surface had contributed to low DO levels that are detrimental for the phytoplankton. Faster decomposition of macrophytes and algal organic biomass due to high temperature (summer) **[Figure-5]** resulted in very high BOD values. The degree of mineralization and bacterial respiration was also very high at this time. BOD values were found to be lower during the other seasons especially in monsoon **[Figure-6]**. Prevalence of hypoxic conditions below critical thresholds over a long period is detrimental to the survival of aquatic biota. Onset of monsoon with higher wind velocities and higher catchment run-off allow the water surface to sunlight and re-aeration, enhancing DO levels **[Figure-7]**. The improvement included greater diurnal cycling **[Figure-8]**, both higher maxima and minima and reduced amount of time spent below the adopted 25% threshold for ensuring survival of all naturally occurring biota.

3.5. Macrophyte spread and DO levels

Dense macrophyte mats limit re-aeration by isolating the air/water interface [24] and block sunlight, limiting photosynthetic oxygen production. The concentration of DO in the lakes diminish as a result of biodegradation of carbonaceous and nitrogenous wastes discharged into the waterbodies, deposited in the sediment and the influx of plant limiting nutrients which leads to eutrophication. [25]. In addition, the large organic load created by water hyacinth mats and other vegetation associated with these mats, increase oxygen consumption [26, 27], and they act as a physical substrate for microbes, the metabolic activity of which further increases oxygen demand [26, 24, 9]. Additionally, the extent of water hyacinth infestation within the lagoons may modify edge roughness, water depth and current velocity allowing flowing water to pass through the middle layers of the water column thus reducing the detention time and greatly inhibiting mixing and re-aeration within the lake [26, 28]. In tropical semi-arid zone lakes, there are also substantial variations in DO between different periods of a day where occasional low DO levels can result in the elimination of key aquatic species. In the case of eutrophic lakes though the DO levels become supersaturated at the mid-day, there are chances of DO reaching 0 ppm due to respiration at night when the concentration of algal biomass is very high and bacteria as well as aquatic biota compete for oxygen resulting in anoxia at night.

During summer around 85% of the exposed water surface area is packed with macrophytes. Total N trapped in the biomass accounts to 1.8 ktons (for a macrophyte cover of 85% in a water spread area of 220 hectares) as water hyacinth can store 1 kg/m^2. Significant diurnal (January and April 2009) variations of DO levels in water were observed to be influenced by the macrophytes in the lake **[Figure-8, 9]**. Figure 8 shows DO measured at the south outlet when it is free of water hyacinth, while the **Figure-9** shows lower DO values measured near the macrophyte infested area which represents restriction of algal growth and algae driven photosynthesis. There was no improvement in the DO levels of the north outlet because of persistent stagnation and the presence of floating macrophytes. As the water flow passes the macrophytes, it undergoes an anaerobic phase, thereby bringing down the DO levels to zero. **Figure-9** gives a comparison between the inlet and outlet DO concentrations, during the dense macrophyte cover.

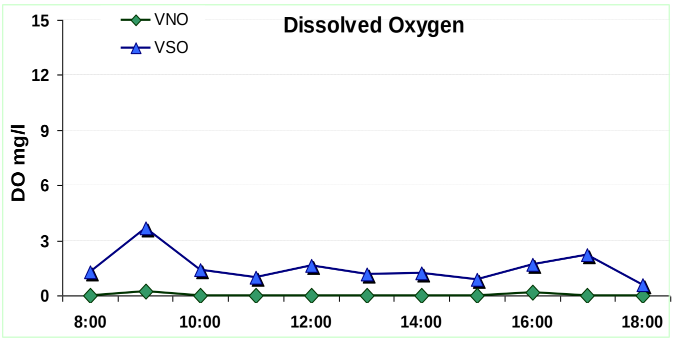

Fig: 8. Diurnal changes of DO levels during April 2009 (summer) at north outlets.

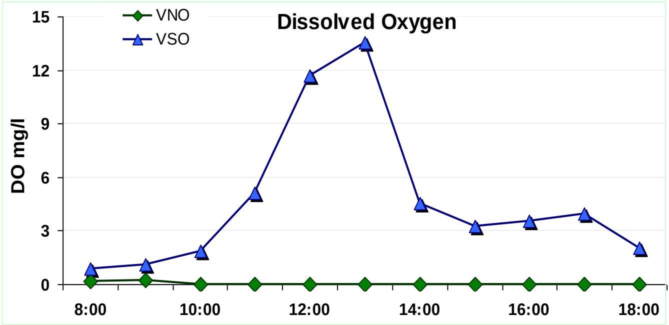

Fig: 9. Diurnal variations in DO concentrations at inlet and outlets

Upstream conditions greatly influences the downstream DO. Improvement in the oxygen content in the Varthur lake outlets shows increasing DO levels with flow. When water is released into storm water drains, its oxygen level is high. However, the oxygen content rapidly diminishes as water move downstream due to mixing of fresh sewage and prevailing anoxic conditions with high organic load and infestation of weeds. This necessitates the clearance of the macrophytes/weeds. Macrophyte removal in the upstream and increasing DO levels at earlier stages would improve the quality of water discharged and that accumulating in the downstream lakes.

3.6. Modified flows, nutrients, proliferation of water hyacinth and rapid nutrient uptake

There is a dynamic interaction between flow, habitat condition and DO saturation in these lakes. Almost all lakes in Bangalore region receive a continuous supplemental dry season flow from sewage or the adjacent agricultural fields. Although the nutrient concentration in the water of Varthur lake was more or less similar with respect to nitrates but an increase in phosphate concentration was observed in summer which correlates positively with the growth of macrophytes and conducive environments for the release of nutrients trapped in the sediments.

The bulk of nutrient uptake during the summer season is performed by the widespread free floating macrophytes. These macrophytes which mainly comprises of water hyacinth and *Alternanthera sp*. covering a substantial portion of the lake surface (85%) captures about 4.5 tons of N/day as depicted in the earlier figure. They propagate very fast with a very high growth rate and engulf the entire water surface in about three months.

The nutrient (C and N) content of the dominant macrophyte population in the lake (from left to right) was investigated. In the lake 10 macrophyte species were observed out of which five dominant macrophyte species arranged as per their abundance from left to right are plotted against their % N content **[Figure-10]**. Higher N content were observed in case of *Lemna gibba* and *Alternanathera phyloxiroides* ~4 g/100 g of dry wt., followed by water hyacinth (2.3 g/100 d of dry wt), *Typha augustifolia* (1.5 g/100 d of dry wt) and *Cyperus* sp. (1.2 g/100 d of dry wt). In other studies, the highest N content was found in *Potamogeton trichoides* Cham. (2.33 g/100 g dry wt.) and *Baldellia ranunculoides* (L.) Parl (2.26 g/100 g dry wt.)[29]. The study conducted in an agricultural drainage lake showed an N content of 2.65 g N /100 g dry wt. in *Potamogeton nodosus* Poir [30]. The N content in *Lemna gibba* in treating the domestic primary effluent in Israel was recorded to be 4.3 % dry wt. which is comparable with the present studies [31]. The study on growth and nutrient storage of water hyacinth showed that 1.6 g N/100 g of dry wt was stored under condition of higher productivity [32].

The study shows that *Alternanthera* sp. together with water hyacinth would have been a dominant accumulator of nutrient in NH_4-N forms. However there was no significant variation in the C content **[Figure-11]** among the major macrophyte species.

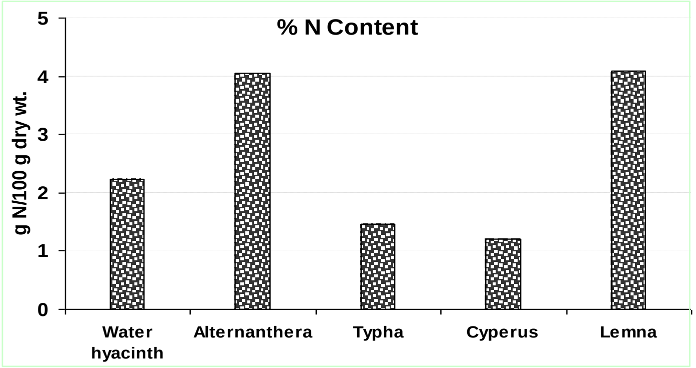

Fig: 10. Variations in percent N content among the dominant macrophytes from left to right.

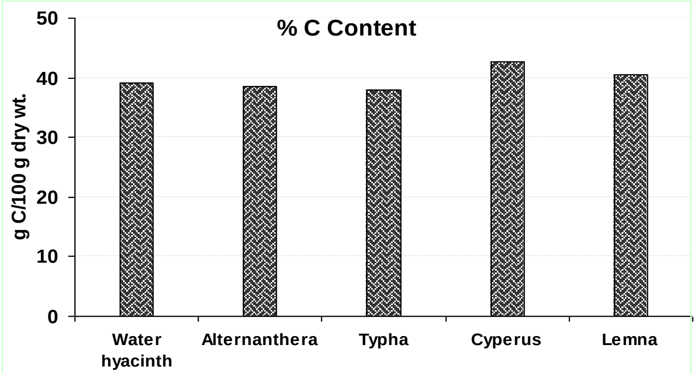

Fig: 11. Variations in percent C Content among the dominant macrophyte species.

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3.7. Plans for the management of macrophytes and associated lower levels of DO

Management arrangements need to recognize that when macrophyte infestations cover the surface of the lagoons, the quality of the aquatic habitat provided is very poor, and opportunities to provide healthy aquatic habitat in a region where most of the existing urban wetlands have been lost or seriously degraded, should be utilized. It is suggested that harvesting and removal of aquatic weeds from the lake rather than letting them sink to the bottom is a necessary prophylactic need. However, due to the large water hyacinth biomass and associated weeds, it was felt that their decomposition process (involving bacteria) would have resulted in significant consumption of the limited DO. Unmanaged exotic aquatic weeds consistently results in poor water quality and reduces the economic value of these otherwise productive habitats. Although the lake examined in this study is impacted by many factors such as altered hydrological regime, increased turbidity and nutrient loads, loss of their riparian zone and run-off from surrounding agricultural areas, the wind induced compaction and removal of macrophytes showed an immediate and substantial improvement in DO levels which were previously excluded because of the low DO content created by weed infestations.

Given the importance of these urban lakes in terms of their role in the livelihood of poor farmers, hydrological cycling, maintenance of micro-climate, as a sink to enormous pollutants and of their high recreational and commercial values there is an immediate need for a rapid improvement of the health of the system which would benefit to maintain the aquatic ecological integrity with optimal balance in urban aquatic systems. The lakes would be very essential further down the years looking at the serious crisis of water, and needs to be well managed for its sustainable functioning and reuse.

Findings of the study show waterbodies further being degraded by the spread and cover of the aquatic weeds/macrophytes and presses on the issues related to complete breakdown of the urban aquatic systems. The results of this study paves a way for initiation and implementation of aquatic weed control programs under existing Urban infrastructure planning and management.

[IV] CONCLUSION

Macrophyte population in the lake maintains the nutrient levels in urban aquatic systems. The increase in nutrient content (32 t N/d) has resulted in a prolific growth of invasive species. During summer, maximum quantity of nutrients in dissolved form is taken up by the macrophytes that cover almost 85% of the lake surface thereby reducing the nutrient content significantly. The lack of air-water interface hampers the aerobic functioning of the lake. Highly anaerobic conditions (-235 mV) are formed which consequently reduces the DO level further creating anoxia. This invasive macrophyte growth in summer raises the quantity of BOD load to about 180 mg/l on the lake significantly. Severe reduced conditions during summer aids in rapid fall of DO levels as low as 0 mg/l. During monsoon in the absence of macrophytes, lake functions as aerobic lagoon driven by micro-algae with satisfactory nutrient uptake and treatability. However in the pre monsoon the system behaves as an aerobic-anaerobic lagoon and finally in the post monsoon period it behaves as an anaerobic–aerobic system.

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