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Spatial Analysis and Characterisation of Lentic Ecosystems: A Case Study of Varthur Lake, Bangalore

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Abstract

Lentic ecosystems′ vital functions such as recycling of nutrients, purification of water, recharge of groundwater, augmenting and maintenance of stream flow and habitat provision for a wide variety of flora and fauna along with their recreation values necessitates their sustainable management through appropriate conservation mechanisms. Failure to restore these ecosystems will result in extinction of species or ecosystem types and cause permanent ecological damage. In Bangalore, lentic ecosystems (for example lakes) have played a prominent role serving the needs of agriculture and drinking water. But the burgeoning population accompanied by unplanned developmental activities has led to the drastic reduction in their numbers (from 262 in 1976 to 81). The existing water bodies are contaminated by residential, agricultural, commercial and industrial wastes/effluents. In order to restore the ecosystem, assessment of the level of contamination is crucial. This paper focuses on characterisation and restoration aspects of Varthur lake based on hydrological, morphometric, physical-chemical and socio-economic investigations for a period of six months covering post monsoon seasons. The results of the water quality analysis show that the lake is eutrophic with high concentrations of phosphorous and organic matter. The morphometric analysis indicates that the lake is shallow in relation to its surface area. Socio-economic analyses show dependence of local residents for irrigation, fodder, etc. These analyses highlight the need and urgency to restore the physical, chemical and biological integrity through viable restoration and sustainable watershed management strategies, which include pollution abatement, catchment treatment, desilting of the lake and educating all stakeholders on the conservation and restoration of lake ecosystems.

Keywords: Lentic ecosystems, watersheds management and conservation, charaterisation

Mathematics Subject Classification Number: 00A99

JEL Classification: O22, Q32, Q57

1.0 Introduction

Lentic ecosystems are one of the most productive ecosystems in the biosphere and play a significant role in the ecological sustainability of the region. Their ecosystem service functions are equally important in terms of sustainable economic and social development. However, continuous inputs of various forms of chemical pollution from a variety of human activities have seriously deteriorated the health status of many lake ecosystems. If this trend continues, it may not only affect human health and social-economic development, but also lead to the collapse of lake ecosystems themselves. (Goldman, *et al*., 1983; Constanza *et al*., 1997; Westman, 1977; Rapport *et al*., 1998). They constitute an essential component of human civilisation, meeting crucial needs to sustain life on earth, such as water (agriculture, drinking, etc.), food (protein production, fodder, etc), biodiversity (diverse flora and fauna), energy (firewood wood, etc), recreation (tourism), transport, water purification, flood control, pollutant sink and climate stabilisers (Ramachandra and Ahalya, 2004; DEP, 2002). Lakes are under increasing threat due to the separate, but often combined impact of identifiable point sources such as municipal and industrial wastewater, and non-point degradation like urban and agricultural run-off within a lake's watershed. Major degrading factors include excessive eutrophication due to nutrient and organic matter loading; sedimentation due to inadequate erosion control in agriculture, construction, logging and mining activities; removal of native vegetation in the catchment; introduction of exotic species; acidification from atmospheric sources and acid mine drainage; and contamination by toxic (or potentially toxic) metals such as mercury and organic compounds such as poly-chlorinated biphenyls (PCBs) and pesticides. In addition, physical changes at the land-lake interface (such as. draining of riparian wetlands) and hydrologic manipulations (such as damming outlets to stabilise water levels) have major impacts on the structure and functioning of these ecosystems (Prasad *et al.,* 2002, Ramachandra, *et a*l., 2005a, 2005b, Wetzel *et al*., 1991)

Lakes have played a major role in the history of Bangalore serving as an important drinking and irrigation sources. They occupy about 4.8% of the city's geographical area (640 sq. km) covering both urban and non-urban areas. Bangalore has many man-made wetlands but has no natural wetlands. They were built for various hydrological purposes and mainly to serve the needs of irrigated agriculture (Ramachandra and Ahalya, 2001). The spatial mapping of water bodies in the district revealed the number of waterbodies to have decreased from 379 (138 in north and 241 in south) in 1973 to 246 (96-north and 150-south) in 1996. Table 1 provides the distribution of tanks by taluks in Bangalore. Spatio-temporal analyses reveal 35% decline in number of waterbodies (Figure 1) due to urbanisation and industrialisation.

Bangalore city is located over ridges delineating four watersheds, viz. Hebbal, Koramangala, Challaghatta and Vrishabhavathi watersheds (spanning over Bangalore north and south taluks). The undulating terrain in the region has facilitated creation of a large number of tanks providing for the traditional uses of irrigation, drinking, fishing and washing. This led to Bangalore having hundreds of such water bodies through the centuries. Even in early second half of 20^{th} century, in 1961, the number of lakes and tanks in the city stood at 262. These, and open spaces generally, were seriously affected however with the enhanced demand for real estate and infrastructure` consequent to urbanisation. The built-up area in the metropolitan area was 16 % of total in 2000 and is currently estimated to be around 23-24 %. Official figures for the current number of lakes and tanks vary from 117 to 81, but recent remote sensing data gives a different picture altogether, showing only 33 lakes visible, out of which only about 18 are clearly delineated while another 15 show only faint signs of their former existence. The tanks were reclaimed for various purposes such as residential layouts, commercial establishments, sport complexes, etc. Consequent to these, decline in groundwater table (20 m to 150 m), flooding, changes in micro climate were noticed (Ramachandra,. et al., 2002a, 2002b). This highlights the need for appropriate conservation, restoration and management measures. In this regard a study was undertaken to characterise Varthur lake. The study consisted of three parts (i) Morphometric survey – to provide the information on the depth, surface area, width, etc of the lake ((Mutreja, 1986)); (ii) Water quality survey – to elucidate the quality of lake water and the nearby groundwater (APHA, 1985; NEERI, 1988; Development Alternatives 2000*;* DWIIH,1995); (iii) Socio-economic survey – to assess the dependency of the nearby residents on the lake ecosystem (Edward, *et al.*, 1997).

2.0 Study area:

Varthur Lake is one of the largest lake located in the Bangalore South taluk of the Bangalore District in Karnataka. Bellandur tank of the Bangalore south taluk (Figure.2) is interconnected to the surrounding wetlands which drain into Varthur and finally into the Dakshina Pinakini river. It has a large surface area and is the main irrigation source to the nearby agricultural fields This lake has played an important role in maintaining water resources for irrigation since its construction over the centuries (Government of Karnataka 1990), it has developed into a complex ecosystem that provides habitat for a wide variety of flora and fauna, including resident and migratory waterfowl. The lake also endows the local community with a pleasant microclimate and considerable aesthetic appeal. The lake is surrounded by small farms that grow rice, ragi, coconut, flowers, and a variety of fruits and vegetables, which are grown using the lake water. The total land irrigated by the lake water amounts to 625 hectares. The largest town in the immediate area is Varthur, which had a population of 5,431 as per 1981 census (Census of India, 1981). Several smaller villages are also located near the periphery of the lake. Figure 3 presents a view of southeastern Bangalore and Varthur Lake's catchment area as surveyed in 1970 to 1974. Human settlements and the roadways are marked in red; the outskirts of Bangalore city proper can be seen in the upper left-hand corner. The loss in lake interconnectivity in Bangalore district is attributed to the enormous increase in population and the reclamation of tanks for various developmental activities.

Varthur Lake is part of a system of interconnected tanks and canals that receive virtually all the surface runoff, wastewater, and sewage from the Bangalore south taluk (Figure 2 and 4). Rapid development and population expansion, both within Bangalore and in the surrounding towns and villages, have taken a heavy toll on many of the tanks in the area, and Varthur is no exception. Analyses of Varthur lake drainage network revealed that the drainage network between Bellandur and Ulsoor in Varthur lake drainage network is lost due to conversion of Chelgatta tank into a golf course (Figure 4). Varthur lake finally joins the Dakshina Pinakini river The Bangalore South taluk alone has experienced a surge in its population from 2,84,556 to 4,45,581 between 1971 and 1981 (Census of India, 1981). Contamination of water supplies is having a negative effect on the quality and quantity of crops produced using the lake water. This poses a threat to the primary source of income for people living near the lake.Pollution loading has exceeded the lake's ability to assimilate contaminants, leading to visible degradation of the quality of water in the lake. Examining the current ecological status and economic value of the lake is crucial for developing appropriate remedial measures.

3. Objectives

The purpose of the study was to identify the most immediate threats to the ecological status of the Varthur lake and to evaluate the necessity of undertaking restoration efforts in order to maintain the benefits provided by this tank. Three components of the Varthur lake ecosystem was studied namely the (i) morphometry, including depth profiling and calculation of volume, to evaluate the risks posed by sedimentation and to provide general morphometric information for future analysis of Varthur lake; (ii) water quality, to determine the extent of the pollution in Varthur lake during the post-monsoon and dry winter seasons and analysis of groundwater to detect potential contamination from lake seepage; and (iii) socio-economic status, of the stakeholders living in close proximity to Varthur lake to determine their dependency on the lake, how their use of the lake has changed over time, and their willingness to support restoration efforts. The results of this study will also provide a base for future analysis of the ecology of the lake and its importance to local residents.

4. Methods

I Morphometric Survey: Depth profile of the lake was collected using calibrated handheld Global Positioning System (GPS). Surface area (area), shoreline, maximum length, maximum width, mean width and volume were estimated using a geo-referenced vector layer.

i.) *Verification of the Shoreline:* Shoreline was digitised from the cadastral map of 1:6000 using MapInfo Professional 5.0, verified with the topographic map of scale 1:50,000, the Survey of

India (SOI). Surface area (area), shoreline, maximum length, maximum width, and mean width of the lake were estimated. The shoreline layer was overlaid on remote sensing data of (MSS data of Indian Remote Sensing Satellite) December 1998 and 2002 using Idrisi 32 software (Ronald, 1999).

ii.) *Bathymetric Analysis:* The depth of the lake was measured at randomly distributed points around the lake. The location of these points was recorded using a handheld GPS (Global Positioning System). The depth of the lake was sampled during November 2005 and February 2006, corresponding to the post-monsoon and dry seasons, respectively. The position of the GPS points taken in the field were rectified to fit the map of the lake by comparing the GPS coordinates for two landmarks (the bridge over the northeast outlet and the main irrigation canal) to previously established coordinates published by the Survey of India, 1980. The November depth samples were measured with a weighted line and measuring tape. A total of 31 sample points were recorded using this method. February samples were taken from a coracle boat using a graduated aluminum pole with a flat disc attached to the bottom. A total of 46 sample points were recorded with this method.

iii.) *Contour Mapping:* The depth data collected in February were converted into data points on the geo-referenced map of Varthur lake using MapInfo Professional 5.0 software. These points were converted to isohyets - contours of 0.25 meter interval using the polyline tool incorporated in the software.

iv.) *Volumetric Analysis:* Estimations of the February volume of Varthur lake were made using two methods, (A and B), based on the data used in the calculations. Method A was a simple manual calculation based on surface area slices at the 0.25 meter intervals used on the initial digitised map. Method B was a more accurate computer-assisted analysis that used a grid file of the lake extrapolated from the original data points and the contour map.

- Method A: This method subjected data from the contour map. The maximum depth of the lake is represented by the 2.0 m contour. This procedure involved finding the volume between the contours and subtracting the volume of each layer that is lost due to the slope of the bottom of the lake.
- Method B: Depth profile was converted to grids at 5 meter intervals through Kriging and volume was computed based on on the Trapezoidal Rule, Simpson's Rule, and Simpson's 3/8 Rule.

II **Characterisation of Lake and Ground water**: Water samples from Varthur lake were collected during October - November 2005 and January 2006. October samples were collected from the shoreline nearest to the following locations: Bellandur Canal, the south-southwest portion of the lake, and the northeast and southeast outlets. Water samples were collected from 10 to 30 cm below the surface of the water during the morning hours. These samples were collected and stored in 500 ml polyethylene containers, with the exception of those collected in borosilicate glass bottles for dissolved oxygen analysis. No preservatives were added as the samples were transported to the laboratory within six hours and either refrigerated or analysed immediately. Bore well water samples were collected in January, from four locations closest to the southern shore of the lake. These samples were collected and stored in clean, white, 500 ml polyethylene containers. On-site analysis of lake water included air and water temperature, transparency and, in the case of October and November sampling, dissolved oxygen. Laboratory analysis included: acidity, alkalinity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), chloride, chlorine residual, coliform bacteria, dissolve oxygen (DO), electrical conductivity (EC), fluoride, hardness, iron, nitrate, pH, phosphate, potassium, sodium, sulphate, solids (total, total dissolved, and total suspended) and turbidity. The water analyses followed standard procedures published by the Indian National Environmental Engineering Research Institute (NEERI, 1988) and the American Public Health Association (APHA, 1985) and Development Alternatives (Development Alternatives 2000). Groundwater samples were tested for ammonia, chloride, coliform bacteria (DWIIH,1995), EC, fluoride, nitrate, and pH using standard methods.

III Socioeconomic Survey: Randomly chosen households from Varthur town, and Baligeri and Ramagondanhalli villages were surveyed using a standard questionnaire (Ramachandra *et al*., 2005b). 22 households took part in the survey, representing a total of 217 people. The questions posed during the interviews were classified under the following headings: demographic information, family history, domestic water usage, groundwater usage, irrigation, other commercial uses, water usage for livestock, livestock fodder, aesthetic value and recreation, fishing and aquaculture, waterfowl, spiritual value, health effects, community involvement in restoration, etc.

Questions regarding domestic water usage, irrigation, other commercial uses, water usage for livestock, livestock fodder, and fishing and aquaculture attempted to quantify residents' direct economic reliance on lake and groundwater resources. Other direct uses, such as recreation and, in some cases, spiritual value, were investigated using qualitative questions regarding use of the lake (Edward, *et al.*, 1997). Any changes in lifestyle, such as a change in occupation, that may have been caused by deterioration in the quality of the lake were investigated in the family history section of the questionnaire. The use of groundwater resources was included in the survey to identify trends in the overall reliance on lake resources compared to groundwater. Usage of groundwater may be indirectly associated with lake water resources as the Varthur lake could be responsible for recharging local aquifers. Questions regarding groundwater recharge were intended to detect changes in the local water table that could be the result of reliance on bore wells.

Questions regarding waterfowl and fish populations pertained to qualitative information about changes in the ecology of the lake, especially the biodiversity and abundance of wildlife. These topics, along with questions regarding aesthetic value, sought information on less tangible benefits provided by the lake that may be affected by a decline in its overall condition. Potential harm to the local population as a result of this deterioration was also investigated through questions regarding mosquito populations and incidents of insect and water-borne diseases. The heritage value of the lake as well as family commitment to remain in the area were investigated through questions regarding both family history and their desire to see future generations remain near Varthur. Determining residents' overall concern for the future of the lake was the motivation behind the question regarding support for future reclamations efforts.

5.0 Results and Discussion:

I. Morphometric Survey: Overlay of vector layer of Varthur lake shoreline (Figure 5) with the remote sensing data (of 2006), it is seen that the general shape and surface area of the lake is virtually the same in 2006, 1998 as it was between 1971 and 1974, in the SOI map. The SOI map was used as a reasonable approximation of the current shoreline of the lake and the shoreline of the lake has not changed significantly since 1998. 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 is estimated to be 1,478,000 m^2.The shoreline of Varthur lake does not appear to have changed considerably between the early 1970's and present day, unlike many other tanks in the district that have decreased drastically in size due to sedimentation and encroachment. Figure 6 is a bathymetric map of Varthur lake and shows the lake has an estimated maximum depth of approximately 2.0 meters. The mean depth is estimated to be 1.05 m and the lake bottom exhibits a very gradual downward slope from west to east, with maximum observed depth occurring near the dam wall. These results are consistent with sedimentation patterns common to dammed reservoirs. Table 2 summarised the volume computation based on Method A. Figure 7 presents the depth profile produced using Method B, which involved software-assisted volumetric analysis incorporating the same contour map as well as the actual data points collected in the field to extrapolate a depth profile of the lake in grid form. This profile produced a maximum estimated depth of 2.55 m, which is 0.55 m greater than that of the previous contour map. Volume computed based on calculus-based formulas - Trapezoidal, Simpson's, and Simpson's 3/8 Rule were applied to the above profile, resulting in three separate but highly similar estimates of the volume. The results of these calculations are summarised below in Table 3. Table 4 lists other morphometric parameters that emphasise the fact that the whole of Varthur lake is shallow in relation to its surface area. The lake exhibits low shoreline development consistent with the lack of topographical diversity in the region; this factor contributes to the regularity of the sedimentation patterns within the lake as there are few formations to interfere with the water currents.

The velocity and turbidity of the water decreases considerably due to the increase in cross-sectional area and the presence of large mats of water hyacinth as silt and sediment-laden water enters Varthur lake from the Bellandur Canal,. At this point, the water no longer contains sufficient energy to displace or carry larger suspended particles. These particles are deposited on the lake bottom near the inlet, forming a delta. Smaller suspended particles are deposited further away from the inlet where the velocity and turbulence decrease further. This forms a gradual downward-slope along the length of the reservoir, with the deepest section occurring near the dam. The velocity of the water increases as its approaches the northeast and southeast outlets, and these areas appear to accumulate less sediment than the main body of the lake. Sediment deposits in Varthur lake is lesser compared to other tanks in the area due to desilting by local residents around the edges of the lake. This activity was observed in several areas along the northern shoreline while conducting field sampling. Varthur lake has a catchment area of 1.8 km^2, the second largest in the Bangalore South taluk (Govt. of Karnataka, 1990). This catchment area contains a substantial human population engaged in agriculture and various industries and, therefore, the potential for accelerated sedimentation due to anthropogenic causes is substantial. Without previous depth profiles of the lake, it is difficult to estimate the rate of sedimentation. However, even if the historical depth of Varthur is very shallow, its lack of depth makes it highly susceptible to increases in sediment loading caused by human development within the catchment area. Loss of depth and volume would reduce the water supply available to local farmers who continue to use Varthur as a primary water source. It would also have a detrimental effect on the quality of water in the reservoir and degrade habitat for fisheries and wildlife. The ability of the lake to moderate the local climate would be reduced, as the amount of energy absorbed and released by the lake would decline along with its depth and volume. Accumulation and impaction of silt on the lake bottom also has the potential to impede the infiltration of rainwater into the aquifers below. This infiltration is the main water source of groundwater recharging in the Bangalore area. Varthur lake represents a major local reservoir of rainwater and a reduction in the permeability of its benthic layers would decrease the water resources available from local open and bore wells. These wells are the primary source of domestic, potable, and agricultural water, and their decline would be detrimental to the people living in the area.

II **Characterisation of surface water**: Results of the water analysis for samples taken near the northeast outlet during October, November and January are presented in Table 5. The pH of the water was found to be slightly alkaline (approximately 7.5 to 8.0) for all water samples. November water samples exhibited a strong ability to neutralise acids in solution due to the presence of bicarbonate. The acidity of the samples was much less than their alkalinity. Total hardness showed little variation during the sampling period, indicating that the overall concentration of calcium and magnesium salts is fairly constant; hardness due to calcium carbonate ranged from 59 to 68% of total hardness for November and January samples. In November, light was able to penetrate the upper 19 to 24 cm of the water column. Transparency was substantially reduced during January. Further examination of physical properties revealed high concentrations of suspended and dissolved solids. The concentration of total dissolved solids (TDS) showed substantial seasonal variability, increasing three-fold between November and winter sampling periods. This increase in TDS corresponds to a similar increase in electrical conductivity. Moderate to high concentrations of total suspended solids (TSS) were also present in January samples. Water from the middle of the lake exhibited the highest concentration of TSS by far. The wide variation between TSS concentrations for various sampling sites could be due to the presence of organic floatables observed during collection of the samples. The presence of these clumps of matter could significantly increase the TSS value for a sample in comparison to a similar sample without clumps. Turbidity from organic and inorganic suspended matter in Varthur has the potential to impact the ecology of the lake in several ways. Many toxic contaminants, such as heavy metals and some pesticides, could potentially find their way into Varthur by adhering to solids in solution. Eventually, much of the suspended matter will settle in the bottom of the lake where they smother benthic organisms and contribute to siltation. Turbidity is also the most important factor in prolonging the survival of faecal coliform in water bodies because the particulate matter shelters bacteria from harmful solar radiation (DWI, 1995).

Dissolved oxygen (DO) levels in Varthur lake were extremely low. Water temperature ranged from 22 to 26°C prior to 9:00 AM on all sampling dates. The high BOD of the water samples indicates that decomposition of organic matter is one of the main factors leading to the low DO concentrations observed in the lake. Much of the remaining oxygen is likely consumed through nighttime respiration by aquatic plants. Eutrophic lakes similar to Varthur often experience a daily cycle of hyper- and hypo-oxygenation due to the high concentration of photosynthetic algae that produce oxygen during daylight hours and consume oxygen at night. However, this requires further investigations to confirm diurnal-nocturnal fluctuations in DO. The low DO content limits diversity of animal life, which can survive in the lake. Anoxic conditions also affect many other chemical processes within the lake that can be detrimental to organisms, such as the conversion of organic nitrate to toxic ammonia. The high BOD values imply that virtually all the organic matter contained in the samples were biologically degradable, and that the combined concentrations of sulphates, nitrates, ferrous iron, and other organic components that cannot be oxidised by bacteria are comparatively low. Based on these findings, only a small proportion of the organic pollution in Varthur could have its origin in industrial effluents. The majority of organic pollution likely comes from animal and plant sources, such as sewage and plant death within the lake. In addition to sewage, several aquaculture ponds are seasonally drained into the lake also have the potential to contribute substantial amounts of nutrient-rich organic debris.

The concentration of chloride ions in November samples averaged 102 mg/l. In January samples, these values increased 60 to 70 percent. October lake water samples contained less than 0.2 mg/l of residual chlorine**.** Sulphate concentrations in the lake were consistently low, however, a substantial decrease in sulfate occurred between November and January sampling dates. Sodium concentrations for November were only moderately high. Elevated levels of potassium were observed in November samples. January samples were well within standard range for unpolluted surface waters. Potassium is also an essential element for plant growth. Elevated levels of potassium were observed in November samples, indicating potential contamination from industrial effluents or fertiliser. Potassium concentrations dropped substantially in January, possibly due to uptake by the increasing macrophyte population. A similar trend was observed for sulfate and could be caused by winter plant uptake as well. Elevated chloride values could be due to many factors, including sewage, industrial effluents, and agricultural runoff. The seasonal variation may due to the fact that January concentrations were not diluted by monsoon rainwater.

Nitrate concentrations present in October samples were low, averaging only 0.24 mg/l. The average concentration of nitrate increased to 1.00 mg/l and 1.27 mg/l in November and January, respectively. Ammonium was estimated to be in excess of 3.0 mg/l for three of the four October samples. Phosphorus concentrations from January samples were very high, averaging 15.1 mg/l. Varthur contains significant amounts of the macronutrients required by aquatic plants in large quantities in order to survive and grow, especially phosphate. Excess amounts of phosphorus could be the result of contamination from sewage and/or fertilisers. Eutrophication has resulted in large populations of algae to develop in Varthur, which imparts a green colour. This process has also assisted in the intrusion of *Eichhornia crassipes* (water hyacinth). Although the amount of lake surface occupied by this plant fluctuated dramatically between sampling dates, the western portion of the lake was consistently covered with mats of hyacinth, as were the two main outlets. Overall, coverage by water hyacinth increased during the winter months. The concentration of nitrate was slightly higher than standard values for unpolluted waters in October samples, but increased substantially in November and January. The relatively low nitrate concentrations observed in Varthur could be a result of several biological processes. Loss of nitrate in Varthur could be the result of *ammonification*, the conversion of organic nitrogen to ammonium during the decomposition of organic matter. High concentrations of ammonia observed in October samples support this explanation. Under anoxic conditions, nitrate may also be converted to nitrite; it is likely that such conditions exist near the bottom sediments of Varthur lake, given the extremely low oxygen levels of the surface layers, and that this process may be partly responsible for the lower concentrations of nitrate in the water. Loss of nitrate also occurs through uptake by macrophytes and algae; during periods of high plant growth, this process may significantly reduce nitrate concentrations in the lake. Ammonia concentrations during November were high enough to be toxic to many forms of aquatic life. When water samples from January were viewed under a microscope, the most dominant zooplankton by far was Daphnia, a species that is highly tolerant of ammonia.

Bacterial culturing confirmed the presence of the bacteria *E. coli* in the lake. The bacterium *Escherica coli* is indigenous to the intestines of animals, including humans. Its presence in Varthur indicates that faecal matter contaminates the lake. Faecal contamination is often associated with other types of pathogenic bacteria and viruses found in untreated sewage. The turbidity of the lake water, along with its warm temperature, mildly alkaline pH, and low oxygen levels, could lead to prolonged survival of pathogenic bacteria for up to several days. The water sample taken from the Bellandur Canal in November was very similar in composition to those taken from Varthur lake, and it is likely that many of the contaminants that enter Bellandur lake from its own substantial catchment area eventually make their way to Varthur.

Characterisation of Groundwater: Results from the groundwater survey are presented in Table 6. These wells were located at opposite ends of the lake, approximately 250m and 750 m from the southeastern and southwestern shorelines, respectively. The groundwater parameters were found to be within the limits set by the 1983 Indian Standards Specification for Drinking Water: ammonia, chloride, electrical conductivity, fluoride, nitrate, and pH. Two of the samples tested positive for minor concentrations of coliform bacteria. There is a possibility that coliform bacteria present in two of the samples could have originated from sewage effluent in the lake.

III Socioeconomic Survey: The socio-economic survey revealed that the total land area irrigated using Varthur lake water is 622.27 hectares and the total number of farmers dependent on the lake water for irrigating their lands is 1159. In Varthur, Sorahumase and Valepura village, the land irrigated by the lake water amounts to 322.27, 223.12 and 76.57 hectares respectively. The type of crops grown in Varthur village and the area under each crop is as follows: Paddy – 312.27 hectares, coconuts –3.33 hectares, bananas –3.75 hectares, Beetle leaf –0.11 hectares, arecanut – 0.04 hectares and Floriculture – 2.15 hectares. In Siddapur village the main crops grown are vegetables and floriculture whereas in the nearby Ramagondanahalli it is vegetables, greens and flowers. All respondents used bore wells to meet their domestic water needs. 9 of the 22 households interviewed purify their drinking water with a filtration system, and one household boiled the water prior to drinking. 20 of the households, representing 83% of the survey population, relied on agriculture as their primary source of income. 12 of these households relied exclusively on lake water to irrigate their crops, and 2 more used both the lake and bore wells for this purpose. 10 of the houses that use the lake for irrigation reported a decline in both the quality and quantity of crops due to pollution of the lake water. 14 households raise cattle, primarily for milk. At least 11 of these farms rely exclusively on plants growing on and around Varthur lake to feed their cattle. 9 of these 11 farms rely on the sale of dairy products for part of their income; the percentage of total income derived from dairy products for these farms ranged from 1 to 74%, with mean and median averages of 32% and 40%, respectively. None of the households were involved in fishing the lake, however, one was actively engaged in aquaculture of carps in lake-water-filled dugouts near the shore. Another respondent indicated a desire to start a similar operation.

All of the residents surveyed indicated that their families had lived in the area for one generation or more. Duration of residency ranged from 30 years to more than 200 years and at least 60% of the families had lived in the area for over 100 years. 19 of the 22 households surveyed would actively support reclamation efforts for Varthur lake. 16 of the 22 households visit the lake on an annual basis to submerge idols during Ganesh festival. 86% of the respondents indicated that they had noticed deterioration in the quality of the lake. Although estimates of when this deterioration began varied widely, (from 6 to 40 years), over half of the estimates ranged from 15 to 20 years ago. 10 of the farms reported a reduction in the quality and quantity of their crops as a consequence of polluted lake water. 18 of the respondents indicated that the mosquito population around Varthur has increased in recent years. One respondent indicated that family members had suffered from malaria and dermatitis. Another household that did not filter or boil their drinking water reported problems with viral fever. The smell given off by the lake in winter months was considered to be a nuisance by 16 of the households involved in the survey. The effect of polluted lake water on crop production could very well be detrimental due to factors such as pathogens contained in the water. It is unclear whether aquaculture has become popular because of a decline in the population of fish in the lake or because of its comparative convenience and increased yield. Several residents lamented the fact that fish stocks have declined and they are no longer able to enjoy this resource.

Water hyacinth is often classified as a nuisance species in Bangalore tanks. However, it provides a significant and inexpensive source of cattle fodder for farmers around Varthur as well as a source of income for residents who gather and sell the water hyacinth. The majority of households in the villages surveyed maintain dairy cattle to feed their families and, in most cases, to supplement their income. While estimates of income derived from dairy varied widely, this income would be reduced if farmers had to purchase fodder outside the lake area. Loss of lake fodder may prevent some households from maintaining cattle at all.

Many residents relied on bore wells or open wells for all their water needs, a trend that increases rapidly as distance from the lake increases. Reliance on bore wells does not necessarily negate their reliance on Varthur lake, however, because Varthur could play an important role in recharging local aquifers in the area. 50% of the population represented in the survey does not filter well water prior to drinking. This makes them more susceptible to potential contamination of groundwater supplies by pollutants in the lake water.

Varthur exhibits several features that could have led to the increase in mosquito populations reported by local residents, including consistently warm water temperatures and large populations of water hyacinth that provide breeding habitat for these insects. Mosquitoes constitute both a nuisance and a public health risk in the vicinity of the lake, as they are carriers of diseases such as malaria, encephalitis, and dengue fever.

Few of the people living near Varthur do not have direct contact with the lake beyond the annual submersion of Ganesha idols. Many respondents were generally unaware of changes in the ecology of the lake unless they pertained to sight, smell, or mosquito populations. Most of the respondents were unable to provide information on wildlife populations, especially fish. Despite these observations, most respondents indicated a willingness to support efforts aimed at restoring Varthur lake to a less polluted state and hoped that their children would remain in the area around the lake to raise their families.

6.0 Opportunities and Initiatives for Restoration

Efforts towards lake restoration and conservation in Bangalore are piecemeal and reactive. Conservation efforts could be far more effective if we could avoid habitat degradation. This approach would require an ability to predict the elements of the lake biota that are most vulnerable to extinction and to identify their ecological attributes (bird migration, fish diversity, etc.). A related point is the need to assess the health of the lake community and to monitor changes in it over time. The preliminary step that has to be implemented in restoring lake for their long-term sustenance includes:

i.) **Pollution impediment**: Wastewater, solid and semi solid wastes entering in to the lake from external sources must be stopped before any restoration work is implemented.

ii.) **Harvesting of Macrophytes**: Water hyacinth and other nuisance vegetation present in the lake, causing eutrophication, must be removed manually or mechanically. Weed infestation can also be controlled by applying chemicals like methyl-chlora-phenoxy-acetic acid, hexazinore, etc., and biological control by means of introducing *Pila globosa* (trophical snail), Chinese grass carp (fast growing fish) etc. that feed on many aquatic plants.

iii.) **Desiltation**: Dredging of the sediments in the lake to improve the soil permeability, water holding capacity and ground water recharge. Recent technological developments do permit wet dredging. Studies in Kolar district reveal that desilting of waterbodies helps in improving the groundwater table while lowering fluorides contamination in groundwater.

iv.) **Rain water harvesting**: The lake can also be used as rainwater harvesting structure. After desiltation or dredging, the storage capacity i.e., the water holding capacity of the lake would increase and as Varthur lake has a large catchment area, it would prove to be an effective rainwater harvesting structure. The bunds surrounding the lake can be strengthened and fencing should be provided around the lake. A draw well can be constructed at one end of the tank with an underground filter media connecting the well and tank bed to fetch clear water.

v.) **Watershed Management:** Watershed management is the rational utilisation of land and water resources for the optimum production with minimum hazard to natural resources. As an extension of the restoration programme, watershed management practices are essential for proper land use, protecting land against all forms of deterioration, conserving water for farm use, proper management of local water for drainage, flood protection and sediment reduction and increasing productivity from all land uses.

vi.) **Best Management Practices:** The restoration programmes with an ecosystem approach through Best Management Practices (BMPs) helps in correcting point and non-point sources of pollution. Key steps for best management practices include:

- Pollution alleviation practices to reduce the engendering of non-point source of pollution (mainly agricultural and storm runoff) through source reduction, waste minimisation and process control.
- Promoting public education programmes regarding proper use and disposal of agricultural hazardous waste materials and regular monitoring of lakes, which are rudimentary. The local schools can undertake the periodic monitoring of water bodies and educating the stakeholders on the importance of restoration and maintenance of the Varthur lake.
- Afforestation with native species in desolate areas in the catchment area to control the entry of silt from run off.
- The shorelines of the lakes should be lined with bricks or stones to control shoreline erosion.
- Constructed wetlands for the purpose of stormwater management and pollutant removal from the surface water flows.
- Infiltration trenches for reducing the storm water sediment loads to downstream areas by temporarily storing the runoff.
- Extended detention dry basins for removing pollutants primarily through the settling of suspended solids.
- Gyration of crops rather than monocultures to reduce the need for N and assist with pest control and help in aeration of soil.

These restoration goals require profound planning, authority and funding along with financial resources and active involvement from all levels of organisation (Governmental and Non-Governmental Organisations (NGOs), research organisations, media, etc.) through interagency and intergovernmental processes all made favourable in innovating and inaugurating the restoration programs. Network of educational institutions, researchers, NGO's and the local people are suggested to help restore the fast perishing Varthur lake ecosystem and conserve it by formulating viable plans and management strategies.

7.0 Summary

Morphometric, physical and chemical charaterisation of the lake revealed that:

(i) The morphometric survey showed that the lake occupies an area of 1 478 000 m^2 with a mean depth of 1.05m. The morphometric results emphasise the fact that the whole of Varthur lake is shallow in relation to its surface area.

(ii) The results of the water quality analysis show that the lake is eutrophic with high concentrations of phosphorous and organic matter. All the parameters analysed were above the standards prescribed for surface waters. The lake was also subjected to faecal contamination. The groundwater analysis did not reveal any contamination by lake water, but further analysis has to be undertaken to rule out the possibility of groundwater pollution.

(iii) Nutrient enrichment is largely responsible for the poor quality and Varthur lake displays many features common to eutrophic water bodies, such as low dissolved oxygen levels and high ammonia content, which result in a reduction in the diversity and number of animal species that can inhabit a lake. Nutrient and organic pollution is likely exacerbating problems like plant overgrowth, pathogenic bacteria, increased mosquito populations, and unappealing smell. The most significant source of this pollution is due to inflow of untreated sewage of the Bangalore city.

(iv) The socio-economic aspects of Varthur lake showed that local residents continue to rely heavily on the lake for cattle fodder and irrigation. It is obvious that Varthur lake continues to provide substantial economic benefits to the local population, despite the tendency of some locals to avoid direct contact with the lake due to the previously mentioned health risks and aesthetic concerns. Factors that elude quantification through a socio-economic surveying, such as microclimate regulation, biodiversity, and the rich heritage associated with the lake, add to the value of this resource. All of these benefits are being eroded by contamination of the lake and, therefore, lake restoration must take place in order to maintain and, perhaps, improve the quality of life currently available to residents of the Varthur lake area. A majority of residents in the area recognise the importance of the lake and are willing to offer their support for such efforts.

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Table 1: Talukwise distribution of tanks

Taluk	No. of tanks
Bangalore North	61
Bangalore South	98
Hoskote	23
Anekal	44
Magadi	11
Nelamangala	13
Devanahalli	12

Table 2 Volume calculation using Method A

Cont. ID	Area (m^2)	Depth (m^3)	Volume
1	11,680	2.00	0
2	166,900	1.75	22,323
3	382,200	1.50	68,638
4	644,100	1.25	128,288
5	862,000	1.00	188,263
6	1,025,000	0.75	235,875
7	1,134,000	0.50	269,875
8	1,253,000	0.25	298,375
9	1,478,000	0.00	341,375
		Total:	**1,553,010**

Table 3 Results of Volume Calculations: February

Method	Information Source	Application	Estimated Volume
A	Contour map		1 553 010 m^3
B	Depth profile in grid form	Trapezoidal Rule Simpson's Rule Simpson's $^3/_8$ Rule	1 574 494 m^3 1 574 473 m^3 1 574 519 m^3

Table 4 Morphometric Parameters of Varthur lake

Parameter	Values from Contour and SI Map	Alternate Values from Depth Profile in Grid Form
Area	1 478 000 m^2	1 477 196 m^2
Maximum observed depth	1.85 m	
Maximum estimated depth	2.0 m	2.55 m
Mean depth	1.05 m	1.07 m
Relative depth	0.15%	0.19%
Shoreline	6 560 m	
Shoreline development	1.52	
Maximum length	1 810 m	
Maximum width	1 040 m	
Mean width	117 m	

Table 5: Comparison of Water Quality Data and Various Pollution Standards

Parameter	Results *from the Northeast Outlet*			Standard value for unpolluted surface waters[1]
Sampling Date	Oct-11	Nov-11	Jan-11	
Acidity, total (mg/l)	n/a	92.0	n/a	
Alkalinity, total (mg/l)	n/a	332.0	n/a	
Alkalinity as HCO3 (mg/l)	n/a	332.0	n/a	
D.O. (mg/l)	2.0	3.0	2.9	
EC (μS/cm)	460	474	1420	10-1000
Hardness, Total (mg/l)	213.6	209.3	232.5	
Hardness, $CaCO_3$ (mg/l)	132.0	124.0	158.1	
Hardness, $MgCO_3$ (mg/l)	n/a	77.6	62.7	
pH (*in situ*)	7.5-8.0	n/a	n/a	
pH (*ex situ*)	7.61	7.55	7.68	
Air Temperature (°C)	28.5	26.0	21.0	
Water Temperature (°C)	27.0	26.0	23.0	
Total Diss. Solids (mg/l)	332.4	370.8	1246	
Total Solids (mg/l)	n/a	n/a	1258	
Total Susp. Solids (mg/l)	n/a	n/a	12	
Transparency (cm)	n/a	27.0	11	
Turbidity (NTU)	50	50	25	
Ammonia (mg/l)	>3.0	n/a	n/a	<3.0
Nitrate (mg/l)	nil	1.074	1.40	≤0.1
Phosphorus (mg/l)	n/a	>1.0	15.54	.005-.020
BOD (mg/l)	n/a	n/a	74.2	≤2.0
COD (mg/l)	n/a	n/a	82.2	≤20.0
Chloride (mg/l)	n/a	100.0	170.0	≤10.0
Chlorine, residual (mg/l)	<0.2	n/a	n/a	
Fluoride (mg/l)	<0.3	n/a	n/a	<0.1
Iron (mg/l)	~0.3	n/a	n/a	
Potassium (mg/l)	130*	20.2	2.2	<10.0
Sodium (mg/l)	907*	32.8	n/a	<50.0
Sulfate (mg/l)	n/a	14.5	8.48	2.0-80.0
Coliform bacteria	positive	positive	n/a	

** total ammonia, depends on pH

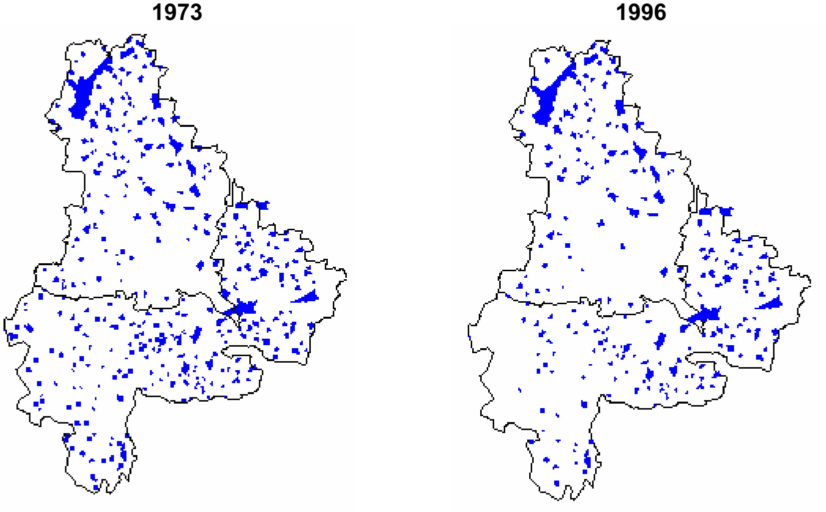
[1,] UNESCO, WHO, UNEP 1996 Water Quality Assessments: A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring. Second Edition. E & FN Spon , Madras.

Table 6 Groundwater Survey Results

Parameter	Site 1	Site 2	Site 3	Site 4
Ammonia (mg/l)	<0.2	<0.2	<0.2	<0.2
Coliform bacteria	negative	positive	Positive	negative
Chloride (mg/l)	0.8	1.1	0.9	0.8
EC (μS/cm)	896	1120	928	832
Fluoride (mg/l)	0.6	0.6	0.6	0.6
Nitrate (mg/l)	<10.0	<10.0	<10.0	<10.0
pH	7.40	7.28	7.41	7.55

Figure 1: Temporal changes analyses of Bangalore City waterbodies

1973 **1996**



Number of water bodies: 389 Number of water bodies: 246

Figure 2: Drainage network in Bangalore South

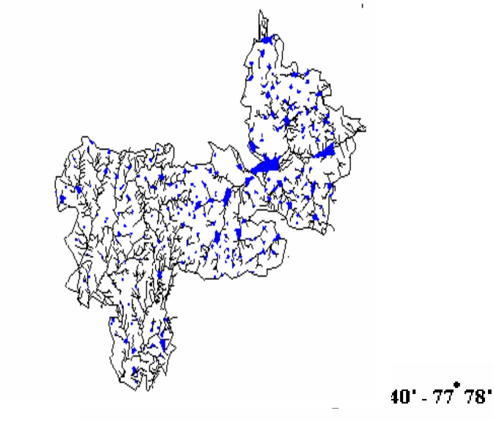
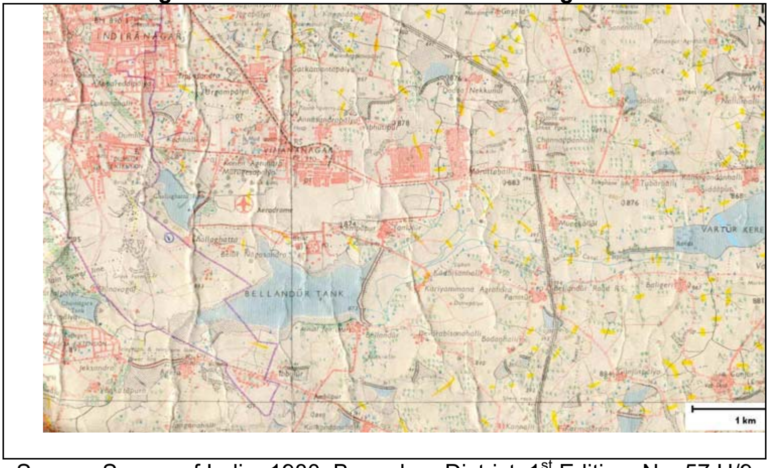


Figure 3: Varthur lake and Surrounding Area



Source: Survey of India, 1980. Bangalore District. 1st Edition No. 57 H/9

Figure 4: Drainage network of Varthur lake: Chain of interconnected lakes

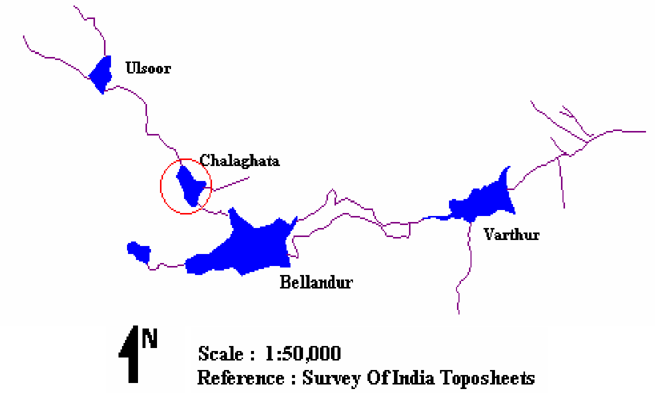


Figure 5: Shoreline of Varthur lake

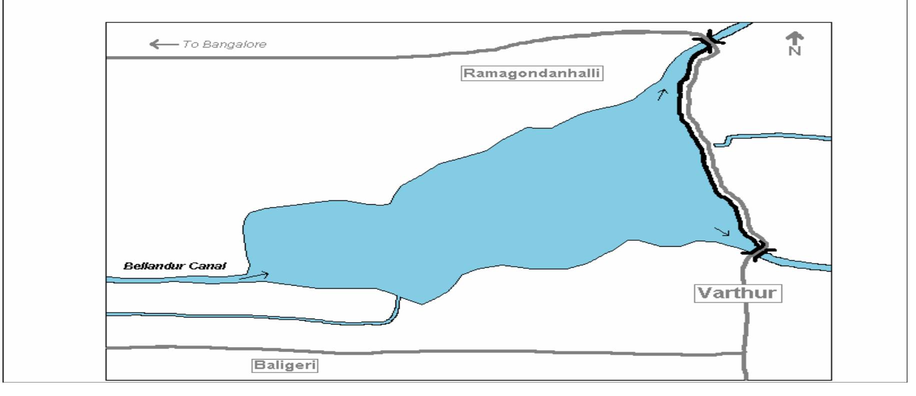


Figure 6: Bathymetric Map of Varthur lake, February

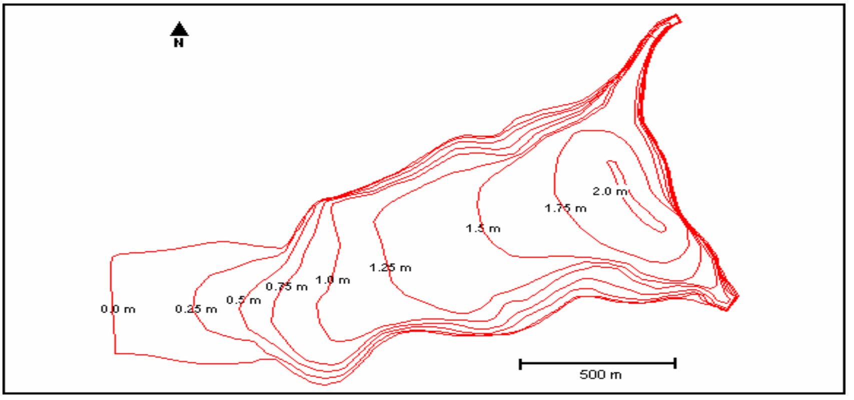


Figure 7: Gridded Depth Profile of Varthur lake, February