EVALUATION OF AQUATIC POLLUTION AND IDENTIFICATION OF PHYTOREMEDIATORS IN VELLAYANI LAKE

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Evaluation of Aquatic Pollution and Identification of Phytoremediators in Vellayani Lake"** is a bonafide record of research work done by me during the course of research and that the thesis has not been previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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Dedicated to Environment

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LIST OF ABREVIATIONS

%	-	percentage
BCF	-	bioconcentration factor
CD	-	critical difference
CFU	-	colony forming units
CRD	-	completely randomized design
et al	-	and others
Fig	-	figure
g	-	gram
i.e.	-	that is
kg	-	kilogram
L	-	litre
mg	-	milligram
ml	-	millilitre
mS	-	millisiemens
µS	-	microsiemens
NTU	-	nephelometric turbidity unit
^{o}C	-	degree celsius
ppm	-	parts per million
viz.,	-	namely

Introduction

1. INTRODUCTION

Just as the world we inherited today is what our past generation left on us, the future generations would inherit the legacy we leave for them. Water is a unique liquid in the sense that without it, life is impossible. On a global scale there is abundance of water of which only less than one per cent is available to the living community. This available water, the "Elixir of Life" is facing a severe threat due to pollution. Water, due to its great solvent power, is constantly threatened to get polluted easily. The availability of good quality water for all forms of lives, from micro-organisms to man, is a serious problem today, because all water resources have been reached to a point of crisis due to unplanned urbanization, unscientific agricultural practices and industrialization (Singh, *et al.,* 2002). The topic of our concern here is pollution of lake water. Water pollution refers to any type of aquatic contamination rendering the water body poisoned by toxic chemicals, which affect living organisms and all forms of life.

Kerala, a relatively small state comprising an area of 38864 km^2 criss–crossed by 44 rivers, harbours, several lakes, lagoons, canals, estuaries and backwaters. The major fresh water lakes of Kerala are Sasthamkotta, Vellayani, Pokkode, Kattakambal, Manakkodi, Enammakal and Muriyad. These lentic water bodies which contribute significantly to the ecological and economic sustainability of the region are currently subjected to acute pressure of rapid developmental activities and indiscriminate utilisation of land and water. The unscrupulous exploitation of this fragile systems and undesirable input of residues exceeding its assimilative capacity is on increase, resulting various kinds of pollution. Vellayani lake is also not an exception.

Vellayani wetland ecosystem comprising a fresh water lake and surrounding padasekharams lies 8^{O} 24’ 09’’ to 8^{O} 26’ 30’’ N latitude and 76^{O} 59’ 08’’ to 76^{O} 59’ 47’’E longitude at an elevation of 29 m above mean sea level. It extends through three panchayaths viz., Kalliyoor, Pallichal, Venganoor and two zones of Thiruvananthapuram Corporation namely Nemom and Thiruvallam. Now, the lake area has shrunken drastically to less than 400 ha from 750 ha in 1926. The Vellayani wetlands is a unique ecosystem that supports a variety of crops, large number of migratory birds and diversified aquatic and terrestrial fauna and flora.

Vellayani lake is the sole drinking water source for Kovalam, Vizhinjam, Pachalloor, Vellayani and adjoining areas. The indiscriminate anthropogenic interventions cause great threat to the quality of water and well as water spread area. Reclamation for farming, housing, tourism and so on, indiscriminate sand mining, intensive agriculture in the catchment resulting heavy load of nutrients and pesticides in water deteriorates the lake water quality and may result in the drying up of many of the rivulets leading to the lake

Vellayani lake has a typical rural environment. The lake is enriched with the growth of a variety of flora and fauna. Unaware of ecological consequences, this wetland ecosystem is being subjected to indiscriminate anthropogenic interventions like discharge of wastes, intensive agriculture, urbanisation, sand mining, tourism related activities, water sports etc. As a result, the system is being destroyed at an alarming rate which may finally lead to the qualitative and quantitative deterioration of the lake and loss if ecological balance. Since the anthropogenic pressure on the lake seems to be quite high and hence a constant monitoring of this water body is quite essential.

Several remediation technologies are being attempted for restoration of degraded lakes. Most of the conventional remediation approaches do not provide acceptable solutions to this catastrophe. Phytoremediation, a plant based and cost effective technology was found ideal for the clean up of the contaminated lakes especially with heavy metals and organic pollutants. Phytoremediation technology, developed on the basis of hyperaccumulating ability of certain plant species, which had very high genetic potential to accumulate larger amount of certain metals is a suitable option for their removal from soil and water. Several aquatic macrophytes viz., *Eichhornea crassipes, Hydrilla vertisilata, Typha angustata, Ipomea aquatica* etc. can remove heavy metals like Zn, Cu, Pb, Ni and Cd from lakes and maintain water quality (Kumar *et al.,* 2008; Weis *et al.,* 2004). Among the different techniques of phytoremediation, phytoextraction by plants is most effective and it offers great promise of commercial development for extraction of metals. Each ecosystem contains several plants having phytoremediation capacity, which may act as the cleaners of the system. The above aquatic macrophytes have to be identified and can be exploited for restoration and preservation of lake.

In view of the above, the present investigation was taken up with the following objectives.

1) To assess the extent of pollution in water and sediments of Vellayani lake.
2) To identify the macrophytes having phytoremediation capacity.

Review of literature

2. REVIEW OF LITERATURE

2.1. VELLAYANI WETLAND ECOSYSTEM

Vellayani wetland ecosystem comprising a fresh water lake and surrounding padasekharams extends through three panchayaths viz., Kalliyoor, Pallichal, Venganoor and two zones of Thiruvananthapuram Corporation namely Nemom and Thiruvallam. Vellayani lake is undergoing drastic reduction in area and water quality, which is the only drinking water source for Kovalam, Vizhinjam, Pachalloor, Vellayani and adjoining areas. Vellayani lake, which was a spread of over 750 ha in 1926 has undergone an alarming rate of depletion in area, now covering hardly 450 ha (Sanjeev, 1994; KAU, 2009; Sobha *et al.,* 2011).

Most of our water resources are gradually becoming polluted due to the addition of foreign materials from the surroundings. These include organic matter of plant and animal origin, land surface washings, industrial, agricultural and sewage effluents. The Vellayani lake is also not different from the above situation. Several reports are there indicating the deterioration of water quality of the lake. The Vellayani wetlands are being subjected to severe qualitative and quantitative degradation (Sanjeev, 1994; Anilkumar, 1999; Krishnakumar, *et al.,* 2005). Sixty per cent of the original lake area has been reclaimed and the average depth of the lake has been decreased to 3 m due to siltation (Sanjeev, 1994).

The Vellayani wetlands is a unique ecosystem that supports a variety of crops, like coconut, banana, rice and vegetables like bitter gourd, snake gourd, cucumber, vegetable cowpea etc. A major portion of the lake expanse is covered by lotus plant, the flowers of which are being widely used in temples and in indigenous medicine. The region experiences rich biodiversity (COA, 2009). Fresh water lakes support a wide array of ecological, climatic and societal functions that are essential for supporting plant, animal and human life and for maintaining the quality of the environment (Ravindran and Ambat, 2007).

2.2. DEGRADATION OF THE ECOSYSTEM

The maintenance of a healthy aquatic ecosystem is dependent on the physico-chemical properties of water and the biological diversity. Lakes are important indicators of environmental degradation. They have a natural role of storing the precious rain water, maintaining ground water table and recharging innumerable wells in the adjoining areas. A large number of streams and rivers in India have been impounded to store the water for multipurpose beneficial uses like irrigation, fisheries, power generation and drinking water supply. As a result of demographic pressure, area of lakes has considerably reduced due to various types of encroachments (Kumar *et al.*, 2008).

The researches of aquatic systems were mainly concentrated on mesotropic to oligotropic deepwater systems rather than tropical freshwater systems. However, during the last two decades fresh water systems have received much attention due to the enhanced awareness of scientific community and public on environment protection and maintenance of a sound and healthy ecosystem.

Lakes have a more complex and fragile ecosystem and they easily accumulate pollutants (Bhatt *et al*., 1999). According to him several characteristics of lakes make them ideal study sites to advance our basic understanding of ecosystem dynamics. Agriculture is the single largest user of fresh water on a global basis and is a major cause of degradation of surface and groundwater resources through erosion and chemical runoff.

Contamination of soils, ground water, sediments surface water and air with trace metals is one of the major environmental problems. Lakes often act as final receptacles to these metals whose concentration in interstitial waters might increase several thousand folds by effluents from waste (Bastian and Hammer, 1993). Pollutants enter aquatic systems via numerous pathways including effluent discharge, industrial, urban and agricultural run off as well as air borne deposition (Kar and Sahoo, 1992).

There are several factors that control the quality of water where sediment quality is one of the major character that decides the carrying capacity of the lake. Sand Mining is a coastal activity referring to the process of the actual removal of sand from the foreshore including rivers, streams and lakes. Sand Mining in India is adversely affecting the rivers, sea, forests & environment. It imparts marked imbalances to the natural environment setting of these fragile ecosystems (Thrivikramaji, 1986). Illegal mining of sand and the lack of governance, in a big way is causing land degradation and threatened its rivers with extinction. Sand mining has been rated as first and aquatic pollution has been rated as second among the prioritized problems of Vellayani ecosystem (COA, 2009). Several other studies conducted by various workers (Krishnakumar, 2002; Sobha *et al.,* 2011) indicated that the lake is under the threat of pollution due to various anthropogenic activities.

The studies on Vellayani lake indicated that pollution could be due to an open drain which directly discharges waste and polluted run off from agricultural fields into the lake. Fish culture by Fisheries Department had also affected the natural biota of the lake. Another factor degrading the lake was constructional aspects and developmental activities in the name of tourism. Sand mining is also posing a threat of decrease in ground water recharge and increase in turbidity by intervening with natural filtering system (Sobha *et al.,* 2011).

2.3. POLLUTION OF FRESH WATER LAKES

The most important fresh water lakes of Kerala are Vellayani, Sasthamkotta and Pookkode lake. Unaware of the ecological consequences these wet land systems have been subjected to uninterrupted reclamation for the past 150 years for various purposes. As a result, the system is being destroyed at an alarming rate of 1 per cent per year (Gopal *et al.*, 1993).

The indiscriminate exploitation of wetlands beyond its supportive capacity, and input residues exceeding its assimilative capacity, pollutes the wet land system of Kerala, the magnitude of which is very alarming. These efforts finally cause harm to living resources, hazards to human health, hindrance to aquatic activities, impairment of water quality and reduction of amenity and finally ecological imbalance leading to catastrophic effects (Varma *et al.*, 2005).

Pollution can be from point or non- point sources. Non-point pollution, once known as “diffuse” pollution, arises from a broad group of human activities for which the pollutants have no obvious point of entry into receiving watercourses. In contrast, in point pollution, wastewater is routed directly into receiving water bodies by discharge pipes, where they can be easily measured and controlled. Obviously, non-point pollution is much more difficult to identify measure and control than point sources. The degree of pollution depends on the material, the physical nature, chemical nature of the material discharged, water depth and hydrographic conditions (Cairns, 1992). Vellayani lake is surrounded by vast areas of agricultural land, the pollution that the lake is experiencing is mainly non-point type (COA, 2009).

Man has realized the importance of water since time immemorial. The problem of freshwater is becoming more acute day by day landing to the realization that its consumption must be regulated. Fresh water has become a scarce commodity due to over exploitation and pollution of water. The causative factors for the pollution of water are industries, agriculture and domestic activities. Water pollution is the biggest menace of urbanization, industrialization and modern agricultural practices. It leads to alteration in physical, chemical and biochemical properties of water bodies as well as that of the environment. It directly or indirectly affects the life processes of flora and fauna of the water body, surrounded by chemical toxicants (UNESCO/WHO, 1978).

2.4. WATER QUALITY

2.4.1. Physical properties

Temperature plays a vital role in determining the biogeochemical reactions and also the self purification efficiency of aquatic ecosystems. The self purification process will be more rapid during pre monsoon season compared to monsoon and post monsoon seasons. The slightly elevated temperature levels in the pre monsoon can oxidize at least a part of the organic matter in water. (Krishnakumar *et al.,* 2002). Changes in air temperature and rainfall can affect river flow and river water temperature, the primary variables that influence water quality. Water temperature is a key element that affects the health of a fresh water ecosystem (Rehana *et al.,* 2011).

Vellayani wetland ecosystem being located in the humid tropical belt, not much variation was observed in temperature during different seasons (Sanjeev, 1994). Radhika *et al.,* 2004 also reported that the seasonal variations in temperature of Vellayani lake were not significant.

No guideline is recommended for the temperature of drinking water. Elevated temperature enhances the growth of micro organisms, changes the taste, colour and accelerates the rate of corrosion, whereas low water temperature may impart deleterious effect on drinking water (Iqbal and Katariya, 1996).

Turbidity is caused mainly by the presence of either colloidal matter or very finely divided suspended matter or even both, that settles with difficulty. Very high turbidity was observed for Vellayani lake water during the pre monsoon period which is mainly attributed to low water level, decaying vegetation, and high planktonic growth (Radhika *et al.,* 2004). Krishnakumar (2005), reported an annual variation of 4 to 11.2 mg L^{-1} for TSS value for lake water of Vellayani. Different wet land ecosystem expressed much variation in turbidity with respect to different seasons.

2.4.2. Electrochemical properties

The pH of water is an important indication of its quality and it is dependent on the carbon-dioxide carbonate–bicarbonate equilibrium. According to Fakayode (2005), the pH of a water body is very important in determination of water quality since it affects other chemical reactions such as solubility and metal toxicity. The pH of fresh water lakes of Kerala ranged from 6.3 to 7.5. Lake waters of Vellayani recorded an annual average pH of 6.45 (Sreejith, 1996; Krishnakumar, 2005).

Measurement of EC in lake water provides rather sufficient information about the quantity of dissolved material found in water. Water bodies that have an EC value of 50-200 µS cm^{-1}, 200-500 µS cm^{-1}, 500-2000 µS cm^{-1} are classified as very soft, soft and hard respectively (Hutter, 1992). Electrical conductivity was maximum during pre monsoon and minimum during monsoon season in Vellayani lake due to increased rate of evaporation leading to high concentration of salts and dilution resulting from precipitation respectively in Vellayani lake (Radhika *et al*., 2004). Krishnakumar (2005) reported an EC value of 0.29 mS cm^{-1} for Vellayani lake water.

2.4.3. Chemical properties

The degradation of water quality is a direct consequence of pollution making them unfit for drinking, fishing, bathing or any other recreational activities. More than 50,000 small and large lakes in India are polluted to the extent of being considered as ‘dead’ (Chopra, 1985). The wetlands of Kerala, especially along the coastal stretch are also polluted to the extent that their fishery and recreational values are fast declining. Many of such aquatic systems are facing severe threat of eutrophication due to the high concentration of several nutrients especially ammonia, nitrate and phosphorus (Varma *et al.,* 2007).

Nitrogen in any form is toxic to aquatic organism and to human population when its limit exceeds the maximum permissible limit (Lindau *et al.*, 1988). Ammonia, nitrite and nitrate all find commercial application and are discharged to the surface waters by user industries. The principal use of above compounds is in agriculture for production of fertilisers as well as their use by farmers. Agriculture together with municipal waste water is the most important source of anthropogenically derived ammonia and nitrate to surface waters (Moore, 1991). Some of the nitrogen added to soils eventually find its way to surface water and ground water. Ammoniacal nitrogen formed in the aquatic systems are oxidised to nitrate under aerobic condition and denitrified to nitrous oxides and nitrogen gas under anaerobic condition.

Nitrate is a problem as a contaminant in drinking water (primarily from groundwater and wells) due to its harmful biological effects. High concentrations can cause methaemoglobinemia, and have been cited as a risk factor in developing gastric an intestinal cancer. Due to these heath risks, a great deal of emphasis has been placed on finding effective treatment processes to reduce nitrate concentrations to safe levels. An even more important facet to reduce the problem are prevention measures to stop the leaching of nitrate from the soil. Treatment processes, such as ion exchange can have an immediate effect on reducing levels in drinking water. These processes do not remove entire nitrate, but can help to bring the concentration down to the suggested level of 10mg L^{-1} (Phathak *et al.*, 2002).

For protection of freshwater aquatic life, waters should not exceed 0.5 mg free ammonia L^{-1} (Frits, 1990). Both nitrate and ammonia concentrations are in general highly variable during a lake's seasonal cycle. During the growing seasonal peak, such concentrations can be very low due mainly to its sequestration by phytoplankton (Rolando Quirós, 2003).

In more reductive media denitrification and nitrate reduction to ammonia would prevail (Stumm and Morgan, 1996). The removal of N from lakes is usually dominated by NO_3-N, denitrification concomitantly with the oxidation of organic matter, but in highly productive surface waters, high pH would favour N release to the atmosphere as ammonia. Krishnakumar, (2005) reported the absence of nitrate in Vellayani lake while Radhika *et al.,* (2004) reported its presence in very low concentrations during different seasons.

Detergents used as cleaning agents containing several pollutants which severely affect the water bodies. They contain surface activity agents and contribute to phosphates of sodium, silicates, sulphates and several other salt builders in water.

Waste water contaminated with detergents carries a huge cap of foam, which is anesthetic for all purposes. Phosphorus is generally considered to be a major bio-growth limiting macro nutrient in aquatic ecosystems (Jorgensen, 1983; Ishikawa and Nishimura, 1989 and Fox, 1989). It plays an important role in controlling the eutrophication. P content of Vellayani lake water ranged from 0.012 to 0.036 mg L^{-1} recording the highest values during pre monsoon season (Radhika *et al.*, 2004).

Phosphorus has a strong affinity to oxides of iron, aluminum and manganese. Reduction and oxidation (redox) of these metals regulate the dynamics of phosphorus in sediments. The high concentrations of Ca-P may temporarily control the release of phosphorus from the sediments because it is a relatively stable, inert, and non-bioavailable phosphorus fraction (Jiang *et al*., 2011).

The phosphorus content of Vellayani lake water was about 0.07 mg L^{-1} (Krishnakumar, 2005). Sasthamkotta lake which is the major fresh water lake of Kerala showed a P content of 2.01 mg L^{-1} while for the Pookot fresh water lake it was 0.04 mg L^{-1}(Sreejith, 1996; Abbasi *et al.*, 1989; Krishnakumar, 2005).

Sulphur has enormous environmental significance since it complexes with many toxic agents, organic materials and hydrogen in surface waters, and is the primary agent of acidification in water. S occurs abundantly in natural waters and the anthropogenic emissions to the atmosphere contribute towards further increase in S content of the environment. S containing biological compounds like metallothionein present in many aquatic species binds numerous toxic metals to the tissues. The main problem associated with increased S deposition is acidification of surface waters (Moore, 1991). Vellayani lake water recorded 6.94 mg sulphate L^{-1} (Krishnakumar, 2005).

Calcium and magnesium are essential elements for water living organisms. In fresh waters hardness is attributed principally by Ca and Mg. They contribute substantially towards the alkalinity of water especially in fresh water wetlands. Vellayani lake water showed an increase in alkalinity during pre monsoon season due to concentration of Ca and Mg salts (Radhika *et al.*, 2004).

Sodium and potassium are important alkali metals found in all fresh waters. Potassium though found in smaller amounts, plays a vital role in metabolic activity of fresh water organisms and hence considered to be an important macronutrient. (Robert *et al.*, 1982). The concentration of Na, K, Ca and Mg in the aquatic environment increases with proximity to industrial areas. Sodium nitrate and calcium nitrate are commonly found in effluents released from industries. The Ca content of Vellayani lake was 4.80 mg L^{-1} (Krishnakumar, 2005). He also reported an annual variation in Mg content in Vellayani lake from 30-150 mg L^{-1}. For sathamkotta fresh water lake , Ca and Mg contents were 7.10 and 2.64 mg L^{-1} (Sreejith, 1996; Krishnakumar, 2005).

Aluminium is the third most abundant element in earth's crust with an average concentration of approximately 8%. Though Al is found in all plants and animal species, it is not essential for survival. Environmental significance of Al has waxed enormously in recent years for two reasons: (1) increased mobilisation due to acidification of surface waters, and (2) potential agent in the genesis of Alzhemier's and related diseases. Relatively large amount of Al was found in surface water in dissolved form due to the decrease in pH of many surface water and soils (Goenaga and Williams, 1988).

Dissolved Al is highly toxic to crop roots and forest and may wash into surface waters. Most of the soluble fraction is composed of non silicate organic Al

(Mulder *et al.,* 1989). It is important to note that toxicity of different Al species is purely understood. Elucidation of the formation of Al species is an important step in managing Al toxicity (Moore, 1991). Lake water aluminum concentrations have a significant influence on the composition of microfossil assemblages of diatoms deposited in lake sediments (Kingston *et al.,* 2011).

2.4.4. Heavy metals

Heavy metals are the stable metals or metalloids whose density is greater than 5 g cm^{-3}; namely Hg, Cd, Co, Pb, Mo, Ni, Fe, Cu, Zn etc. (Nies, 1999). Heavy metals are stable and cannot be degraded or destroyed, and therefore tend to accumulate in soil, water and sediments. The principal manmade sources are industrial point sources and non point sources like combustion by products, traffic etc. The toxic heavy metals entering the ecosystem may lead to geoaccumulation, bioaccumulation and biomagnification. Heavy metals like Fe, Cu, Zn, Ni and other trace elements are important for proper functioning of biological systems and their deficiency or excess could lead to a number of disorders. Heavy metal contamination of the biosphere has increased sharply since 1900 and poses major environmental and human health problems worldwide (Ensley, 2000). Apeti *et al.,* (2005) reported that the lake ecosystems are in particular vulnerable to heavy metal pollution and their bioaccumulation as well as bio-magnification is always a threat.

There is significant generation of municipal solid waste in Kerala which is a major source of heavy metals. It was reported that even in urban areas, only 50 % of the solid waste is collected. The remaining wastes are left to decay in the drains and on the road sides which may finally reach the nearby aquatic systems and contaminate them. About 80% of the municipal solid wastes contain appreciable concentration of heavy metals (Padmalal *et al.,* 2002). Heavy metals are toxic even at very low concentrations and pose serious problems due to their possible entry into the food chain (Vasanthy *et al.,* 2004).

Iron with an average abundance of five per cent by weight, is the fourth most abundant element in the earth's crust. It is routinely detected in municipal effluents and areas near iron and steel industries. Fe residues in surface waters are extremely variable, reflecting differences in underlying bed rock, erosion and to a lesser degree industrial and municipal discharge (Moore, 1991).

The oxidation- reduction cycle is important in controlling the fate of Fe in most surface waters. The cycle varies seasonally depending on the availability of oxygen. The oxygenated water results in oxidation of Fe^{2+} to insoluble Fe^{3+} which settles to the bottom to repeat the cycle (Moffett and Zika, 1987). The Vellayani wetland ecosystem being originated from acidic parent materials recorded the presence of Fe in water (Krishnakumar *et al.*, 2005).

Zn occurs in the earth's crust at an average concentration of 70 mg kg^{-1} making it the 24^{th} most abundant element. Enormous amount of Zn is mobilised each year from natural and anthropogenic sources. The concentration of extractable Zn in fresh waters usually ranges from < 0.001 to approximately 0.05 mg L^{-1} (Moore, 1991). The toxicity of Zn to aquatic plants is highly variable with EC_{50} ranging from < 0.01 to > 100 mg L^{-1}. This variability is due to the effect of different physico chemical conditions on Zn uptake and ability of several species to adapt to high Zn levels (Starodub *et al.,* 1987). Vellayani wetlands recorded a total Zn content of 1.06 mg L^{-1}(Krishnakumar *et al.*, 2005).

Copper is a natural constituent of soil and will be transported into streams and waterways in runoff either due to natural weathering or anthropogenic soil disturbances. The median concentration of copper in natural water is 4–10 ppb. It is predominantly in the Cu (II) state. Most of it is complexed or tightly bound to organic matter. However, in some cases, copper is predominantly associated with carbonates. In anaerobic sediments, Cu (II) will be reduced to Cu (I) and insoluble cuprous salts will be formed. Cu is highly toxic to most species of aquatic plants and is routinely used as an algicide and herbicide. Inhibition of growth generally occurs at a concentration < 0.1 mg Cu L^{-1}. Some species such as duck weed *Lemna minor* is relatively insensitive to Cu (Moore, 1991). The water soluble ligands are widely suspected of binding Cu and thereby reducing potential toxic effects.

Lead is one of the oldest metals known to man and is discharged in the lake water through paints, pipes, building material, gasoline etc. Lead is a well known metal toxicant and it is gradually being phased out of the materials that human beings regularly use. Dixit and Tiwari (2007) found that lead from automobiles released into atmosphere find its way in the run off waters. The discharge of heavy metals in the environment has much obvious impact on aquatic systems. There may be an increase in residue levels in water, sediments and biota, decreased productivity and increase in exposure of humans to harmful substances.

Atmospheric fallout is usually the most important source of lead in the freshwaters (Moore, 1984). Vellayani wetlands recorded a total Pb content of 1.32 mg L^{-1} (Krishnakumar *et al.*, 2005).

Cadmium is a non essential metal that is toxic to fish and other aquatic organisms even when present in very low concentration. The toxic effect of cadmium is exacerbated by the fact that it has an extremely long biological half – life and is therefore retained for long periods of time in organisms after bioaccumulation.. Cadmium is contributed to the surface waters through paints, pigments, glass enamel, deterioration of the galvanized pipes etc. The wear of studded tires has been identified as a source of cadmium deposited on road surfaces. The permissible limit for the drinking water set by WHO is 0.01 mg L^{-1} (Sindhu, 2002).

Naga (2002) carried out the analysis of heavy metal ions present in the lake water of Hussain Sagar Lake and found that the very presence of various heavy metal ions in their dissolved state, are hindering the beneficial uses of the lake waters. The heavy metal concentrations were generally high during summer and after monsoon the concentration gradually decreases, as rainfall flushes out the lake water (Dixit and Tiwari, 2007). Metals such as Cd, Pb and Zn are most likely to have increased detrimental environmental effects as a result of lowered pH (Puri *et al*., 2011).

Vellayani lake has a relatively large catchment which is mostly fertile cultivable land. Being predominantly an agricultural region, application of chemical fertilizers and pesticides are bound to be high (Sanjeev, 1994). Improperly managed agricultural activities may impact surface water by contributing nutrients, pesticides, sediment, and bacteria, or by altering stream flow. Fertilizer and pesticide use, tillage, irrigation and drainage can affect water quality and hydrology.

2.4.5. Biologically related chemical properties

Dissolved oxygen (DO) is essential for the metabolism of aerobic organisms and also influences many chemical processes within lakes. Oxygen can occur in water as a product of photosynthesis, or can enter by diffusion from the air and by wave action. The solubility of oxygen is a function of temperature, pressure and the concentration of ions in water. Coastal waters typically require a minimum of 4.0 mg L^{-1} and also do better with 5.0 mg L^{-1} of oxygen to provide for optimum ecosystem function and highest carrying capacity (UNESCO/WHO, 1978).

Dissolved oxygen (DO) is very crucial for survival of aquatic organisms and it is also used to evaluate the degree of freshness of a river (Fakayode, 2005). Seasonal values of DO in the surface water of Vellayani lake fluctuated from 4.83 to 7.11, 4.11 to 6.81 and 4.71 to 6.60 mg L^{-1} during pre monsoon, monsoon and post monsoon seasons respectively. No significant temporal and spatial variation was observed in waters of Vellayani lake for DO (Radhika *et al.*, 2004).

BOD represents the amount of oxygen required for the microbial decomposition of organic matter in water. Seasonal values of BOD in surface water of Vellayani lake varied from 10.2 to 21.9, 2.9 to 20.1 and 4.1 to 18.3 mg L^{-1} during pre monsoon, monsoon and post monsoon respectively. Low values of BOD during monsoon may be due to low temperature, lesser quantity of suspended solids in water as well as increased microbial population (Radhika *et al.*, 2004). BOD of Vellayani lake water ranged from 0.92 to 4.5 mg L^{-1} (Krishnakumar, 2005).

Chemical oxygen demand (COD) is a reliable parameter for judging the extend of organic pollution and is a measure of oxygen required for complete oxidation of organic matter by a strong oxidant. Seasonal values of COD in the surface water of Vellayani lake fluctuated from 12.8 to 33.4, 27.4 to 43.2 and 22.4 to 32.7 mg L^{-1} during pre monsoon, monsoon and post monsoon seasons respectively. The values were higher for bottom water and were attributed due to accumulation of oxidisable organic matter at the bottom (Radhika *et al.*, 2004). Higher ratio of COD/BOD points out excessive quantity of organic matter which is not decomposed by microorganisms.

2.4.4. Microbiological properties

The study of ecological relationships of microbes, developed in the early 1960's along with interest in ecology and environmental quality. Microbes play a far more important role in natural environments than their small size would suggest. The maximum number of total coliform, faecal coliform and total plate count was observed during summer and rainy seasons and minimum during winter (Agarwal and Govind, 2010).

Faecal coliform bacteria are classified within the family Enterobacteriaceae. The most common species of fecal coliform is *Escherichia coli*, prokaryotic, gram-negative, rod-shaped bacteria. They range in size from 1.1-1.5 mm in width and from 2-6 mm in length. *Escherichia coli* is facultatively anaerobic and may be nonmotile or motile with peritrichous flagella (Breed et al., 1957). These bacteria are very abundant within the intestinal tracts of warmblooded mammals. Therefore, their presence in aquatic environments is indicative of contamination with animal wastes. Although most *E. Coli* bacteria are harmless, some strains may be highly pathogenic (Joklik, 1972). The value of determining fecal coliform concentrations in a water source is to establish the extent to which the water has been polluted with fecal wastes. Its presence is indicative of the potential for other pathogenic microbes, including those that cause typhoid fever, bacterial or viral gastroenteritis, or hepatitis A (Joklik, 1972).

The presence of coliforms shows danger of faecal pollution and consequent hazard of disease occurrence through pathogenic organism (Ramesh, 2005). Numerous studies have been done on contamination of water bodies on world wide, particularly with a view to reversing the trend and/or the resultant effects on human health (Hill *et al.,* 2005, 2006; Meyer *et al.,* 2005; Mishra *et al.,* 2008; Rai, 2008).

From the bacterial point of view, *E. coli* is considered as a more significant index for evaluating pollution than the other microorganisms (Pipes, 1982). The presence of *Escherichia coli* in recreational waters is commonly used as an indicator of recent fecal contamination. Recreational waters and beaches contaminated with faecal bacteria may contain pathogens that pose a health risk to humans (Dufour, 1984). Hill *et al.,* (2006) in a study conducted on the effect of rainfall on faecal coliforms reported that the presence of faecal coliforms is an index of bacteriological quality of water. Their presence in the studied streams further lent support to the inference that faecal deposits and waste dumps find their way into them. Usha *et al.,* (2006) observed a higher bacterial count during the monsoon season. The water samples showed the highest plate count during the rainy seasons as the bacteria are mainly derived from the soil and sewage that gain access to the lake through rain water or storm water.

Eutrophication or algal bloom occurs when the water becomes rich of nutrients (nitrogen, phosphorus, etc.) by domestic drainage, water runoff from agricultural fields or by addition of detritus of algae and other plant species. It decreases the level of dissolved oxygen because these species covering the water surface allow very little transfer of oxygen from air to enter water by diffusion. Also the resultant oxygen produced by these species on water surface does not get a chance to dissolve in water as most of it goes into atmosphere. Further when algae die and sink to the bottom of the water body, their decay by bacteria further reduces the concentration of dissolved oxygen to levels which are too low to support fish production (Dachs *et al.,* 2000).

2.5. SEDIMENT QUALITY

2.5.1. Physical properties

Sediments form a natural buffer and filter system in the material cycles of waters. Sediment in our rivers is an important habitat as well as a main nutrient source for aquatic organisms. The sediments are both carriers and potential sources of natural geochemical constituents derived principally from rock weathering.They govern the nutrient economy of an aquatic system. Furthermore, sediments have an impact on ecological quality because of their quality, or their quantity, or both. (Stronkhorst *et al*., 2004).

The texture of sediment is one of the important physical parameters of an aquatic environment which influence the physicochemical and biological characteristics of the system. Wide annual variation in sediment texture was generally observed. This was mainly due to due to the transport of sediments from one place to another and reversal exchange with the tidal currents (Hakanson and Janson, 1983). Sediment texture is the major controlling factor for the adsorption and desorption of the chemical components. The texture of the sediment has a significant role in the physico-chemical processes as well as in the species diversity of the depositional environment (Babu *et al.,* 2000). The textural characteristics of sediments play a significant role in the distribution and concentration of C, N and P, both in the bottom sediments and in the overlying water column (Sobha *et al*., 2009).

The organic carbon content in sediment is derived from primary production within the water body and also from terrigenous run off. The reduced organic matter provides the main source for heterotrophic organisms in the aquatic sediment (Hakanson and Jannson, 1983). Soil organic carbon (SOC) is a main factor affecting soil quality and agriculture sustainability. Being a source and sink of plant nutrients, SOC plays an important role in terrestrial C cycle (Freixo *et al*., 2002). The organic carbon content of sediments of different aquatic systems of Thiruvananthapuram district varied from 0. 29 to 6.5 % (Sobha *et al.,* 2009).

The soil organic carbon loss from irrational land use often leads to some negative impacts on both terrestrial and aquatic ecosystems, and on atmospheric environment (Reeder *et al.*, 1998; Bronson *et al*., 2004). The study of the vertical distribution of soil organic carbon and its relationship with soil pH showed that the organic carbon content in undisturbed wetland and cultivated lowland rice fields had a marked decrease from 0-10 cm to 40-60 cm and a smaller change downward (Chi *et al.,*2010).

2.5.2. Electrochemical properties

The major factors governing the pH of soil are concentration of reduced Fe, Mn, carbonic acids, carbonates and humic acid (Patric and Mikkelson, 1971). The acidic pH reported is mainly due to the genetic nature of the soils of that area rich in Fe and Al oxides and due to the organic acids produced by the micro organisms for the decomposition of organic wastes either added to the lake by human interventions or by the death and decay of existing macrophytes.

Electrical conductivity of sediment is mainly controlled by the salts present, reduced Fe and Mg, nature of the waste incorporated, rate of primary production, rate of other biological activities etc. Sobha *et al.*, (2009) reported EC of various aquatic systems of Thiruvananthapuram districts ranged from 0.106 to 0.592 mS cm^{-1} during post monsoon and 0.094 to 0.831 mS cm^{-1} during pre monsoon. The receipt of fresh water from Karamana and Killiaar was responsible for reducing the EC at certain points.

2.5.3. Chemical properties

Sediment is a major source of nitrates. Nitrogen is an important nutrient element in the sediment that controls the quantity of overlying water in an aquatic system. N sources are mainly nitrogenous organic matter, non biological activity, turbulence, quantities of fresh water inflows. N content in sediment is depending upon local condition of rainfall, quantities of fresh water inflows, turbulence and biological activities (Kemp, 1971). The comparatively low concentration of N in the estuarine region may be attributed to the denitrification process that takes place in the overlying water due to anoxic condition that prevails in the region (Santhosh, 1999).

Phosphorous is one among the chief nutrients in an aquatic environment. The increased P content is due to loading from cultivated lands, domestic and industrial sewage increased the eutrophication (Parry, 1998). The P content ranged from 0.012 to 0.096 mg kg^{-1} during post monsoon and 0.012 to 0.097 mg kg^{-1} pre monsoon season in various aquatic systems of Thiruvananthapuram district. The major sources of P were waste disposed to the aquatic systems and the decaying vegetation (Sobha *et al.,* 2009)

Potassium is also a naturally occurring constituent in sediment. The major source in fresh water is weathering of rocks. But the quantity increases in the polluted water due to the disposal of domestic wastes. Nair *et al.,* (1984) observed a high concentration of K during the monsoon season. However Sobha *et al.,* (2009) observed the highest concentration of K during the post monsoon season which was mainly due to the disposal of waste and the after effects of monsoon.

Sodium is an important constituent in sediment. The carbonates, sulphates, nitrates and chlorides of sodium are found abundantly in nature. Many industrial wastes and domestic sewage are rich in sodium and increase in its concentration in the natural water after disposal of wastes and anthropogenic activities (Trivedi and Goel, 1986). Season wise analysis of Na in aquatic systems of Thiruvananthapuram district showed a range in Na content from 1.38 to 8.02 mg kg^{-1} during post monsoon to 0.26 to 1.9 mg kg^{-1} during pre monsoon (Sobha *et al.,* 2009).

Calcium and magnesium exist in different combinations with anions in natural water and soil. Disposal of sewage and industrial waste also contribute to the content of Ca and Mg and has a great affinity to absorb on the soil particle and in turn affects the soil texture. Water and sediment interaction play an important role in the concentration of Ca and Mg ions in the water and soil (Santhosh, 2002). Vellayani wet land eco system contained 3.9 and 1.4 ppm of Ca and Mg respectively (Krishnakumar *et al.,* 2005)

The accumulation of heavy metals in sediments may be the water pollution source in case of environmental condition change (Chen *et al*., 1996). Santos *et al.,* (2005) conducted a study on coastal sediments and soils and found out that the most anthropogenic sources of metals are industrial, petroleum contamination and sewage disposal. A large portion of metallic substances discharged into the aquatic environment is ultimately incorporated into the sediment either by adsorption or by complexation process.

Iron, which is the most abundant element in Kerala rivers is mainly derived from industrial wastes, fertilizers and domestic waste. It is an important waste in sediment of estuaries (Nair *et al.,* 1987). The concentration of Fe in the sediment ranged from 8690 to 88741 mg kg^{-1} during post monsoon and its fluctuation during pre monsoon was from 15855 to 17840 mg kg^{-1}.

Zinc is an essential element required in trace quantities to sustain biological life, but in large concentration is proved to be lethal. It is a common contaminant in industrial effluent (Dean *et al.,* 1972). The concentration of Zn varied from 0.4 to 18.6 mg kg^{-1} during post monsoon and from 1 to 2.2 mg kg^{-1} during pre monsoon. The higher values of Zn values during post monsoon was due to the influence of chemical waste from industry disposed near the sampling sites (Sobha *et al.,* 2009).

Copper despite its toxic effects is reckoned as an essential component of many enzymes. The major sources are leachings from copper mines, industries related to the manufacture of agricultural chemicals, paints etc. The different aquatic system showed a range in Cu content from 47.2 to 335 mg kg^{-1} during post monsoon season. During pre monsoon season, only one location recorded presence of Cu in the sediments (Sobha *et al.,* 2009).

Cadmium is a hazardous heavy metal like mercury. Cd is not essential for plants and animals. So Cd in the environment can cause only harm and no gain. The average concentration of Cd in sediment is 0.2 ppm (Abbasi *et al.,* 1998). The Cd content of Vellayani lake fluctuated from 41 to 45 ; 42 to 51 and 39 to 51 335 mg kg^{-1} during pre monsoon, monsoon and post monsoon seasons respectively (Resmi *et al.,* 2007).

The concentration of lead in the earth's crust has been estimated as 12.5 ppm ranking it as the 36^{th} element in the order of abundance (Abbasi *et al.*, 1998). Pb reaches the aquatic sediment through precipitation, erosion and leaching of soil as well as municipal and industrial waste. The different aquatic systems of Thiruvananthaspuram showed a Pb content ranged from 21.1 to 99.4 mg kg^{-1} during post monsoon season and from 0.4 to 29.4 mg kg^{-1} during pre monsoon season.

Al concentrations are directly related to the soil pH and toxic concentrations can occur only at pH values below 5. In non calcareous soils, when the pH drops sharply, clay minerals are attacked by the acid and K, Mg, Fe and Al from the clay become soluble. Free Al is commonly found in water above such soils. (van Mensvoort *et al.,* 1985). The relatively high concentrations of Al_2O_3 and related species are found naturally in sediments. Very high quantities of Al_2O_3 has been reported from various river sediments ranging from 5 to 16.2 % (Mudroch and Duncan, 1986; Subramanian *et al.*, 1988).

2.6. MACROPHYTES

Aquatic plants are important components of many freshwater ecosystems. Many natural and anthropogenic factors influence the distribution and abundance of aquatic plants. Species of aquatic plants vary greatly in their anatomy, physiology, life-history traits, and ability to tolerate inorganic and biological stressors. Key examples of inorganic stressors are extreme regimes of flow velocity, irradiance, salinity, ice cover, temperature, nutrients, and pollutants. Stressors associated with competition, herbivory, and disease may also limit the ability of species to utilize otherwise suitable habitats. Some aquatic plants have a cosmopolitan distribution and display high levels of polymorphism and phenotypic plasticity in response to variations of environmental factors; these qualities allow them to occur over a wide range of conditions. Other species, however, have narrower tolerances and are potentially useful indicators of environmental conditions, in terms of either their presence or relative abundance within communities (Paresh and Bill, 2006).

2.7. Pollution abatement through phytoremediation

Phytoremediation, a plant based and cost effective technology for the clean up of contaminated soil and water, is getting much popular due to its eco-friendly nature. Rapid growth in population and massive industrialisation in recent years has resulted in pollution of the biosphere with toxic metals which is a major environmental problem, since these metals may find their way to the human and animal system through plants. Most of the conventional remediation approaches do not provide acceptable solutions to this catastrophe while phytoremediation can be easily used for the detoxification of contaminated ecosystem since it basically involves the extraction or inactivation of these toxic metals in a system (Lombi *et al.,* 2001).

Phytoremediation technology was developed on the basis of certain plant species called hyperaccumulators, which had very high genetic potential to accumulate larger amount of certain metals which can be used for their removal from soil and water. Hyperaccumulators are conventionally defined as species capable of accumulating metals at levels 100 fold greater than those typically measured in common non-accumulator plants. However, excessive accumulation of these metals can be toxic to most plants. A series of fascinating scientific discoveries combined with an interdisciplinary research have allowed the development of this concept into a promising cost effective, and environment friendly technology. It is being currently divided into

1. Phytoextraction: hyperaccumulators removes metals or organics from soil and concentrate them in the harvestable plant parts.
2. Phytodegradation: use plants and associated microorganisms to degrade organic pollutants.
3. Rhizofiltration: use plant roots to absorb and adsorb pollutants, mainly metals, from water and aqueous waste streams.
4. Phytostabilization: use plants to reduce the bioavailability of pollutants in the environment.
5. Phytovolatalization: use plants to volatalize pollutants and the use of plants to remove pollutants from air (Salt *et al.,* 1998).

Among the different techniques of phytoremediation, phytoextraction by plants is most effective and it offers great promise of commercial development for extraction of metals. Various plants show different behaviour regarding the ability to accumulate elements in roots, stem and /or leaves. The ability to produce biomass at high rate especially shoot biomass (Cunningham *et al.*, 1995) is an ideal character for hyperaccumulators since its disposal is more easy.

The wetlands are often considered sinks for contaminants, and several wetland plants are utilized for removal of pollutants, including metals. The approach is generally based on ‘‘phytostabilization’’, where the plants are used to immobilize metals and store them below ground in roots and/or soil, in contrast to ‘‘phytoextraction’’. Storing metals below ground is the preferable alternative since mechanical harvesting of plants would be destructive to wetlands comprised of rooted plants. The extent of uptake and how metals are distributed within plants can have important effects on the residence time of metals in plants and in wetlands, and the potential release of metals (Wies and Wies, 2004, 2003).

Though phytoremediation has a long history of over 300 years, its industrial and environmental applications are quite recent. A. Baumann, a German botanist reported the phytoremediation ability of *Viola calaminaria* for Zn in 1885. This was the first scientific report on phytoremediation. Several aquatic weeds, such as *Salvinia*, *Lemna*, *Azolla and Eichhornia* sedges like *Typha latifolia* possess the unique ability for uptake and even hyper accumulate heavy metals and other toxic substances from soil and water through their roots and concentrate them in roots, stem and leaves (Chaney, 1983; Chaney *et al.*, 1995).

Phytoremediation technologies were found to be one of the successful tools for the decontamination of surface water (Rice *et al*., 1997). Phytoextraction, using hyperaccumulating plants is proved to be the most effective method for the clean up of the metal contaminated soil and water systems (Cunningham *et al*., 1997). *Eichhornia crassipes*, *Cyperus pangorei*, *Bacopa monnieri* were effective at removal of Fe, Mn, Cu, Zn and Al from aquatic systems of Kuttanad (Thampatti, *et al*., 2007; KAU, 2009).

Kumar *et al.*, (1989) have investigated elemental composition of certain aquatic plants by energy dispersive analysis of X-Rays (EDAX) and found high level of heavy metals such as Al, Si, Mn and Fe being found accumulated in *Vallisneria spiralis*, *Hydrilla verticillata* and *Azolla pinnata*.

Stratford *et al.* (1984) found that the metals' accumulations in water hyacinth increased linearly with the solution concentration in the order of leaves<stems<roots in water hyacinth. The uptake and accumulation of Fe (Jayaweere *et al.*, 2007), Al, Zn, Cu, Cd and Pb by *Eichhornea crassipes* increased with increase of the above metals in soil or water (KAU, 2009).

Materials and Methods

3. MATERIALS AND METHODS

The present study entitled "Evaluation of aquatic pollution and identification of phytoremediators in Vellayani lake" has been carried out at the College of Agriculture, Vellayani during the pre monsoon, monsoon and post monsoon periods of the year 2010. The main objective of the study was to assess the extent of pollution and to identify the phytoremediators in Vellayani lake.

3.1. General description of the area

3.1.1. Geographic setting

Vellayani wetland ecosystem comprising a fresh water lake and surrounding padasekharams lies 8^{O} 24' 09'' to 8^{O} 26' 30'' N latitude and 76^{O} 59' 08'' to 76^{O} 59' 47''E longitude at an elevation of 29 m above mean sea level. It extends through three panchayaths viz., Kalliyoor, Pallichal, Venganoor and two zones of Thiruvananthapuram Corporation namely Nemom and Thiruvallam. Vellayani lake, which is the sole drinking water source for Kovalam, Vizhinjam, Pachalloor, Vellayani and adjoining areas is undergoing drastic reduction in area and water quality. Now, the lake area has shrunken drastically to less than 400 ha from 750 ha in 1926. The Vellayani wetlands is a unique ecosystem that supports a variety of crops, large number of migratory birds and diversified aquatic and terrestrial fauna and flora. Location of the study is presented in Fig 1.

3.1.2. Hydrology of lake

Vellayani lake is a fresh water lake, with a depth of 1 to 2.5 m during summer and 3 to 4 m during monsoon (Radhika & Devi, 2007). The main source of water for this lake comes mainly from two sources viz., Pallichal and Nedinjal streams. About 64 rivulets and channels of the adjoining areas discharge water into this lake. The

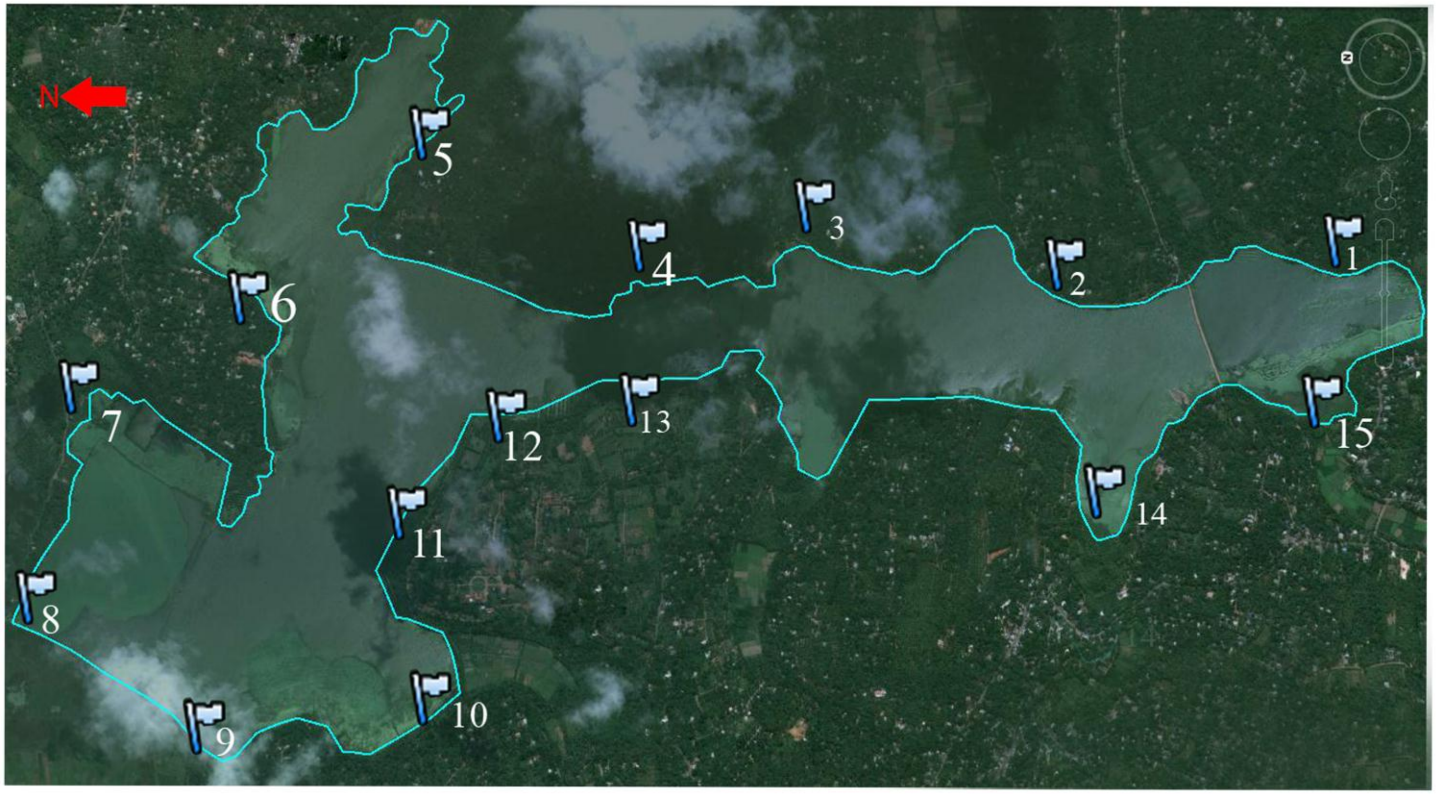

Fig. 1. Vellayani fresh water lake

1. Panangode 2. Kizhur-manalivila 3. Kakkamoola 4. Manamukku 5. Reservoir bund 6. Pallichalthodu
7. Palapoor 8. Karithalaykkal 9. Aaratukadavu RB 10. Valiyavilagam 11. Kulangara
12. Mannamvarambu 13. Kochukovalam 14. Venniyoor 15. Kattukulam

lake is about a metre above sea level permitting easy dewatering through the Madhupalam spillway near Thiruvallam that empties into the Karamana river. Major part of the lake is static, but it flows through a narrow channel, which opens to Karamana river.

3.1.3. Socio economic perspective

Vellayani lake water is the principal source of food, drinking water, irrigation and fishing for local dependent communities of peripheral villages. It carries agricultural run-off from surrounding village pockets and household sewage at certain extent.

3.1.4. Geology

During the past, the tidal water had reached much inward along the lower basin of Karamana river and also along the basin of its existing tributary from south, protected all around by hills, the area of tributary basin got totally submerged. Subsequent to regression of sea water, the deeper portion of tributary became Vellayani lake.

3.1.5. Climate

Climatic data during the study period was collected from the Meteorological Observatory of College of Agriculture, Vellayani. The climatological data collected, include rainfall, maximum and minimum temperature, evaporation and relative humidity for the year 2010 are given in Table 1.

Interpretation of climatic data reveals that the region enjoys a humid tropical climate. The two spells of monsoon viz., south west monsoon during June to September and North East monsoon during October to November prevails in the area, the latter being dominant. No rain was received during the months of January to March.

Average maximum and minimum temperature recorded in the area were 34.6^0C and 22.3^0C respectively. Maximum temperature was recorded during the month of April and minimum during November. The average monthly evaporation was 3.5 mm and the rate of evaporation was highest during the month of April and May. Relative humidity was highest during the month of November and lowest during April.

Table 1. Weather parameters at Vellayani during the year 2010

Sl No	Month	Temp. Max (^{0}C)	Temp. Min (^{0}C)	RF (mm)	RH (%)	Evaporation (mm)
1	Jan 2010	31.4	22.8	0	89.2	3.4
2	Feb 2010	32.1	23.9	0	90.5	3.7
3	March 2010	33.9	24.4	0	88.4	4.4
4	April 2010	34.6	25.5	61	80	4.6
5	May 2010	32.0	25.1	278	84	4.6
6	June 2010	30.4	22.9	245.2	89.3	3.0
7	July 2010	36.6	22.8	199.3	87.6	3.5
8	Aug 2010	30.5	22.7	87.2	89.7	3.5
9	Sept 2010	30.8	22.6	134.4	83.8	3.4
10	Oct 2010	30.6	23.1	510.6	89.4	3.2
11	Nov 2010	30.4	22.3	261.8	91.4	2.9
12	Dec 2010	30.0	22.7	176.6	89.6	2.8
	Mean	31.9	23.4	162.8	87.7	3.6

3.1.6. Agro ecosystem

The Vellayani wetlands is a unique ecosystem that supports a variety of crops, like coconut, banana, rice and vegetables like bitter gourd, snake gourd, cucumber, vegetable cowpea etc. A major portion of the lake expanse is covered by lotus plant, the flowers of which are being widely used in temples and in indigenous medicine.

3.1.7. Flora and Fauna

The region experiences rich biodiversity. The common aquatic macrophytes observed in the area were *Pistia stratiotes, Ipomea aquatica, Eleocharis dulcis, Nelumbo nucifera, Brachiaria mutica, Colocasia esculenta, Scirpus grossus, Echinocloa colona, Eichhornea crassipes, Nymphaea odorata, Dryopteris erythrosora, Limnocharis flava* etc.

The lake and its ecosystem support more than 160 species of aquatic birds. The common migratory birds reported in this area are wood sandpiper, green sandpiper, marsh sandpiper, black winged slilt, migratory ducks like garganey and pintail etc.

3.2. Components of the study

The study consisted of two parts

1. Evaluation of aquatic pollution in Vellayani lake

2. Identification of hyper accumulators / phytoremediators found in the Vellayani lake

3.2.1. Evaluation of aquatic pollution

A reconnaissance survey was carried out along the banks of Vellayani lake and 15 locations representing the entire area were selected as sampling sites (Table 2). Water and sediment samples were collected at two points, 10 m away from the bank during pre-monsoon (April), monsoon (Sep) and post monsoon (Dec) periods. These samples were analyzed for various physical, chemical and biological properties. Comparing these values with permissible limits prescribed by ISI/WHO or other such agencies, the extent of pollution in the aquatic system was assessed.

3.2.2. Identification of phytoremediators

Actively growing native macrophytes found in the lake at the above 15 locations were collected during the three sampling periods. The plants were thoroughly washed and their fresh weight was measured. They were separated into shoot and root and dried in a hot air oven at 80 ± 5^{0}C to find out their dry weight. Plant intensity for individual macrophyte was calculated as measure of plant growth and predominance of a species.

The collected plants were powdered and subjected to chemical analysis to find out their chemical composition. The amount of element removed from sediment/water was calculated by multiplying concentration with dry weight and expressed on dry weight basis. The bioconcentration factor and translocation index for each element were worked out from the data on elemental composition and dry weight, for all plants found in the study area. The bioconcentration factor and average content of elements in the plant were compared with the standard values for designating hyperaccumulation and based on this, the plants were rated for their hyperaccumulation capacity.

The materials and methods adopted for the study are briefed in this chapter.

3.3. Materials

3.3.1. Location

Table 2. Locations selected for the study with geo reference points

Site No	Name of the site	Geo reference Points	Description
1	Panangode	8^0 24'387" N $76^0$59'702" E	Bordered by coconut trees, mixed vegetation, lake dominated by aquatic macrophytes, sparse settlement near the lake area
2	Kizhur-manalivila	8^0 25'107" N $76^0$59'480"E	Bordered by coconut palms, urban settlement-lake portion protected by walls, washing, bathing, cattle wading are common.
3	Kakkamoola	8^0 25'479" N $76^0$59'538" E	Mixed vegetation with settlement, frequent anthropogenic influences, thick riparian vegetation, rivulets join with the lake, domestic waste disposed to the lake.
4	Manamukku	8^0 25'346" N $76^0$59'720" E	Mixed vegetation dominated by coconut, shore well protected by granite rubbles, thick growth of *Pandanus* along the shore line, rivulet joins the lake, sparse settlement near the lake area
5	Reservoir bund	$8^0$26'585"N $76^0$59'47" E	Bordered by *Pandanus*, moderately thick riparian vegetation dominated by *Eichhornea*, no human settlement
6	Pallichalthodu	$8^0$26'592"N $76^0$59'51" E	Moderately thick vegetation dominated by coconut, one canal joins the lake.
7	Palapoor	$8^0$26'290"N $76^0$58'907"E	Intensively cultivated area with banana and vegetables, lake dominated by lotus, pump house present, semi urban settlement.

Plate 1. Panangode (Site 1)

Plate 2. Kizhur-Manalivila (Site 2)

Plate 3. Kakkamoola (Site 3)

Plate 4. Manamukku (Site 4)

Plate 5. Reservoir bund (Site 5)

Plate 6. Pallichalthodu (Site 6)


Plate 7. Palapoor (Site 7)


Plate 8. Karithalaykkal (Site 8)


Plate 9. Arattukadavu RB (Site 9)


Plate 10. Valiyavilagam (Site 10)


Plate 11. Kulangara (Site 11)


Plate 12. Mannamvarambu (Site 12)


Plate 13. Kochukovalam (Site 13)


Plate 14. Venniyoor (Site 14)


Plate 15. Kaattukulam (Site 15)

8	Karithalaykkal	8025'560"N 76059'35"E	Thick vegetation dominated by coconut, intensive cultivation of crops like banana, cucurbitaceous vegetables, yard long bean and amaranthus, pump house present, semi urban settlement.
9	Aaratukadavu RB	8026'590"N 76059'50"E	Thick riparian vegetation, shore protected by Pandanus, area is associated with some rituals of Vellayani temple, one rivulet joins the lake, semiurban settlement
10	Valiyavilagam	8026'261"N 76059'325"E	Shore partially protected by granite rubbling, lake dominated by lotus plants, one pump house present (non functional), semiurban settlement
11	Kulangara	8025'529"N 76059'645" E	One temple and a school for deaf and dumb are present, shore well protected by granite rubbling, operating site for water tourism and sports, sparse riparian vegetation
12	Mannamvarambu	8025'509"N 76059'652" E	Thick riparian vegetation bordered by coconut trees, the area belongs to College of Agriculture, Vellayani is well protected
13	Kochukovalam	8025'495"N 76059'545" E	Thick riparian vegetation bordered by coconut trees, the area belongs to College of Agriculture, Vellayani is well protected
14	Venniyoor	8024'742"N 76059'669"E	Blunt end of the lake, thick riparian vegetation, bordered by coconut palms, an aqua farm and a hatchery are present
15	Kaattukulam	8025'872"N 76059'724" E	Moderately thick vegetation dominated by coconut, lake is mainly covered by lotus, semiurban settlement, wastes are disposed to the lake, fishing activities are very common

3.4. Methods

Different methods used for the analysis of sediment, water and plant samples are presented in the Tables 3 to 5.

3.4.1. Survey

A reconnaissance survey was conducted to locate the sites for the collection of soil, water and plant samples. Fifteen locations each at a distance of 1.5 to 2.0 km apart were selected and geocoded, around the perimeter of Vellayani lake so as to cover the entire area. Three seasons viz., pre monsoon (April-May), monsoon (June-Sept) and post monsoon (Dec-Jan) were selected for the collection of water, sediment and plant samples.

3.4.2. Water and sediment sampling

Surface water and lake sediment samples were collected from two points at each site, 10 m away from the bank during the above three sampling periods. The samples were labeled carefully and brought to the laboratory for further analysis. The water samples were preserved in non reactive plastic bottles at -15^{o}C in a deep freezer till analysis. The sediment samples were preserved in air-dry plastic bags. A portion of fresh soil sample from each site was kept separately in wet condition for specific determinations at -15^{o}C (Allen, 1989). Freshly collected water samples were used for studying the microbiological properties.

3.4.3. Plant Sampling

Actively growing native aquatic macrophytes from one square metre area of the lake from each site were collected by hand, washed with lake water to remove periphyton and sediment particles. The collected plant species were placed in plastic bags, labeled carefully and brought to the laboratory. Polythene tools were used in sampling and storing the collected matrices to avoid the metal contamination. Plant species were identified according to Shah (1978a, 1978b). Fresh weight of total plants collected from one square metre area and that of individual plants from the same area were recorded. These samples were initially shade dried and later oven dried at a temperature of 80 ± 5°C.

3.4.4. Processing of sediment and plant samples

Part of the sediment samples were air dried, powdered and sieved through 2 mm sieve and stored in air tight bottles. The sieved sediment was subjected to physical and chemical evaluation. The oven dried plant samples, both shoot and root were powdered and stored in butter paper covers for chemical analysis.

3.4.5. Chemical analysis of water, sediment and plant samples

3.4.5.1. Water

Table 3. Standard analytical methods followed in water analysis

Sl No	Parameters	Methods	Reference
A. Physical properties			
1	Temperature	Thermometer	Gupta (1999)
2	Colour	Forel – Ule colour scale method	Gupta (1999)
3	Turbidity	Turbidimetry	Gupta (1999)
4	Suspended solids	Filtration method	Gupta (1999)

B. Chemical properties			
5	pH	pH meter	Jackson (1973)
6	EC	Conductivity meter	Jackson (1973)
7	BOD	Incubation and titration	APHA (1999) Gupta (1999)
8	COD	Titration	APHA (1999) Gupta (1999)
9	NH_4- N and NO_3-N	Macro-Kjeldahl distillation	Bremner and Keeney (1965)
10	Phosphates	Spectrophotometry	Watanabe and Olsen (1965)
11	Potassium, sodium	Flame photometry	Jackson (1973)
12	Calcium, magnesium	Versanate titration method	Hesse (1971)
13	Sulphates	Turbidimetry	Chesnin and Yien (1951)
14	Aluminium	Aluminon method	Jayman and Sivasubramaniam (1974)
15	Carbonates and bicarbonates	Titration	Tandon (1995)
16	Iron, zinc, copper, cadmium and lead	AAS	Tandon (1995)
C. Biological properties			
17	Bacterial counts	Serial dilution and plate count method	Waksman (1992)
18	Coliforms	Serial dilution and plate count method	Waksman (1992)
19	Algae	Haemocytometer method	Singleton and Sainsburg (2006)

3.4.5.2. Sediment

Table 4. Standard analytical methods followed in sediment analysis

Sl. No	Properties	Method	Reference
A. Physical properties			
1	Texture	Hydrometer method	Piper (1942)
B. Chemical properties			
2	pH	pH meter	Jackson (1973)
3	EC	Conductivity meter	Jackson (1973)
4	Organic carbon	Walkley and Black rapid titration method	Walkley and Black (1934)
5	NH_4-Nand NO_3-N	2M KCl extraction and macro-Kjeldahl distillation and titration	Bremner and Keeney (1965)
6	Neutral normal NH_4OAC extractable potassium and sodium	Flame photometry	Jackson (1973)
7	Neutral normal NH_4OAC extractable calcium and magnesium	Versanate titration method	Hesse (1971)
8	Normal KCl extractable aluminium	Aluminon Method	Yuan (1959)
9	0.5 N HCl extractable iron, zinc, copper, cadmium and lead	AAS	O'Connor (1988)
10	Bray No.1 extractable phosphorus	Spectrophotometry	Jackson (1973)
11	0.01N $Ca(PO_4)_2$ extract-able sulphur	Turbidimetry	Chesnin and Yien (1950)

12	Water extractable carbonates and bicarbonates	Titration	Tandon (1995)

3.4.5.3. Macrophytes

Table 5. Standard analytical methods followed in plant analysis

Sl. No	Properties	Method	Reference
		Elemental Composition	
1	Nitrogen	Micro Kjedahl method	Jackson (1973)
2	Phosphorus	Nitric- perchloric acid (9:4) digestion and spectrophotometry using vanadomoldophosphoric yellow colour method	Jackson (1973)
3	Potassium and sodium	Nitric - perchloric acid (9:4) digestion and flame photometry	Jackson (1973)
4	Calcium and magnesium	Nitric - perchloric acid (9:4) digestion and versanate titration	Piper (1966)
5	Sulphur	Nitric - perchloric acid (9:4) digestion & turbidimetry	Chesnin and Yien (1950)
6	Aluminium	Nitric - perchloric acid (9:4) digestion and Aluminon method	Jayman and Sivasubramaniam (1974)
7	Iron, zinc, copper, cadmium and lead	Nitric- perchloric acid (9:4) digestion and AAS	Hesse (1971)

Aquatic macrophytes identified in the study area are presented below.

Table 6. Macrophytes identified in the Vellayani wetland ecosystem

Sl No.	Common name	Scientific name
1	Buffalo Grass	*Brachiaria mutica*
2	Colocasia	*Colocasia esculenta*
3	Kora grass	*Scirpus grossus*
4	Jungle rice	*Echinocloa colona*
5	Kulavaazha	*Eichhornea crassipes*
6	Fern	*Dryopteris erythrosora*
7	Naagapola	*Limnocharis flava*
8	Lotus	*Nelumbo nucifera*
9	Injipullu	*Panicum repens*
10	Water cabbage	*Pistia stratiotes*
11	Aambal	*Nymphaea odorata*
12	Neyyambal	*Nymphoides indicus*
13	Kuzhalpullu	*Eleocharis dulcis*
14	Water spinach	*Ipomea aquatica*

3.4.6. Computed indices (Chaney *et al.*, 1995)

$$\text{Plant intensity (w/w)} = \frac{\text{Weight of individual plant in one m}^2 \text{ X } 100}{\text{Total weight of plants in one m}^2}$$

$$\text{Bioconcentration factor (BCF)} = \frac{\text{Concentration in plant part}}{\text{Concentration in growing medium}}$$

$$\text{Translocation index} = \frac{\text{Concentration in shoot}}{\text{Concentration in root}}$$

Plate 16. *Brachiaria mutica*

Plate 17. *Colocasia esculenta*

Plate 18. *Dryopteris erythrosora*

Plate 19. *Echinocloa colona*

Plate 20. *Eichhornea crassipes*

Plate 21. *Eleocharis dulcis*

Plate 22. *Ipomea aquatica*

Plate 23. *Limnocharis flava*

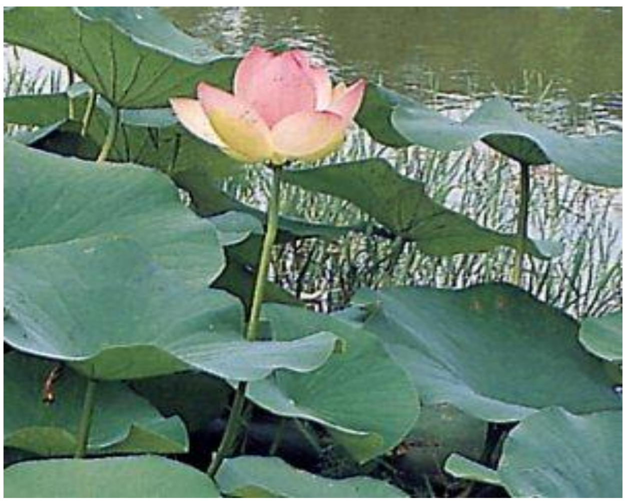

Plate 24. *Nelumbo nucifera*

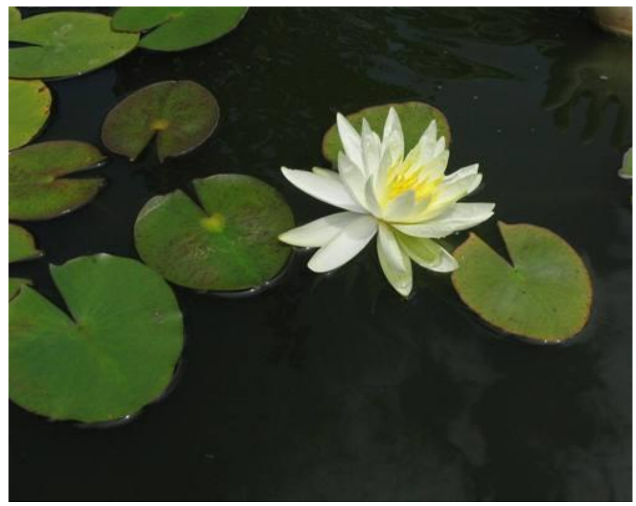

Plate 25. *Nymphaea odorata*

Plate 26. *Nymphoides indicus*

Plate 27. *Panicum repens*

Plate 28. *Pistia stratiotes*

Plate 29. *Scirpus grossus*

3.4.7. Statistical Analysis

Data generated from the experiment were subjected to statistical analysis (Cochran and Cox, 1965). ANOVA was done in CRD with two replications in split plot fashion with sites in the main plot and the three seasons viz., pre monsoon, monsoon and post monsoon in the subplot.

Microbiological analysis was done in the same way after logarithmic transformation and square root transformation in the case of values which showed wide variation and with zero values respectively.

Results

4. RESULTS

The results obtained for the project entitled “Evaluation of aquatic pollution and identification of phytoremediators in Vellayani lake” carried out during 2009-2011are presented in this chapter. The data are arranged under three sections viz., water, sediment and macrophytes.

4.1. Water

The water samples of Vellayani lake collected from 15 locations during pre monsoon, monsoon and post monsoon seasons were analysed for their physical, chemical and biological properties and the results are furnished under the same sub titles.

4.1.1. Physical properties

Data on physical properties of water namely temperature, colour, turbidity and suspended solids are presented in tables 7 and 8. Data on water temperature (Table 7) revealed that no variation was observed between locations within a season. The seasonal variation was also very meager. It ranged from 26 to 28^0 C. The value of site mean was 27^0 C.

The colour of lake water showed wide variation between locations within a season. During pre monsoon season, the colour index varied from 3 to 19 (Pale blue to Yellowish brown colour). During monsoon season not much variation was observed in colour, since the values ranged between 18 and 21 (Yellowish brown colour). In the post monsoon season, it showed a wide range starting from 2 to 20 (Pale blue to Yellowish brown colour).

Table 7. Temperature and colour of water during different seasons of 2010

Location		Temperature ^{0}C				Colour			
		Pre-M	M	Post-M	Mean	Pre-M	M	Post-M	Mean
Site 1	Panangode	28	26	27	27	17	20	16	18
Site 2	Kizhur-manalivila	28	26	27	27	12	20	12	15
Site 3	Kakkamoola	28	26	27	27	16	21	17	18
Site 4	Manamukku	28	26	27	27	4	20	5	10
Site 5	Reservoir bund	28	26	27	27	14	19	14	16
Site 6	Pallichalthodu	28	26	27	27	13	21	14	16
Site 7	Palapoor	28	26	27	27	15	18	16	16
Site 8	Karithalaykkal	28	26	27	27	16	20	17	18
Site 9	Aaratukadavu RB	28	26	27	27	3	21	2	9
Site 10	Valiyavilagam	28	26	27	27	3	21	3	9
Site 11	Kulangara	28	26	27	27	16	20	18	18
Site 12	Mannamvarambu	28	26	27	27	6	20	7	11
Site 13	Kochukovalam	28	26	27	27	19	20	20	20
Site 14	Venniyoor	28	26	27	27	15	19	16	17
Site 15	Kaattukulam	28	26	27	27	19	20	20	20
Mean		28	26	27		13	20	13	

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

Data on turbidity and suspended solids of water are presented in the Table 8. The site, season and their interaction effect was significant. The mean value of turbidity and suspended solids showed an enhancement in the monsoon season and recorded the highest values. The above parameters were lowest during the pre monsoon season. The highest value for turbidity was showed by Kakkamoola (Site 3) during the pre monsoon and post monsoon seasons. Mannamvarambu (Site 12) showed the highest value during the monsoon season. The lowest value was showed by Palapoor (Site 7), Valiyavilagam (Site 10) and Reservoir bund (Site 5) during the pre monsoon, monsoon and post monsoon seasons respectively. The highest value for site mean was showed by the Kakkamoola (Site 3) and lowest by Valiyavilagam (Site 10).

Table 8. Turbidity and suspended solids of water during different seasons of 2010

Location		Turbidity (NTU)				Suspended Solids (mg L^{-1})			
		Pre-M	M	Post-M	Mean	Pre-M	M	Post-M	Mean
Site 1	Panangode	5.02	8.98	2.48	5.5	125	250	225	200
Site 2	Kizhur-manalivila	5.98	6.77	3.16	5.3	53.0	50.8	42.5	49
Site 3	Kakkamoola	31.2	40.6	11.0	27.6	42.5	56.7	45.0	48
Site 4	Manamukku	12.7	14.9	7.80	11.8	110	200	145	152
Site 5	Reservoir bund	5.12	6.66	0.98	4.3	125	250	125	167
Site 6	Pallichalthodu	4.54	5.14	3.87	4.5	360	700	275	445
Site 7	Palapoor	4.07	5.68	3.83	4.5	535	1150	225	637
Site 8	Karithalaykkal	7.86	5.83	1.13	4.9	225	700	87.5	338
Site 9	Aaratukadavu RB	10.7	15.2	8.19	11.4	175	350	110	212
Site 10	Valiyavilagam	4.89	5.10	2.35	4.1	125	200	75.0	133
Site 11	Kulangara	11.4	16.3	8.94	12.2	45.0	63.2	42.5	50
Site 12	Mannamvarambu	10.2	51.5	8.76	23.5	625	2550	650	1275
Site 13	Kochukovalam	8.81	22.0	2.28	11.0	175	350	200	242
Site 14	Venniyoor	12.4	17.5	6.52	12.1	275	750	450	492
Site 15	Kaattukulam	10.7	13.7	5.63	10.0	575	3200	550	1442
Mean		9.71	15.7	5.13		238	721.4	216.5	
Range		4.07-31.2	5.10-51.5	0.98-11.0		42.5-625	50.8-3200	42.5-650	
CD(0.05)	Site	54.1				263.8			
	Season	23.4				127.0			
	Site X Season	90.7				492.1			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

The suspended solids also showed a similar trend as that of turbidity, ie; recording the highest values during the monsoon season. The highest value was showed by Mannamvarambu (Site 12) in the pre monsoon and post monsoon seasons. Kattukulam (Site 15) showed the highest value during the monsoon season. The lowest value was showed by Kakkamoola (Site 3) in the pre monsoon season. In the monsoon and post monsoon seasons, Kizhur- Manalivila (Site 2) showed the lowest value. The highest site mean was for Kattukulam (Site 15) and lowest for Kizhur-Manalivila (Site 2).

4.1.2. Chemical properties

Data on electrochemical properties of water are presented in the Table 9. Both pH and EC were significantly influenced by season and site. The interaction effect was also significant. The water pH was highest during monsoon season and the mean values were almost same for both pre monsoon and post monsoon periods. The highest value for pH was showed by Karithalaykkal (Site 8) during the pre monsoon and post monsoon seasons. Valiyavilagam (Site 10) showed the highest value during the monsoon season. The lowest value was showed by Panangode (Site 1) during the pre monsoon and monsoon seasons. Venniyoor (Site 14) showed the lowest value during the post monsoon season. The highest value for site mean was shown by Karithalaykkal (Site 8).

EC was lowest during monsoon and then increased to the highest mean value during post monsoon season. Panangode (Site 1) showed the highest value during the pre monsoon season. During the monsoon season the highest value was showed by Kakkamoola (Site 3). In the post monsoon season the highest value was showed by Aaratukadavu (Site 9). The value ranged from 51 to 162 μS cm^{-1}. Locations viz., Pallichalthodu (Site 6), Venniyoor (Site 14) and Panangode (Site 1) recorded the lowest values for EC during pre monsoon, monsoon and post monsoon seasons respectively. The site mean was highest for Karithalaykkal (Site 8) and lowest for Panangode (Site 1) and Kattukulam (Site 15).

Table 9. Electrochemical properties of water during different seasons of 2010

Location		pH				EC ($\mu S\ cm^{-1}$)			
		Pre-M	M	Post- M	Mean	Pre-M	M	Post-M	Mean
Site 1	Panangode	4.35	6.50	6.15	5.67	119	91	51	87
Site 2	Kizhur-manalivila	6.55	6.95	6.45	6.65	110	101	113	108
Site 3	Kakkamoola	6.05	6.55	6.25	6.28	114	117	92	108
Site 4	Manamukku	6.00	6.60	6.35	6.32	114	107	96	106
Site 5	Reservoir bund	6.20	6.75	6.35	6.43	114	107	90	104
Site 6	Pallichalthodu	6.75	6.95	6.25	6.65	91	96	123	103
Site 7	Palapoor	6.55	6.85	6.15	6.52	109	107	86	101
Site 8	Karithalaykkal	6.85	7.00	6.65	6.83	113	109	160	127
Site 9	Aaratukadavu RB	6.60	6.85	6.25	6.57	97	91	162	117
Site 10	Valiyavilagam	6.80	7.30	6.15	6.75	117	103	99	106
Site 11	Kulangara	6.05	6.80	6.40	6.42	110	108	149	122
Site 12	Mannamvarambu	6.20	6.80	6.35	6.45	112	108	156	125
Site 13	Kochukovalam	6.50	7.05	6.15	6.57	115	111	118	115
Site 14	Venniyoor	6.45	6.85	6.10	6.47	118	89	150	119
Site 15	Kaattukulam	6.45	6.60	6.55	6.53	103	99	58	87
Mean		6.29	6.83	6.30		110	103	114	
Range		4.35-6.85	6.50-7.30	6.10-6.65	5.67-6.83	91-119	89-117	51-162	
CD(0.05)	Site	0.190				5.85			
	Season	0.067				2.41			
	Site X Season	0.261				9.36			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

Data on Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are presented in Table 10.

Table 10. Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of water during different seasons of 2010

Location		BOD ($mg\ L^{-1}$)				COD ($mg\ L^{-1}$)			
		Pre-M	M	Post-M	Mean	Pre- M	M	Post- M	Mean
Site 1	Panangode	39	4	20	21	116	45	91	84
Site 2	Kizhur-manalivila	7	1	4	4	96	41	86	74
Site 3	Kakkamoola	14	8	11	11	33	23	25	27
Site 4	Manamukku	9	1	5	5	21	11	19	17
Site 5	Reservoir bund	10	0	8	6	116	47	76	80
Site 6	Pallichalthodu	12	1	7	7	17	4	19	13
Site 7	Palapoor	7	1	4	4	126	45	86	86
Site 8	Karithalaykkal	7	1	5	4	121	42	90	84
Site 9	Aaratukadavu RB	25	2	18	15	105	52	87	81
Site 10	Valiyavilagam	23	9	7	13	114	42	103	86
Site 11	Kulangara	6	1	2	3	16	14	12	14
Site 12	Mannamvarambu	32	8	26	22	13	8	11	11
Site 13	Kochukovalam	22	5	14	14	48	22	43	38
Site 14	Venniyoor	14	15	11	13	20	15	8	14
Site 15	Kaattukulam	18	9	8	12	17	10	12	13
Mean		16	4	10		65	28	51	
Range		6 -39	0-15	2-26		13-126	4 - 47	8 - 103	
CD(0.05)	Site	1.54				3.25			
	Season	0.584				1.23			
	Site X Season	2.26				4.79			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

The site, season and interaction effects were significant. Both the characters were at their lowest values during monsoon and highest during pre monsoon. The site wise variation in all the three seasons was very wide. The highest value was showed by Panangode (Site 1) during the pre monsoon season. Venniyoor (Site 14) and Mannamvarambu (Site 12) showed the highest values during the monsoon and post monsoon seasons respectively. Kulangara (Site 11) showed the lowest value during both the pre monsoon and post monsoon seasons. Reservoir bund (Site 5) showed the lowest value during the monsoon season. The value of site mean was highest for the Mannamvarambu (Site 12) and lowest for Kulangara (Site 11).

In the case of COD, the highest value was showed by Palapoor (Site 7) during the pre monsoon season. Reservoir bund (Site 5) showed the highest value in the monsoon season. For the post monsoon season, Valiyavilagam (Site 10) showed the highest value. Mannamvarambu (Site 12), Pallichalthodu (Site 6) and Venniyoor (Site 14) showed the lowest values for COD in the pre monsoon, monsoon and post monsoon seasons respectively. The highest value for site mean was showed by both Palapoor (Site 7) and Valiyavilagam (Site 10). The lowest value was showed by Mannamvarambu (Site 12).

The data on ammoniacal nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N) are presented in the Table 11. The effect of site, season and their interactions were significant. The NH_4-N content was highest during the post monsoon season and lowest during the monsoon season. The site wise variation was very wide. The highest value was showed by Palapoor (Site 7) during the pre monsoon season, Kakkamoola (Site 3) during the monsoon season and Kaattukulam (Site 15) during the post monsoon season. The lowest value was showed by Valiyavilagam (Site 10) during the pre monsoon and post monsoon seasons. During the monsoon season, the lowest value of 0.1 ppm was recorded by three sites viz., Panangode (Site 1), Mannamvarambu (Site 12) and Kochukovalam (Site 13).

Table 11. NH_4-N and NO_3-N contents in water during different seasons of 2010

Location		NH_4-N (mg L^{-1})				NO_3-N (mg L^{-1})			
		Pre- M	M	Post- M	Mean	Pre- M	M	Post- M	Mean
Site 1	Panangode	15.5	0.10	22.5	12.7	4.61	0.92	4.59	3.37
Site 2	Kizhur-manalivila	2.10	1.40	1.40	1.6	12.4	0.46	10.4	7.75
Site 3	Kakkamoola	11.3	2.70	12.2	8.7	0.38	0	0.45	0.28
Site 4	Manamukku	2.70	0.30	2.79	1.9	5.45	1.37	4.56	3.79
Site 5	Reservoir bund	16.5	1.40	17.2	11.7	8.73	0.49	9.35	6.19
Site 6	Pallichalthodu	2.50	2.20	4.80	3.2	0.32	0	0.34	0.22
Site 7	Palapoor	27.5	0.20	24.5	17.4	0.42	0	0.33	0.25
Site 8	Karithalaykkal	6.00	1.00	5.51	4.2	0.33	0	0.33	0.22
Site 9	Aaratukadavu RB	1.38	1.45	1.60	1.5	0.35	0	0.35	0.23
Site 10	Valiyavilagam	1.00	1.65	1.35	1.3	0.44	0	0.51	0.32
Site 11	Kulangara	3.65	1.10	5.60	3.5	0.33	0	0.41	0.25
Site 12	Mannamvarambu	1.55	0.10	4.25	2.0	0.36	0	0.36	0.24
Site 13	Kochukovalam	14.9	0.10	12.2	9.1	0.45	0	0.47	0.31
Site 14	Venniyoor	4.15	0.45	4.75	3.1	5.38	3.76	5.39	4.84
Site 15	Kaattukulam	31.7	0.30	44.3	25.4	6.00	3.69	6.05	5.25
Mean		9.50	0.96	11		3.06	0.71	2.92	
Range		1.00-27.5	0.1-2.70	1.35-44.3		0.32-12.4	0-3.76	0.33-10.4	
CD(0.05) Site		2.08				0.664			
CD(0.05) Season		0.767				0.273			
CD(0.05) Site X Season		2.97				1.05			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

The NO_3-N content was highest during pre monsoon season and was undetecable in most of the sites during the monsoon season. The site wise variation was not that much wide as in the case of NH_4-N. The highest value was showed by the Kizhur-Manalivila (Site 2) in the pre monsoon and post monsoon seasons. Venniyoor (Site 14) showed the highest value in the monsoon season. The site mean was also highest for Kizhur-Manalivila (Site 2). During the monsoon season NO_3-N was not detected only in six sites.

The P content of water was below detectable limits and hence not presented.

The K and S contents of water (Table 12) were significantly influenced by the site and season. The interaction effect was also significant. Both the parameters showed lowest values during the monsoon season and there after a gradual increase was observed. The highest value was showed by Karithalaykkal (Site 8) in the pre monsoon season. During the monsoon and post monsoon seasons, Aaratukadavu RB (Site 9) showed the highest value. The lowest value was showed by Mannamvarambu (Site 12) in the pre monsoon season. Palapoor (Site 7) and Kaattukulam (Site 15) showed the lowest value for monsoon and post monsoon seasons respectively. The highest value for the site mean was showed by Aaratukadavu (Site 9) and lowest by Manamukku (Site 4).

The S content of water was highest during pre monsoon season and lowest during monsoon season. The season wise variation was comparatively lower for S, though the difference was significant. The highest value (22.0 mg L^{-1}) during the pre monsoon season was showed by both Reservoir bund (Site 5) and Kulangara (Site 11). Kaattukulam (Site 15) and Valiyavilagam (Site 10) showed the highest value during monsoon and post monsoon seasons respectively. The lowest value was showed by Panangode (Site 1) for all the three seasons. The highest value for site mean was showed by Valiyavilagam (Site 10).

Table 12. Concentration of K and S in water during different seasons of 2010

Location		K (mg L^{-1})				S (mg L-1)			
		Pre- M	M	Post- M	Mean	Pre- M	M	Post- M	Mean
Site 1	Panangode	4.60	1.40	3.20	3.1	8.50	4.50	9.00	7.3
Site 2	Kizhur-manalivila	2.70	1.80	4.50	3.0	20.5	17.0	18.5	18.7
Site 3	Kakkamoola	3.70	1.10	3.40	2.7	21.0	17.5	17.5	18.7
Site 4	Manamukku	3.25	0.80	2.50	2.2	19.5	17.5	17.5	18.2
Site 5	Reservoir bund	4.45	1.50	6.10	4.0	22.0	17.0	18.5	19.2
Site 6	Pallichalthodu	4.30	1.70	3.30	3.1	21.0	18.5	18.5	19.3
Site 7	Palapoor	4.40	0.65	5.80	3.6	20.5	18.0	17.5	18.7
Site 8	Karithalaykkal	5.05	2.10	5.20	4.1	20.5	17.5	19.5	19.2
Site 9	Aaratukadavu RB	4.70	2.30	7.30	4.8	18.0	16.0	16.5	16.8
Site 10	Valiyavilagam	3.30	2.00	2.90	2.7	20.0	18.0	20.5	19.5
Site 11	Kulangara	4.10	1.30	4.90	3.4	22.0	18.0	18.0	19.3
Site 12	Mannamvarambu	2.20	1.40	5.00	2.9	20.5	18.0	18.0	18.8
Site 13	Kochukovalam	3.20	2.00	3.00	2.7	18.5	18.5	17.5	18.2
Site 14	Venniyoor	6.00	1.40	3.60	3.7	19.0	17.5	20.0	18.8
Site 15	Kaattukulam	4.10	2.10	1.70	2.6	19.5	19.0	19.5	19.3
Mean		4.00	1.57	4.16		19.4	16.8	17.8	
Range		2.20-5.05	0.65-2.30	1.70-7.30		8.50-22.0	4.50-19.0	9.00-20.5	
CD(0.05) Site		0.823				2.34			
CD(0.05) Season		0.427				0.580			
CD(0.05) Site X Season		1.65				2.24			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

Ca and Mg contents in water are presented in the Table 13. There was only a slight variation in the mean value of Ca during the three seasons. However the Ca content was highest during the monsoon season. The site wise variation was high.

Table 13. Concentration of Ca and Mg in water during different seasons of 2010

Location		Ca (mg L^{-1})				Mg (mg L^{-1})			
		Pre- M	M	Post-M	Mean	Pre-M	M	Post-M	Mean
Site 1	Panangode	23	8	17	16	4	4	1	3
Site 2	Kizhur-manalivila	10	9	9	9	1	3	5	3
Site 3	Kakkamoola	10	8	8	9	1	2	5	3
Site 4	Manamukku	8	9	6	8	2	2	6	3
Site 5	Reservoir bund	6	8	8	7	3	2	7	4
Site 6	Pallichalthodu	7	12	7	9	2	1	5	3
Site 7	Palapoor	8	11	9	9	4	1	4	3
Site 8	Karithalaykkal	8	9	8	8	2	3	5	4
Site 9	Aaratukadavu RB	10	7	10	9	1	2	4	2
Site 10	Valiyavilagam	8	9	12	10	2	3	2	2
Site 11	Kulangara	7	11	8	9	3	1	4	3
Site 12	Mannamvarambu	8	8	9	8	1	2	2	2
Site 13	Kochukovalam	10	13	8	10	1	2	5	3
Site 14	Venniyoor	8	12	10	10	1	2	4	2
Site 15	Kaattukulam	9	10	6	8	1	2	3	2
Mean		9.3	9.6	9		1.9	2.2	4.07	
Range		6 – 23	7-13	6-17		1-4	1-4	1-7	
CD(0.05)	Site	5.30				2.28			
	Season	1.68				0.945			
	Site X Season	6.52				3.66			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

The highest value was showed by Panangode (Site 1) for the pre monsoon and post monsoon seasons. In the monsoon season Kochukovalam (Site 13) showed the highest value. The lowest value was showed by Reservoir bund (Site 5) and Aarattukadavu-RB (Site 9) during pre monsoon and monsoon season respectively. Manamukku (Site 4) and Kaattukulam (Site 15) showed the lowest value (6 mg L^{-1}) in the post monsoon season. The site mean was highest for the Panangode (Site 1).

Mg content was highest during post monsoon season and lowest during pre monsoon season. The site wise variation was comparatively more prominent during post monsoon season. During the post monsoon season a slight increase in the value was seen. During the pre monsoon and monsoon seasons, the highest value was showed by Panangode (Site 1). In the post monsoon season, Reservoir bund (Site 5) showed the highest value. The site means showed a slight variation in the values and the highest value was showed by two sites, viz., Reservoir bund (Site 5) and Karithalaykkal (Site 8).

Concentration of Fe and Zn in water are presented in the Table 14. Here also the site, season and interaction effects were significant. Both Fe and Zn contents were below detectable levels during the monsoon season. Their values showed only a slight variation between pre monsoon and post monsoon seasons. The highest value for Fe was showed by Venniyoor (Site 14) during both pre monsoon and post monsoon seasons and the lowest by Mannamvarambu (Site 12). The highest value for site mean was also showed by the Venniyoor (Site 14).

With regard to Zn, the highest value was showed by Panangode (Site 1) for both pre monsoon and post monsoon seasons. Kizhur- Manalivila (Site 2), Kulangara (Site 11) and Mannamvarambu (Site 12) showed the lowest value of 0.0001 mg L^{-1}

for both pre monsoon and post monsoon seasons. The highest value for site mean was showed by Panangode (Site 1).

Table 14. Concentration of Fe and Zn in water during different seasons of 2010

Location		Fe (mg L^{-1})				Zn (mg L^{-1})			
		Pre-M	M	Post-M	Mean	Pre- M	M	Post- M	Mean
Site 1	Panangode	0.22	0	0.27	0.16	0.085	0	0.075	0.053
Site 2	Kizhur-manalivila	0.23	0	0.23	0.15	0.0001	0	0.0001	0.0001
Site 3	Kakkamoola	0.21	0	0.22	0.14	0.025	0	0.020	0.015
Site 4	Manamukku	0.26	0	0.25	0.17	0.015	0	0.010	0.008
Site 5	Reservoir bund	0.23	0	0.23	0.15	0.08	0	0.070	0.052
Site 6	Pallichalthodu	0.22	0	0.21	0.14	0.025	0	0.010	0.012
Site 7	Palapoor	0.22	0	0.23	0.15	0.0055	0	0.0065	0.004
Site 8	Karithalaykkal	0.26	0	0.23	0.16	0.050	0	0.045	0.032
Site 9	Aaratukadavu RB	0.23	0	0.22	0.15	0.006	0	0.0045	0.004
Site 10	Valiyavilagam	0.22	0	0.23	0.15	0.003	0	0.0015	0.002
Site 11	Kulangara	0.19	0	0.19	0.13	0.0001	0	0.0001	0.0001
Site 12	Mannamvarambu	0.18	0	0.19	0.12	0.0001	0	0.0001	0.0001
Site 13	Kochukovalam	0.25	0	0.24	0.16	0.045	0	0.045	0.030
Site 14	Venniyoor	0.67	0	0.71	0.46	0.035	0	0.020	0.018
Site 15	Kaattukulam	0.23	0	0.27	0.17	0.055	0	0.050	0.035
Mean		0.25	0	0.26		0.03	0	0.02	
Range		0.18-0.67	0	0.19-0.71		0.0001-0.085	0	0.0001-0.075	
CD(0.05)	Site	0.019				0.003			
	Season	0.008				0.002			
	Site X Season	0.034				0.009			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

Cu was not detected in water and hence not presented here.

Table 15. Concentration of Na and Al in water during different seasons of 2010

Location		Na (mg L^{-1})				Al (mg L^{-1})			
		Pre- M	M	Post-M	Mean	Pre- M	M	Post-M	Mean
Site 1	Panangode	15.9	11.6	6.20	11.2	5.44	5.42	5.89	5.58
Site 2	Kizhur-manalivila	10.2	11.4	12.9	11.5	5.90	5.09	4.80	5.26
Site 3	Kakkamoola	10.3	8.90	8.70	9.3	5.41	5.77	5.61	5.60
Site 4	Manamukku	10.3	7.70	8.70	8.9	5.63	4.94	5.83	5.47
Site 5	Reservoir bund	10.8	11.3	25.4	15.8	5.85	5.89	5.61	5.78
Site 6	Pallichalthodu	8.80	10.8	13.6	11.1	5.90	5.52	5.49	5.64
Site 7	Palapoor	11.7	12.1	16.2	13.3	5.90	5.90	5.63	5.81
Site 8	Karithalaykkal	10.4	10.3	13.9	11.5	5.61	5.09	5.77	5.49
Site 9	Aaratukadavu RB	9.80	10.0	12.8	10.9	5.50	5.77	5.77	5.68
Site 10	Valiyavilagam	11.5	11.0	10.5	11.0	5.50	4.43	5.46	5.13
Site 11	Kulangara	9.20	8.80	12.4	10.1	5.44	4.89	5.75	5.36
Site 12	Mannamvarambu	9.70	8.90	14.7	11.1	5.91	5.89	5.76	5.85
Site 13	Kochukovalam	10.0	10.3	11.5	10.6	5.29	5.79	5.06	5.38
Site 14	Venniyoor	10.6	13.1	12.6	12.1	5.39	4.96	5.47	5.27
Site 15	Kaattukulam	8.80	11.7	6.70	9.1	5.56	4.96	5.72	5.41
Mean		10.5	10.5	12.5		5.61	5.35	5.57	
Range		8.80-15.9	7.70-13.1	6.20-25.4		5.29-5.91	4.43-5.90	4.80-5.89	
CD(0.05) Site		2.51				0.368			
CD(0.05) Season		0.839				0.179			
CD(0.05) Site X Season		3.25				0.694			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

Data on Na and Al contents in water are presented in the Table 15. Site, season and interaction effects were significant. For Na the highest value was observed during post monsoon season and for other two seasons, the mean values were same. Regarding the site values, the highest Na content was recorded by Panangode (Site 1), Venniyoor (Site 14) and Reservoir bund (Site 5) during pre monsoon, monsoon and post monsoon seasons respectively. The lowest value of 8.80 mg L^{-1} was showed by Pallichalthodu (Site 6) and Kaattukulam (Site 15) for the pre monsoon season. Manamukku (Site 4) and Panangode (Site 1) showed the lowest value for monsoon and post monsoon seasons respectively. The highest value for the site mean was showed by the Reservoir bund (Site 5) and lowest by Manamukku (Site 4).

The Al content was highest during pre monsoon season and lowest during monsoon season. The highest value was showed by Mannamvarambu (Site 12) in the pre monsoon season. In the monsoon and post monsoon seasons, Palapoor (Site 7) and Panangode (Site 1) showed the highest values respectively. The lowest value was recorded by Kochukovalam (Site 13) in the pre monsoon season. Valiyavilagam (Site 10) and Kizhur- Manalivila (Site 2) showed the lowest value for monsoon and post monsoon season respectively. The value of site mean was highest for Mannamvarambu (Site 12) and lowest for Valiyavilagam (Site 10).

Carbonates and Bicarbonates were not present in any of the sites during three sampling periods.

Cd and Pb contents in water are presented in the Table 16 and were significantly influenced by site, season and their interactions. Cd content was negligible in most of the sites in all the three seasons except Manamukku (Site 4), Reservoir bund (Site 5), Valiyavilagam (Site 10), Venniyoor (Site 14) and Kattukulam (Site 15). Data on seasonal means revealed that Cd content was highest during the pre monsoon season and lowest during the monsoon season. Regarding sites, the highest value was recorded by the reservoir bund (Site 5) during all the three seasons.

Table No.16. Concentration of Cd and Pb in water during different seasons of 2010

Location		Cd (mg L^{-1})				Pb (mg L^{-1})			
		Pre- M	M	Post- M	Mean	Pre- M	M	Post- M	Mean
Site 1	Panangode	0.0001	0.0001	0.0001	0.0001	0.1	0.01	0.055	0.0550
Site 2	Kizhur-manalivila	0.0001	0.0001	0.0001	0.0001	0.25	0.015	0.215	0.1600
Site 3	Kakkamoola	0.0001	0.0001	0.0001	0.0001	0.065	0.015	0.05	0.0433
Site 4	Manamukku	0.025	0.01	0.02	0.0183	0.0001	0.0001	0.0001	0.0001
Site 5	Reservoir bund	0.025	0.01	0.03	0.0217	0.0001	0.0001	0.0001	0.0001
Site 6	Pallichalthodu	0.0001	0.0001	0.0002	0.0001	0.175	0.01	0.145	0.1100
Site 7	Palapoor	0.0001	0.0001	0.0001	0.0001	0.185	0.015	0.15	0.1167
Site 8	Karithalaykkal	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Site 9	Aaratukadavu RB	0.02	0.0001	0.01	0.0100	0.19	0.02	0.125	0.1117
Site 10	Valiyavilagam	0.015	0.01	0.015	0.0133	0.0001	0.0001	0.0001	0.0001
Site 11	Kulangara	0.0001	0.0001	0.0001	0.0001	0.115	0.01	0.15	0.0917
Site 12	Mannamvarambu	0.0001	0.0001	0.0001	0.0001	0.145	0.01	0.125	0.0933
Site 13	Kochukovalam	0.0001	0.0001	0.0001	0.0001	0.06	0.01	0.06	0.0433
Site 14	Venniyoor	0.015	0.01	0.01	0.0117	0.15	0.01	0.15	0.1033
Site 15	Kaattukulam	0.025	0.01	0.015	0.0167	0.15	0.015	0.115	0.0933
Mean		0.008	0.003	0.007		0.106	0.009	0.089	
Range		0.0001-0.025	0.0001-0.01	0.0001-0.03		0.0001-0.25	0.0001-0.02	0.0001-0.215	
CD(0.05)	Site	0.003				0.019			
	Season	0.001				0.012			
	Site X Season	0.005				0.05			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

Pb content also followed the same trend as that of Cd for seasonal variation in its concentration. The highest value was recorded by the Kizhur-Manalivila (Site 2) during the pre and post monsoon seasons. The site mean was highest for Kizhur – Manalivila (Site 2) and lowest by Karithalaykkal (Site 8).

4.1.3. Biological properties

The biological properties of lake water viz., total bacterial count, Coliform count and algal count are presented Tables 17 and 18. Site, seasons and their interactions were significant only for bacteria and coliforms.

Among the different seasons, the bacterial count was lowest during monsoon season and highest during post monsoon season. The site wise variation within each season was also very wide. The highest value was showed by Kakkamoola (Site 3) and Venniyoor (Site 14) during the pre monsoon and post monsoon season respectively. During the monsoon season, Valiyavilagam (Site 10) and Kochukovalam (Site 13) showed the highest value. The value of the site mean was highest for Venniyoor (Site 14) and lowest for Palapoor (Site 7).

Regarding the Coliform count, a gradual increase in number from pre monsoon to post monsoon season was observed. Here also the site wise variation within each season was high. Panangode (Site 1) recorded the highest value for pre monsoon season. Valiyavilagam (Site 10) for monsoon season. During the post monsoon season, Panangode (Site 1) and Kizhur- Manalivila (Site 2) showed the highest value.

Table 17. Total bacteria and Coliforms in water during different seasons of 2010

Location		Total bacteria (CFU/ml)				Coliforms (CFU/ml)			
		Pre-M	M	Post-M	Mean	Pre-M	M	Post-M	Mean
Site 1	Panangode	80	10	90	60	6	1	8	5
Site 2	Kizhur-manalivila	2	17	13	11	1	2	8	4
Site 3	Kakkamoola	900	100	200	400	3	2	3	3
Site 4	Manamukku	6	17	17	13	1	1	6	3
Site 5	Reservoir bund	5	9	6	7	4	3	1	3
Site 6	Pallichalthodu	3	17	4	8	1	2	2	2
Site 7	Palapoor	2	7	6	5	3	1	1	2
Site 8	Karithalaykkal	6	8	11	8	2	2	2	2
Site 9	Aaratukadavu RB	8	17	17	14	3	2	2	2
Site 10	Valiyavilagam	50	170	80	100	1	10	4	5
Site 11	Kulangara	2	17	2	7	1	2	1	1
Site 12	Mannamvarambu	3	17	3	8	1	3	1	2
Site 13	Kochukovalam	30	170	170	123	2	4	4	3
Site 14	Venniyoor	500	100	900	500	2	1	7	3
Site 15	Kaattukulam	50	20	170	80	1	1	6	3
Mean		110	46	113		2	3	4	
Range		2 - 900	7-170	2-900		1-6	1-10	1-8	
CD(0.05)	Site	1.365				0.752			
	Season	0.535				0.340			
	Site X Season	2.072				1.318			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

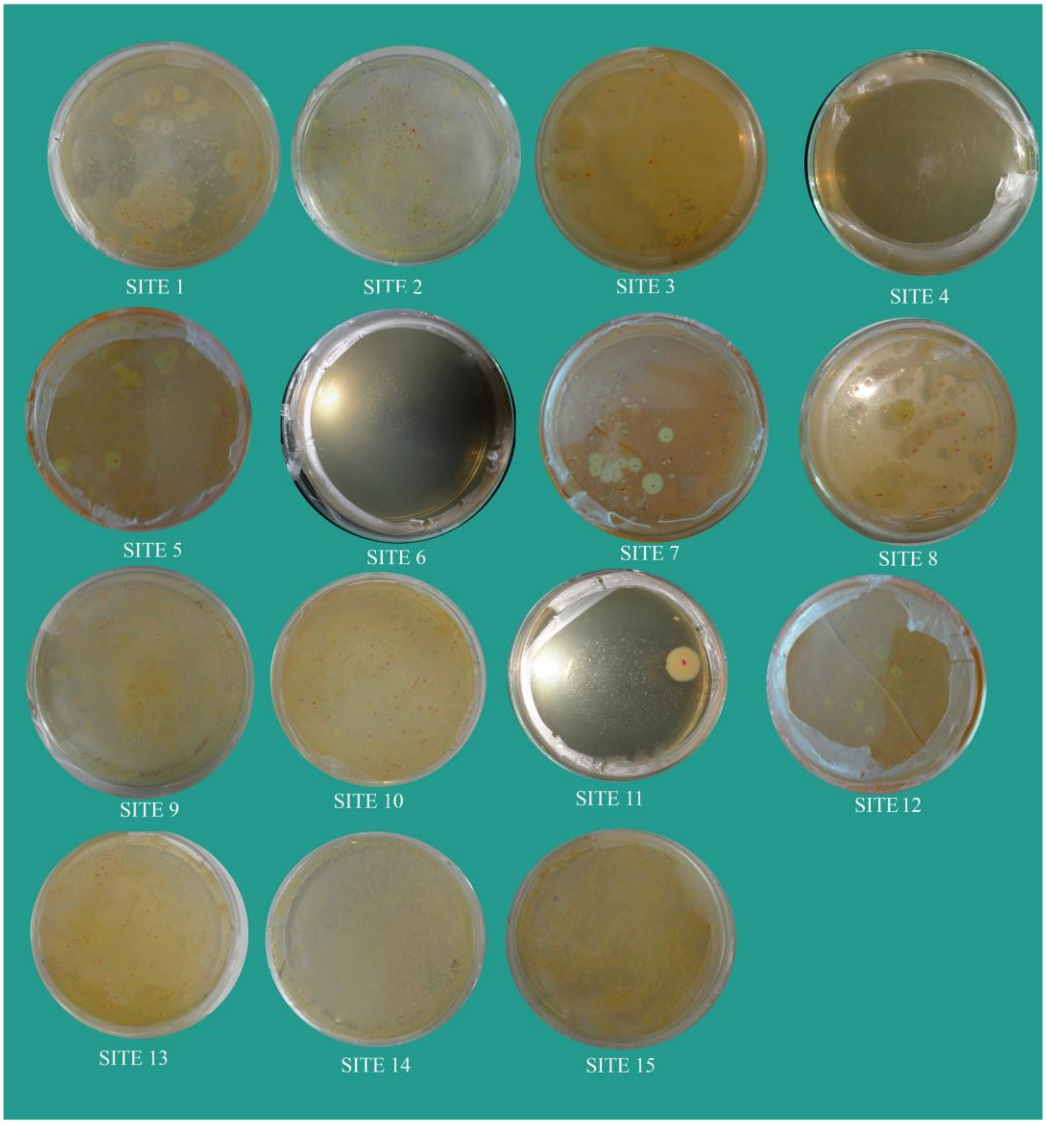

Plate 30. Total bacteria in different sites

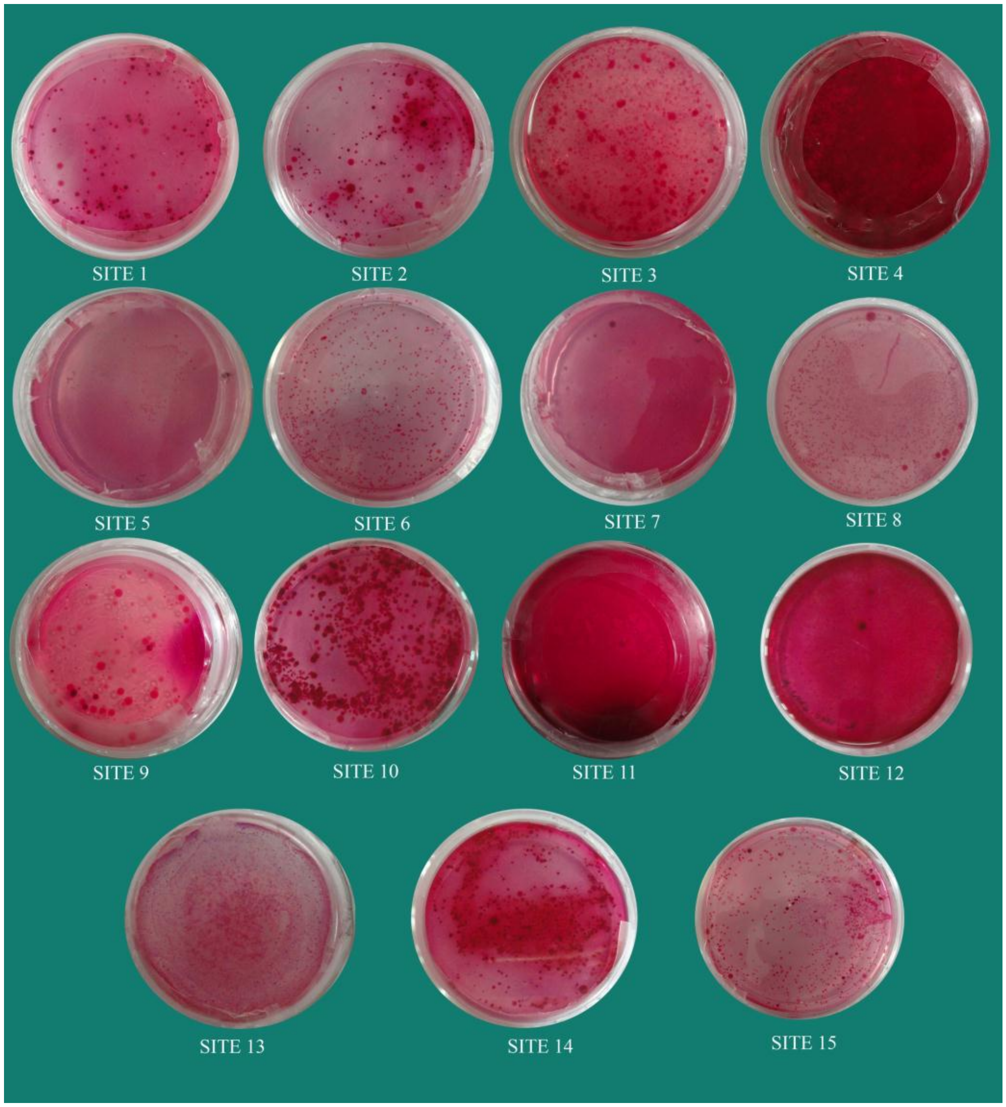

Plate 31. Coliforms in different sites

Table 18 Algal count in water during different seasons of 2010

Location		Algae (10^6cells/ml)			
		Pre-M	M	Post-M	Mean
Site 1	Panangode	1	1	1	1
Site 2	Kizhur-manalivila	1	1	1	1
Site 3	Kakkamoola	1	1	1	1
Site 4	Manamukku	1	1	1	1
Site 5	Reservoir bund	1	1	1	1
Site 6	Pallichalthodu	1	1	1	1
Site 7	Palapoor	1	1	1	1
Site 8	Karithalaykkal	1	1	1	1
Site 9	Aaratukadavu RB	1	1	1	1
Site 10	Valiyavilagam	1	1	1	1
Site 11	Kulangara	1	1	1	1
Site 12	Mannamvarambu	1	1	1	1
Site 13	Kochukovalam	1	1	1	1
Site 14	Venniyoor	1	1	1	1
Site 15	Kaattukulam	1	1	1	1
Mean		1	1	1	
CD(0.05) Site		0.227			
CD(0.05) Season		7.969			
CD(0.05) Site X Season		0.309			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

Algal population was seen uniformly distributed in all the 15 sites throughout the three seasons. Algae do not showed any significant difference between the sites. Season wise variation within the sites was also not significant.

4.2. Sediment

The electrochemical properties of sediment during pre monsoon, monsoon and post monsoon periods are presented in Table 19.

Table 19. Electrochemical properties of sediment during different seasons of 2010

Location		pH				EC (µS cm^{-1})			
		Pre-M	M	Post-M	Mean	Pre-M	M	Post-M	Mean
Site 1	Panangode	3.45	6.35	5.00	4.93	120	73	127	107
Site 2	Kizhur-manalivila	6.55	6.90	6.50	6.65	107	75	107	96
Site 3	Kakkamoola	5.55	6.45	5.35	5.78	213	107	183	168
Site 4	Manamukku	5.45	6.15	5.80	5.80	128	109	110	116
Site 5	Reservoir bund	5.70	6.40	5.75	5.95	68	51	85	68
Site 6	Pallichalthodu	6.15	7.45	5.95	6.52	123	86	125	111
Site 7	Palapoor	5.95	6.35	5.50	5.93	104	92	106	101
Site 8	Karithalaykkal	6.10	6.45	5.80	6.12	187	178	192	186
Site 9	Aaratukadavu RB	6.35	6.85	5.80	6.33	68	54	78	67
Site 10	Valiyavilagam	5.55	6.05	5.70	5.77	141	139	151	144
Site 11	Kulangara	5.60	6.50	5.75	5.95	165	141	162	156
Site 12	Mannamvarambu	5.85	6.50	5.60	5.98	150	120	152	141
Site 13	Kochukovalam	5.80	6.35	5.75	5.97	79	55	65	66
Site 14	Venniyoor	6.75	6.95	6.75	6.82	74	71	88	78
Site 15	Kaattukulam	6.40	7.05	6.30	6.58	83	72	87	81
Mean		5.81	6.58	5.82		121	94.8	121	
Range		3.45-6.55	6.05-7.45	5.00-6.75		68-213	51-178	65-192	
CD(0.05) Site		0.194				25.005			
CD(0.05) Season		0.088				8.195			
CD(0.05) Site X Season		0.342				31.74			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

Comparing the pH of different seasons, it was observed that the pH was highest during the monsoon season and lowest during the pre monsoon season. During the above two seasons, the lowest pH was recorded by Panangode (Site 1) and the highest pH by Venniyoor (Site 14). During the monsoon season, the highest pH was noted at Pallichalthodu (Site 6) and lowest at Valiyavilagam (Site 10). Regarding the site mean, the highest value was showed by Venniyoor (Site 14) and the lowest by Panangode (Site 1).

The electrical conductivity of the sediment showed a different trend with seasons from that of pH. The electrical conductivity was lowest during monsoon season, while the other two seasons recorded the same mean values. Karithalaykkal (Site 8) recorded the highest values during monsoon and post monsoon seasons, while Kakkamoola (Site 3) showed the highest value of 213 $\mu S\ cm^{-1}$ during pre-monsoon season. But a uniform trend was not observed for the lowest value. However, Kochukovalam recorded the lowest value for site mean.

The organic carbon and extractable P content of sediment are presented in the Table 20. The organic carbon content ranged from 4.5 to 41.5 g Kg^{-1}. It was observed that the organic carbon content was highest during the pre monsoon season and lowest during the post monsoon season. The organic carbon content was highest for Panangode (Site 1) during pre monsoon and post monsoon seasons. Karithalaykkal (Site 8) was highest in OC content during monsoon season. Comparing the site mean, the lowest value was noted at Mannamvarambu (Site 12) and highest at Panangode (Site 1).

Extractable P content of the sediment showed a different trend with the season. The extractable P content was highest during post monsoon which was significantly higher than other two seasons which were on par with each other.

Table 20. Organic carbon and extractable P content of sediment during different seasons

Location		OC (g kg^{-1})				P (mg kg^{-1})			
		Pre-M	M	Post-M	Mean	Pre-M	M	Post-M	Mean
Site 1	Panangode	41.5	19.5	32.5	31.2	0.835	2.00	1.61	1.48
Site 2	Kizhur-manalivila	25.0	20.0	15.5	20.2	2.39	2.68	2.09	2.39
Site 3	Kakkamoola	10.0	12.5	12.5	11.7	1.84	0.89	1.85	1.53
Site 4	Manamukku	16.0	20.0	10.0	15.3	4.16	3.57	2.68	3.47
Site 5	Reservoir bund	10.5	21.5	14.5	15.5	1.94	0.86	2.57	1.79
Site 6	Pallichalthodu	16.5	15.5	13.0	15.0	2.64	4.71	2.54	3.30
Site 7	Palapoor	28.5	12.5	4.50	15.2	1.94	3.36	3.75	3.02
Site 8	Karithalaykkal	18.5	30.5	20.6	23.2	3.62	0.75	10.9	5.09
Site 9	Aaratukadavu RB	24.0	12.0	18.0	18.0	5.66	4.25	6.52	5.48
Site 10	Valiyavilagam	35.0	21.5	7.50	21.3	3.74	0.57	1.47	1.93
Site 11	Kulangara	10.5	10.0	8.50	9.70	1.85	2.61	0.95	1.80
Site 12	Mannamvarambu	4.50	6.50	11.0	7.30	4.39	3.90	1.89	3.39
Site 13	Kochukovalam	23.5	6.00	21.5	17.0	2.82	3.25	1.92	2.66
Site 14	Venniyoor	16.5	11.0	15.5	14.3	0.145	0.72	3.78	1.55
Site 15	Kaattukulam	16.5	18.5	15.5	16.8	1.45	5.29	2.66	3.13
Mean		19.8	15.8	14.7		2.63	2.63	3.14	
Range		4.5-41.5	6.00-30.5	4.5-32.5		0.145-5.66	0.57-4.71	0.95-10.9	
CD(0.05)	Site	2.77				0.716			
	Season	1.32				0.321			
	Site X Season	5.12				1.243			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

Aaratukadavu (Site 9) showed the highest value in P content during the pre monsoon season. The value was highest for Pallichalthodu (Site 6) and Karithalaykkal (Site 8) for monsoon and post monsoon season respectively.

Regarding the site mean, the highest value was observed for Aarattukadavu (Site 9). The extractable P content of sediment was very low.

Table 21. NH_4-N and NO_3-N content of sediment during different seasons of 2010

Location		NH_4-N (mg kg^{-1})				NO_3-N (mg kg^{-1})			
		Pre-M	M	Post-M	Mean	Pre-M	M	Post-M	Mean
Site 1	Panangode	71.5	88.5	70.0	76.7	81.2	13.0	86.1	60.1
Site 2	Kizhur-manalivila	130	89.5	138	119	54.9	5.60	56.6	39.0
Site 3	Kakkamoola	94.5	64.0	109	89.2	72.7	15.1	75.5	54.4
Site 4	Manamukku	17.0	49.5	14.0	26.8	59.9	16.4	61.7	46.0
Site 5	Reservoir bund	57.5	65.0	65.0	62.5	87.4	11.0	95.8	64.7
Site 6	Pallichalthodu	99.5	86.0	109	98.2	66.4	11.4	77.1	51.6
Site 7	Palapoor	30.5	79.5	34.5	48.2	58.3	12.6	60.8	43.9
Site 8	Karithalaykkal	107	254	105	155	94.7	6.50	95.0	65.4
Site 9	Aaratukadavu RB	52.0	75.0	52.0	59.7	70.1	15.5	60.4	48.7
Site 10	Valiyavilagam	92.5	71.0	110	91.2	66.6	8.15	68.0	47.6
Site 11	Kulangara	34.5	103	39.0	58.8	59.2	16.8	74.6	50.2
Site 12	Mannamvarambu	38.5	141	41.5	73.7	52.9	43.5	50.7	49.0
Site 13	Kochukovalam	46.0	96.0	68.0	70.0	45.6	5.75	40.4	30.6
Site 14	Venniyoor	113	116	65.5	98.2	80.0	5.80	86.5	57.4
Site 15	Kaattukulam	44.0	80.5	39.5	54.7	40.1	6.90	46.3	31.1
Mean		68.6	97.3	70.8		66.0	13.0	69.0	
Range		17-130	49.5-254	39-138		40.1-94.7	5.60-43.5	40.4-95.8	
CD(0.05)	Site	4.909				3.269			
	Season	2.244				1.387			
	Site X Season	8.693				5.37			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

Ammoniacal nitrogen (NH_4-N) and Nitrate Nitrogen (NO_3-N) contents of the sediment are presented in the Table 21. NH_4-N content was highest during the monsoon season and lowest during the pre monsoon season. Kizhur-manalivila (Site 2) showed the highest value during the pre monsoon and post monsoon seasons. In the monsoon season, the highest value was showed by Karithalaykkal (Site 8). The highest site mean was also observed for Karithalaykkal (Site 8). The lowest value was showed by Manamukku (Site 4) during the pre monsoon and monsoon seasons. Kulangara (Site 11) showed the lowest value in the post monsoon season.

For NO_3-N a reverse trend was observed. The lowest value was showed in the monsoon season and the highest value in the post monsoon season. Karithalaykkal (Site 8) showed the highest value during the pre monsoon season. Mannamvarambu (Site 12) and Reservoir bund (Site 5) showed the highest value during the monsoon and post monsoon season respectively. The lowest value was showed by Kaattukulam (Site 15), Kizhur-manalivila (Site 2) and Kochukovalam (Site 13) for pre monsoon, monsoon and post monsoon seasons respectively. The highest value for site mean was showed by Karithalaykkal (Site 8) and lowest by Kaattukulam (Site 15).

Extractable K and Na content of the sediment are presented in the Table 22. Regarding extractable K, the lowest value was observed during the monsoon season and highest during the pre monsoon season. The highest value was showed by Aaratukadavu (Site 9) during the pre monsoon and post monsoon season. Valiyavilagam (Site 10) showed the highest value during the monsoon season. The lowest value was showed by Kulangara (Site 11) for all the three seasons. The value ranged from 2.40 to 31.0 mg kg^{-1}.

Table 22. Extractable K and Na content of sediment during different seasons of 2010

Location		K (mg kg^{-1})				Na (mg kg^{-1})			
		Pre-M	M	Post-M	Mean	Pre- M	M	Post-M	Mean
Site 1	Panangode	14.2	7.00	12.4	11.2	16.9	17.3	13.2	15.8
Site 2	Kizhur-manalivila	15.9	15.1	17.7	16.2	14.9	13.1	12.9	13.6
Site 3	Kakkamoola	15.8	6.75	15.9	12.8	9.00	11.5	10.8	10.4
Site 4	Manamukku	6.70	7.90	6.00	6.90	5.25	16.1	5.80	9.10
Site 5	Reservoir bund	17.8	14.0	19.2	17.0	10.7	19.5	10.6	13.6
Site 6	Pallichalthodu	15.3	9.60	13.1	12.7	10.7	11.4	9.00	10.4
Site 7	Palapoor	10.2	12.5	8.40	10.4	7.05	10.4	5.70	7.70
Site 8	Karithalaykkal	11.7	12.1	11.1	11.6	8.05	18.8	9.20	12.0
Site 9	Aaratukadavu RB	36.3	14.5	31.0	27.3	12.4	33.8	9.60	18.6
Site 10	Valiyavilagam	10.5	19.7	10.0	13.4	8.95	13.3	7.80	10.0
Site 11	Kulangara	5.35	2.40	5.70	4.50	6.50	7.20	5.50	6.40
Site 12	Mannamvarambu	7.65	3.00	7.00	5.90	5.05	8.70	6.00	6.60
Site 13	Kochukovalam	6.70	14.4	8.70	9.90	11.9	47.6	13.5	24.3
Site 14	Venniyoor	19.0	13.8	17.2	16.7	10.9	15.8	12.6	13.1
Site 15	Kaattukulam	15.0	7.20	11.0	11.1	18.3	22.4	7.20	16.0
Mean		13.9	10.7	13.0		10.46	17.79	9.29	
Range		5.35-36.3	2.40-19.7	5.70-31.0		5.05-18.3	7.20-47.6	5.50-13.5	
CD(0.05)	Site	2.239				3.725			
	Season	0.882				1.726			
	Site X Season	3.415				6.683			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

The behaviour of extractable Na was quite different. The values were comparatively low but the monsoon season showed a highest value while comparing pre monsoon and post monsoon seasons. Kattukulam (Site 15) showed the highest value during the pre monsoon season. During the monsoon and post monsoon season, the highest value was showed by Kochukovalam (Site 13). Mannamvarambu (Site 12) showed the lowest value during the pre monsoon season. Kulangara (Site 11) showed the lowest value during monsoon and post monsoon season. Regarding the site mean, the highest value was showed by Kochukovalam (Site 13) and the lowest value by Kulangara(Site 11).

Extractable Ca and Mg contents in sediments are presented in the Table 23. Ca content showed a decreasing trend towards the monsoon season. Kizhur – Manalivila (Site 2) showed the highest value during the pre monsoon season. Karithalaykkal (Site 8) and and Aaratukadavu (Site 9) showed the highest value during the monsoon season. During the post monsoon season, the highest value was showed by Panangode (Site 1). The highest value for site mean was recorded for Kizhur- Manalivila (Site 2).

Regarding extractable Mg, the highest value was showed by Venniyoor (Site 14) in the pre monsoon season. Valiyavilagam (Site 10) showed the highest value during the monsoon season. During the post monsoon season the highest value was showed by Kizhur – Manalivila (Site 2). The lowest value was showed by Kakkamoola (Site 3), Palapoor (Site 7) and Panangode (Site 1) during pre monsoon, monsoon and post monsoon seasons respectively. The highest value for site mean was observed for Valiyavilagam (Site 10).

Table 23. Extractable Ca and Mg contents of sediment during different seasons of 2010

Location		Ca (mg kg^{-1})				Mg (mg kg^{-1})			
		Pre- M	M	Post-M	Mean	Pre- M	M	Post-M	Mean
Site 1	Panangode	330	230	390	317	119	66	36	74
Site 2	Kizhur-manalivila	740	380	360	493	105	42	102	83
Site 3	Kakkamoola	460	300	330	363	35	96	72	68
Site 4	Manamukku	500	340	160	333	80	42	42	55
Site 5	Reservoir bund	270	400	390	353	105	114	90	103
Site 6	Pallichalthodu	470	370	240	360	138	24	66	76
Site 7	Palapoor	390	240	190	273	134	18	54	69
Site 8	Karithalaykkal	350	460	300	370	65	30	48	48
Site 9	Aaratukadavu RB	590	460	270	440	126	102	60	96
Site 10	Valiyavilagam	640	125	210	325	110	180	60	117
Site 11	Kulangara	370	200	170	247	65	66	42	58
Site 12	Mannamvarambu	560	200	210	323	85	30	54	56
Site 13	Kochukovalam	480	420	220	373	105	156	78	113
Site 14	Venniyoor	500	370	350	407	186	72	60	106
Site 15	Kaattukulam	590	340	250	393	108	78	54	80
Mean		482	322	269		104	74	61	
Range		270-740	125-460	160-390		35-186	18-180	36-102	
CD(0.05) Site		89.561				41.397			
CD(0.05) Season		39.872				18.032			
CD(0.05) Site X Season		154.423				69.838			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

Extractable S and Fe contents of the sediment are presented in the Table 24. Both the parameters showed a decreasing trend towards the monsoon season and thereafter a slight increase in the value was seen. The highest value for S was showed

Table 24 Extractable S and Fe contents of sediment during different seasons of 2010

Location		S (mg kg^{-1})				Fe (mg kg^{-1})			
		Pre- M	M	Post-M	Mean	Pre- M	M	Post-M	Mean
Site 1	Panangode	43.5	18.5	20.5	27.5	17.2	16.7	16.8	16.9
Site 2	Kizhur-manalivila	97.5	86.0	46.0	76.5	19.8	16.3	16.3	17.5
Site 3	Kakkamoola	205	95.5	111	137	18.1	15.7	15.7	16.5
Site 4	Manamukku	196	58.0	101	118	18.9	16.5	16.6	17.3
Site 5	Reservoir bund	43.5	20.5	37.5	33.8	16.8	16.1	16.2	16.4
Site 6	Pallichalthodu	203	92.5	107	134	16.2	15.8	15.7	15.9
Site 7	Palapoor	115	57.5	57.0	76.5	15.2	14.9	14.2	14.8
Site 8	Karithalaykkal	184	102	112	132	15.6	15.8	14.9	15.4
Site 9	Aaratukadavu RB	84.5	22.5	74.0	60.3	14.8	15.6	14.6	15.0
Site 10	Valiyavilagam	74.5	56.5	31.5	54.2	16.6	13.5	15.5	15.2
Site 11	Kulangara	66.0	48.0	60.0	58.0	15.6	13.5	15.0	14.7
Site 12	Mannamvarambu	65.5	49.0	70.5	61.7	15.4	13.8	16.7	15.3
Site 13	Kochukovalam	112	82.0	81.0	91.7	15.7	16.7	15.1	15.8
Site 14	Venniyoor	115	84.0	102	100	16.9	15.7	16.5	16.4
Site 15	Kaattukulam	61.0	53.5	57.0	57.2	16.6	16.4	15.7	16.2
Mean		111	61.7	71.1		16.6	15.5	15.7	
Range		43.5-205	18.5-95.5	20.5-112		14.8-19.8	13.5-16.7	14.2-16.8	
CD(0.05) Site		4.93				0.246			
CD(0.05) Season		1.963				0.113			
CD(0.05) Site X Season		7.601				0.437			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

by Kakkamoola (Site 3) during the pre monsoon and monsoon seasons. For the post monsoon season, Karithalaykkal (Site 8) showed the highest value. The lowest value was showed by Panangode (Site 1) and Reservoir bund (Site 5) during the pre monsoon season. Panangode (Site 1) showed the lowest value for the rest of the two seasons. The value ranged from 18.5 to 205 mg kg^{-1}. The highest value for site mean was observed for Kakkamoola (Site 3).

Extractable Fe content was seen highest for Kizhur- Manalivila (Site 2) in the pre monsoon season. In the monsoon season, Kochukovalam (Site 13) and Panangode (Site 1) showed the highest value. Panangode (Site 1) showed the highest value during the post monsoon season. The lowest value was showed by Aaratukadavu (Site 9) in the pre monsoon season. Valiyavilagam (Site 10) and Kulangara (Site 11) showed the lowest value during the monsoon season. Palapoor (Site 7) showed the lowest value during the post monsoon season. Regarding the site mean, Kizhur- Manalivila (Site 2) showed the highest value.

Extractable Cu and Zn contents of the sediment are presented in the Table 25. The values of extractable Cu and Zn showed almost same trend, recording an increase in values during pre monsoon period followed by a decrease during monsoon and a further increase towards post monsoon period. Regarding extractable Cu, the highest value was showed by Reservoir bund (Site 5) during the pre monsoon, monsoon and post monsoon seasons. The lowest value was showed by Manamukku (Site 4), Valiyavilagam (Site 10) and Kulangara (Site 11) during pre monsoon, monsoon and post monsoon seasons respectively. The value ranged from 0.08 to 1.67 mg kg^{-1}. The highest value for site mean was showed by Reservoir bund (Site 5).

In the case of extractable Zn, the highest value was showed by Venniyoor (Site 14) during the pre monsoon season. Reservoir bund (Site 5) showed the highest value during the monsoon and post monsoon season. The lowest value was showed by Kattukulam (Site 15) during the pre monsoon and post monsoon season.

Valiyavilagam (Site 10) showed the lowest value during the monsoon season. The highest value for site mean was showed by Reservoir bund (site 5).

Table 25. Extractable Cu and Zn contents of sediment during different seasons

Location		Cu (mg kg^{-1})				Zn (mg kg^{-1})			
		Pre- M	M	Post- M	Mean	Pre- M	M	Post- M	Mean
Site 1	Panangode	0.64	0.37	0.56	0.52	0.64	0.42	0.54	0.53
Site 2	Kizhur-manalivila	0.69	0.37	0.44	0.50	0.88	0.50	0.80	0.73
Site 3	Kakkamoola	0.12	0.28	0.43	0.28	0.88	0.41	0.76	0.68
Site 4	Manamukku	0.09	0.51	0.24	0.28	0.66	0.58	0.56	0.60
Site 5	Reservoir bund	1.67	1.40	0.66	1.24	1.35	1.15	1.25	1.25
Site 6	Pallichalthodu	0.41	0.24	0.14	0.26	0.46	0.60	0.33	0.46
Site 7	Palapoor	0.88	0.26	0.34	0.49	1.35	0.83	0.92	1.03
Site 8	Karithalaykkal	0.66	0.75	0.53	0.65	0.89	0.83	0.84	0.85
Site 9	Aaratukadavu RB	0.44	0.30	0.55	0.43	0.79	0.38	0.77	0.65
Site 10	Valiyavilagam	0.66	0.08	0.42	0.39	0.53	0.18	0.48	0.40
Site 11	Kulangara	0.54	0.09	0.16	0.26	0.47	0.25	0.36	0.36
Site 12	Mannamvarambu	0.55	0.23	0.56	0.45	0.97	0.49	0.94	0.80
Site 13	Kochukovalam	0.66	0.53	0.46	0.55	0.78	0.91	0.63	0.77
Site 14	Venniyoor	0.67	0.29	0.48	0.48	1.40	0.30	1.11	0.94
Site 15	Kaattukulam	0.68	0.28	0.32	0.43	0.42	0.44	0.34	0.40
Mean		0.62	0.40	0.42		0.83	0.55	0.71	
Range		0.09-1.67	0.08-1.40	0.16-0.66		0.42-1.40	0.18-1.15	0.34-1.25	
CD(0.05)	Site	0.167				7.418			
	Season	4.536				3.651			
	Site X Season	0.176				0.141			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

Table 26. Extractable Cd and Pb content of the sediment during different seasons of 2010

Location		Cd (mg kg^{-1})				Pb (mg kg^{-1})			
		Pre- M	M	Post- M	Mean	Pre- M	M	Post- M	Mean
Site 1	Panangode	0.01	0.015	0.02	0.015	0.0001	0.26	0.0001	0.087
Site 2	Kizhur-manalivila	0.02	0.0001	0.015	0.012	1.20	0.32	1.045	0.855
Site 3	Kakkamoola	0.015	0.0015	0.015	0.0105	0.535	0.415	0.43	0.460
Site 4	Manamukku	0.0001	0.0001	0.0001	0.0001	0.225	0.215	0.21	0.217
Site 5	Reservoir bund	0.025	0.04	0.0001	0.022	0.375	0.425	0.345	0.382
Site 6	Pallichalthodu	0.015	0.015	0.0001	0.01	0.175	0.22	0.14	0.178
Site 7	Palapoor	0.0001	0.0001	0.0001	0.0001	0.485	0.545	0.435	0.488
Site 8	Karithalaykkal	0.025	0.015	0.015	0.018	0.54	0.715	0.54	0.598
Site 9	Aaratukadavu RB	0.015	0.0001	0.015	0.01	0.455	0.325	0.41	0.397
Site 10	Valiyavilagam	0.015	0.01	0.01	0.012	0.66	0.145	0.5	0.435
Site 11	Kulangara	0.01	0.0001	0.015	0.0084	0.06	0.04	0.025	0.042
Site 12	Mannamvarambu	0.0001	0.0001	0.0001	0.0001	0.51	0.43	0.415	0.452
Site 13	Kochukovalam	0.0001	0.0001	0.0001	0.0001	0.465	0.195	0.335	0.332
Site 14	Venniyoor	0.015	0.0001	0.01	0.0084	0.215	0.15	0.28	0.215
Site 15	Kaattukulam	0.02	0.1	0.015	0.045	0.48	0.215	0.44	0.378
Mean		0.012	0.013	0.009		0.425	0.308	0.37	
Range		0.0001-0.025	0.0001-0.1	0.0001-0.02		0.0001-1.20	0.04-0.715	0.0001-1.045	0.042-0.855
CD(0.05) Site		5.176				2.302			
CD(0.05) Season		2.61				0.018			
CD(0.05) Site X Season		1.011				6.985			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

Extractable Cd and Pb contents of sediment are presented in Table 26. It also followed the same trend as that of Fe and Cu, showing highest values during pre monsoon and decrease towards post monsoon. Cd content was negligible in most of the sites during the Monsoon season. It ranged from 0.0001 to 0.1 mg kg^{-1}. During the pre monsoon season, Reservoir bund (Site 5) and Karithalaykkal (Site 8) showed the highest value. Kaattukulam (Site 15) showed the highest value during the monsoon season. In the post monsoon season, the highest value was showed by Panangode (Site 1). The highest value for site mean was also showed by Panangode (Site 1).

Regarding Extractable Pb content, the highest value was showed by Kizhur-Manalivila (Site 2) during the pre monsoon and post monsoon season. The mean value for Pb was seen highest during pre monsoon season and lowest during monsoon season. After monsoon the values showed a gradual increase. During the monsoon season, the highest value was showed by Karithalaykkal (Site 8). The lowest value was showed by Panangode (Site 1) during pre monsoon and post monsoon seasons. Kulangara (Site 11) showed the lowest value during the monsoon season.

The extractable Al content of sediment is presented in the Table 27. The value showed a decreasing trend towards the monsoon season and thereafter an increase was observed recording the highest value during post monsoon season. The highest value was showed by Kizhur-Manalivila (Site 2) during the monsoon and post monsoon seasons. In the pre monsoon season, the highest value was showed by Kulangara (Site 11). Karithalaykkal (Site 8) showed the lowest value during the pre monsoon and monsoon seasons. During the post monsoon season, Palapoor (Site 7) showed the lowest value. The value ranged from 33.2 to 49.2 mg kg^{-1}. The highest site mean was showed by Kulangara (Site 11).

Table 27. Extractable Al content of sediment during different seasons of 2010

Location		Al (mg kg^{-1})			
		Pre- M	M	Post- M	Mean
Site 1	Panangode	47.4	40.0	47.0	44.8
Site 2	Kizhur-manalivila	34.2	48.0	49.2	43.8
Site 3	Kakkamoola	46.6	40.8	47.8	45.1
Site 4	Manamukku	46.6	45.9	48.8	47.1
Site 5	Reservoir bund	39.4	34.8	42.7	39.0
Site 6	Pallichalthodu	40.3	42.4	42.8	41.8
Site 7	Palapoor	34.8	34.4	33.2	34.1
Site 8	Karithalaykkal	34.1	33.5	36.4	34.7
Site 9	Aaratukadavu RB	46.8	44.7	44.6	45.4
Site 10	Valiyavilagam	45.2	46.0	46.5	45.9
Site 11	Kulangara	48.2	46.2	47.2	47.2
Site 12	Mannamvarambu	34.2	36.3	39.3	36.6
Site 13	Kochukovalam	35.9	43.2	39.1	39.4
Site 14	Venniyoor	46.6	37.1	43.6	42.4
Site 15	Kaattukulam	39.1	38.9	38.2	38.7
Mean		41.28	40.79	43.06	
Range		34.1-48.2	33.5-48	33.2-49.2	34.1-47.2
CD(0.05)	Site	2.319			
	Season	0.881			
	Site X Season	3.413			

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon

Carbonates and bicarbonates were not detected in the sediment samples.

Table 28. Textural classes of sediment collected from different locations of Vellayani lake.

Location		Sand %	Silt %	Clay %	Textural class
Site1	Panangode	70.24	8	21.76	Sandy clay loam
Site 2	Kizhur-manalivila	60.24	6	29.76	Sandy clay loam
Site 3	Kakkamoola	78.24	4	17.76	Sandy loam
Site 4	Manamukku	72.24	10	17.76	Sandy loam
Site 5	Reservoir bund	86.24	4	9.76	Loamy sand
Site 6	Pallichalthodu	62.24	10	27.76	Sandy clay loam
Site 7	Palapoor	86.24	4	9.76	Loamy sand
Site 8	Karithalaykkal	86.24	4	9.76	Loamy sand
Site 9	Aaratukadavu RB	78.24	6	15.76	Sandy loam
Site 10	Valiyavilagam	92.24	2	5.76	Sand
Site 11	Kulangara	92.24	2	5.76	Sand
Site 12	Mannamvarambu	92.24	2	5.76	Sand
Site 13	Kochukovalam	88.24	4	7.76	Sand
Site 14	Venniyoor	70.24	8	21.76	Sandy clay loam
Site 15	Kaattukulam	64.24	6	29.76	Sandy clay loam

Textural class of sediment collected from Vellayani lake is presented in Table 28. the textural classes ranged from sandy to sandy clay loam. Out of the 15 locations, four locations were sandy, five locations were sandy clay loam, three were loamy sand and the remaining were sandy loam in texture.

4.3. Aquatic macrophytes

4.3.1. Occurance and distribution

The macrophytes present in the lake during different seasons were collected, identified and later subjected to different chemical analysis. The details are presented below in tables 29 to 47.

Table 29 shows the locations from where the aquatic macrophytes were collected during different seasons. Fourteen types of aquatic macrophytes were available from different sites during the three sampling seasons. *Brachiaria mutica* was found in the pre monsoon season at Kaattukulam (Site 15) only. But it was not present in any of the sites in the monsoon and post monsoon seasons. *Colocasia esculenta* was found at Aarattukadavu (Site 9) and Kaattukulam (Site 15) in the pre monsoon season and was absent in the other two seasons. Even though *Scirpus grossus* was present in all the three seasons, it was found at Panangode (Site 1), Kizhur-manalivila (Site 2) and Pallichalthodu (Site 6) in the pre monsoon season. In the monsoon season, it was present only in Pallichalthodu (Site 6) and in post monsoon season, at Kizhur- Manalivila (Site 2) only.

Echinocloa colona was seen at Panangode (Site 1) and Venniyoor (Site14) in the pre monsoon season and was absent in the monsoon and post monsoon seasons. *Eichhornea crassipes* was not present in any of the sites in the pre monsoon season. But it was seen at Aarattukadavu (Site 9) in the monsoon and post monsoon seasons. *Dryopteris erythrosora* was found in pre monsoon and post monsoon seasons. It was located at Panangode (Site 1), Mannamvarambu (Site 12), Venniyoor (Site14) and Kaattukulam (Site15) during pre monsoon season and at Mannamvarambu (Site 12) only during the post monsoon season. *Limnocharis flava* was seen at Panangode (Site 1) only for the pre monsoon season. In the rest of the seasons it was not found.

Nelumbo nucifera was present in all the three seasons. It was seen at Palapoor (Site 7), Valiyavilagam (Site 10) and Kaattukulam (Site15) during pre monsoon and post monsoon seasons. In the monsoon season it was present in more locations viz., Panangode (Site 1), Aarattukadavu (Site 9), Valiyavilagam (Site 10) and Kaattukulam (Site 15). *Panicum repens* was present in all the three seasons and it was abundantly present in the pre monsoon season. In the pre monsoon season, it was located at Panangode (Site 1), Manamukku (Site 4), Reservoir bund (Site 5), Aarattukadavu (Site 9), Kulangara (Site 11), Mannamvarambu (Site 12) and Kochukovalam (Site13). In the monsoon season it was seen at Manamukku (Site 4) and Kochukovalam (Site 13) and in the post monsoon season it was present at Manamukku (Site 4), Kulangara (Site 11) and Mannamvarambu (Site 12).

Pistia stratiotes was present at Venniyoor (Site 14) in the pre monsoon season and at Kaattukulam (Site 15) in the monsoon season. *Nymphaea odorata* was found in all the three seasons at Kochukovalam (Site 13). Apart from this site, it was present at Venniyoor (Site 14) during the monsoon season and at Panangode (Site 1) and Venniyoor (Site 14) during the post monsoon season. *Nymphoides indicus* was present at Kakkamoola (Site 3) during all the three seasons. In addition to that, during the monsoon season it was seen at Kizhur-Manalivila (Site 2) and Palapoor (Site 7) and in the post monsoon season at Pallichalthodu (Site 6) only. *Eleocharis dulcis* was found at Karithalaykkal (Site 8) in all the three seasons. In the post monsoon season, it was located at Venniyoor (Site 14) also. *Ipomea aquatica* was present only in the monsoon and post monsoon seasons at Reservoir bund (Site 5).

Table No. 29. Occurance of native macrophytes during different seasons of 2010

Seasons	Pre- monsoon															Monsoon															Post- monsoon														
Locations / Plants	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1															X																														
2									X						X																														
3	X	X				X															X											X													
4	X													X																															
5																								X															X						
6	X											X		X	X																											X			
7	X																																												
8							X			X					X	X								X	X					X							X			X					X
9	X			X	X				X		X	X	X						X									X						X							X	X			
10														X																X															
11													X															X	X		X												X	X	
12			X														X	X				X											X			X									
13								X															X															X						X	
14																				X															X										

Plants

1. *Brachiaria mutica*
2. *Colocasia esculenta*
3. *Scirpus grossus*
4. *Echinocloa colona*
5. *Eichhornea crassipes*
6. *Dryopteris erythrosora*
7. *Limnocharis flava*
8. *Nelumbo nucifera*
9. *Panicum repens*
10. *Pistia stratiotes*
11. *Nymphaea odorata*
12. *Nymphoides indicus*
13. *Eleocharis dulcis*
14. *Ipomea aquatica*

Locations

1. Panangode 2. Kizhur-Manalivila 3. Kakkamoola 4. Manamukku 5. Reservoir bund 6. Pallichalthodu 7. Palapoor
8. Karithalaykkal 9. Aarattukadavu 10.Valiyavilagam 11. Kulangara 12.Mannamvarambu 13.Kochukovalam 14.Venniyoor
15. Kaattukulam

Table 30. Distribution of aquatic macrophytes in Vellayani Lake during different seasons of 2010

Sl No	Name of the plant		No.of sites from where plants were obtained		
	Common Name	Scientific Name	Pre-M	M	Post-M
1	Buffalo Grass	*Brachiaria mutica*	1	NF	NF
2	Colocasia	*Colocasia esculenta*	2	NF	NF
3	Kora grass	*Scirpus grossus*	3	1	1
4	Jungle rice	*Echinocloa colona*	1	NF	NF
5	Kulavaazha	*Eichhornea crassipes*	NF	1	1
6	Fern	*Dryopteris erythrosora*	4	NF	1
7	Naagapola	*Limnocharis flava*	1	NF	NF
8	Lotus	*Nelumbo nucifera*	3	4	2
9	Injipullu	*Panicum repens*	7	2	3
10	Water cabbage	*Pistia stratiotes*	1	1	
11	Aambal	*Nymphaea odorata*	1	2	3
12	Neyyambal	*Nymphoides indicus*	1	3	2
13	Kuzhalpullu	*Eleocharis dulcis*	1	1	2
14	Water spinach	*Ipomea aquatica*	NF	1	1

Pre-M= Premonsoon, M=Monsoon, Post-M= Post Monsoon; NF= Not found

Table 30 shows the number of sites from where the aquatic macrophytes were obtained during different seasons. Plants were present in highest number of sites during the pre monsoon season and least during the monsoon season. Regeneration of some of the plant species was found towards the third sampling period ie; the post monsoon season. *Brachiaria mutica* was seen at only one site during the pre monsoon season and it was absent for the next two seasons. *Colocasia esculenta* was seen at two sites in the pre monsoon season and was absent in the monsoon and post monsoon season. *Scirpus grossus* was found at 3 sites in pre monsoon season and at one site only during monsoon and post monsoon seasons. *Echinocloa colona* was observed only at one site in the pre monsoon season. In next two seasons it was not found in any of the 15 sites. *Eichhornea crassipes* was present only at one site during monsoon and post monsoon seasons. *Dryopteris erythrosora* was found in pre monsoon and post monsoon seasons only. Four sites recorded its presence during the pre monsoon season and one site in the post monsoon season.

Limnocharis flava was collected only in the pre monsoon season and that too from one site. For the rest of the seasons it was not found. *Nelumbo nucifera* was present in all the three seasons and was a common macrophyte in the lake. It was found at three sites in pre monsoon season, four sites in monsoon season and from two sites in post monsoon season. *Panicum repens* was seen in all the three seasons and was collected from seven sites during pre monsoon season, two sites during monsoon season and three sites during post monsoon season. It thrived well in all the three seasons. *Pistia stratiotes* was present in the first two sampling seasons, viz., pre monsoon and monsoon season only.

Nymphaea odorata was present throughout the three seasons and was collected from one site during the pre monsoon season, two sites during monsoon season and three sites during post monsoon season. *Nymphoides indicus* was found in all the three seasons. It was present at one site during pre monsoon, three sites at monsoon and two sites during post monsoon seasons. *Eleocharis dulcis* was also found in all the three sampling periods. But was present only at one site during pre monsoon and monsoon seasons and from two sites during post monsoon season. *Ipomea aquatica* was not found in the the pre monsoon season though was present in monsoon and post monsoon seasons at one site each.

Growth intensity of aquatic macrophytes during pre monsoon season are presented in Table 31. At Panangode (Site 1) , five species were identified and *Scirpus* *grossus* was the dominant one. At eight locations only a single species was found. At Venniyoor (Site 14), three species and at Kaattukulam (Site 15), four species of aquatic macrophytes were observed. In the remaining sites, only two species each were identified.

Table 31. Growth intensity (%) of aquatic macrophytes during pre monsoon season.

Sl No	Plants⁄location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	*Brachiaria mutica*															15
2	*Colocasia esculenta*									25						10
3	*Scirpus grossus*	30	100				100									
4	*Echinocloa colona*	10													15	
5	*Eichhornea crassipes*															
6	*Dryopteris erythrosora*	20											20		10	10
7	*Limnocharis flava*	20														
8	*Nelumbo nucifera*							100			100					65
9	*Panicum repens*	20			100	100				75		100	80	25		
10	*Pistia stratiotes*														75	
11	*Nymphaea odorata*													75		
12	*Nymphoides indicus*			100												
13	*Eleocharis dulcis*								100							
14	*Ipomea aquatica*															

Plant intensity of aquatic macrophytes during monsoon season are presented in Table 32. At ten locations (Site 1 to 8, 10 and 14) only a single species was found. At Kulangara (Site 11) and Mannamvarambu (Site12), no plants were found in the lake. At Aarattukadavu (Site 9), Kochukovalam (Site 13) and Kaattukulam (Site 15) two species of aquatic macrophytes were identified.

Table 32 Growth intensity (%) of aquatic macrophytes during monsoon season

Sl. No	Plants/location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	*Brachiaria mutica*															
2	*Colocasia esculenta*															
3	*Scirpus grossus*						100									
4	*Echinocloa colona*															
5	*Eichhornea crassipes*									75						
6	*Dryopteris erythrosora*															
7	*Limnocharis flava*															
8	*Nelumbo nucifera*	100								25	100					50
9	*Panicum repens*				100									35		
10	*Pistia stratiotes*															50
11	*Nymphaea odorata*													65	100	
12	*Nymphoides indicus*		100	100				100								
13	*Eleocharis dulcis*								100							
14	*Ipomea aquatica*					100										

Plant intensity of aquatic macrophytes during post monsoon season are presented in Table 33. At thirteen locations (Site 1 to 11, 13and 15) only a single species was found. At Mannamvarambu (Site12) and Venniyoor (Site 14) two species of aquatic macrophytes were identified.

Table 33. Growth intensity (%) of aquatic macrophytes during post monsoon season

Sl No.	Plants/location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	*Brachiaria mutica*															
2	*Colocasia esculenta*															
3	*Scirpus grossus*		100													
4	*Echinocloa colona*															
5	*Eichhornea crassipes*									100						
6	*Dryopteris erythrosora*												55			
7	*Limnocharis flava*															
8	*Nelumbo nucifera*							100			100					100
9	*Panicum repens*				100							100	45			
10	*Pistia stratiotes*															
11	*Nymphaea odorata*	100												100	50	
12	*Nymphoides indicus*			100			100									
13	*Eleocharis dulcis*								100						50	
14	*Ipomea aquatica*					100										

Wet weight and dry weight of aquatic macrophytes collected during pre monsoon, monsoon and post monsoon seasons are presented in Table 34. The wet biomass was highest for *Colocasia esculenta* and *Pistia stratiotes* during pre monsoon season, *Pistia stratiotes* and *Ipomea aquatica* during monsoon season and *Ipomea aquatica* during post monsoon season. But the dry biomass weight was not in tune with the above observations. Dry weight was highest for *Scirpus grossus* and *Panicum repens* during the pre monsoon season, *Scirpus grossus* during monsoon season and *Eleocharis dulcis* during post monsoon season.

Table 34. Wet weight and dry weight of aquatic macrophytes collected during different seasons

Sl No.	Scientific Name of the Plant	Wet weight (g m^{-2})			Dry weight (g m^{-2})		
		Pre-M	M	Post-M	Pre-M	M	Post- M
1	*Brachiaria mutica*	15	NF	NF	8	NF	NF
2	*Colocasia esculenta*	25	NF	NF	10	NF	NF
3	*Scirpus grossus*	20	25	20	12	14	10
4	*Echinocloa colona*	10	NF	NF	6	NF	NF
5	*Eichhornea crassipes*	NF	15	15	NF	3	2.9
6	*Dryopteris erythrosora*	10	NF	14	4	NF	3.9
7	*Limnocharis flava*	25	NF	NF	3	NF	NF
8	*Nelumbo nucifera*	15	20	21	4	3	5
9	*Panicum repens*	20	15	15	12	9	10
10	*Pistia stratiotes*	25	30	NF	3.2	3.5	NF
11	*Nymphaea odorata*	10	17	12	1.6	3	2
12	*Nymphoides indicus*	15	25	10	4	8	3
13	*Eleocharis dulcis*	20	15	20	10	8	12
14	*Ipomea aquatica*	NF	30	28	NF	9	8

4.3.2. Elemental composition

Data on N content of aquatic macrophytes during different seasons are presented in Table 35. In general the N content of shoot was higher compared to that of root for all the plants present in the lake. *Pistia stratiotes* recorded the highest N content in shoot during pre monsoon and *Eichhornea crassipes* recorded the highest values during the monsoon and post monsoon seasons. However the root N content was highest for *Colocasia esculenta* during the pre monsoon season. *Pistia stratiotes* showed the highest value for root N content in the monsoon season and *Scirpus grossus* in the post monsoon season.

Table 35. N content of aquatic macrophytes during different seasons of 2010

Sl No	Scientific Name of the Plant	Shoot (%)			Root (%)		
		Pre-M	M	Post-M	Pre-M	M	Post-M
1	*Brachiaria mutica*	0.1	NF	NF	0.001	NF	NF
2	*Colocasia esculenta*	1.4	NF	NF	0.8	NF	NF
3	*Scirpus grossus*	0.76	0.2	1.1	0.5	0.4	0.7
4	*Echinocloa colona*	1.3	NF	NF	0.8	NF	NF
5	*Eichhornea crassipes*	NF	1.7	2.1	NF	0.2	0.3
6	*Dryopteris erythrosora*	1.47	NF	1.3	0.75	NF	0.25
7	*Limnocharis flava*	1.2	NF	NF	0.5	NF	NF
8	*Nelumbo nucifera*	1.46	1.275	1.1	0.6	0.525	0.47
9	*Panicum repens*	0.8	0.585	0.7	0.035	0.2	0.13
10	*Pistia stratiotes*	1.6	1.2	NF	0.7	0.7	NF
11	*Nymphaea odorata*	1.1	0.95	1.6	0.1	0.095	0.08
12	*Nymphoides indicus*	0.9	0.83	0.8	0.035	0.0036	0.035
13	*Eleocharis dulcis*	1	0.5	0.7	0.008	0.009	0.3
14	*Ipomea aquatica*	NF	1.3	1.5	NF	0.01	0.01

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon; NF= Not found

Data on P content of aquatic macrophytes during different seasons are presented in the Table 36. The P content was highest for shoot in almost all the plants, except *Eichhornea crassipes*. The highest value was showed by *Dryopteris erythrosora* in the pre monsoon and post monsoon seasons for both shoot and root. In the monsoon season the highest value was showed by *Eleocharis dulcis* for shoot and in the case of root it was for *Eichhornea crassipes.* The P content of the shoot ranged from 64 to 42135 mg kg^{-1} and for root it ranged from 9.43 to 32500 mg kg^{-1}.

Table 36. P content of aquatic macrophytes during different seasons of 2010

Sl No	Scientific Name of the Plant	Shoot (mg kg^{-1})			Root (mg kg^{-1})		
		Pre-M	M	Post-M	Pre-M	M	Post-M
1	*Brachiaria mutica*	35500	NF	NF	102	NF	NF
2	*Colocasia esculenta*	35683	NF	NF	14850	NF	NF
3	*Scirpus grossus*	3033	1020	3900	191	9.43	210
4	*Echinocloa colona*	64	NF	NF	17.2	NF	NF
5	*Eichhornea crassipes*	NF	3850	4500	NF	32500	20500
6	*Dryopteris erythrosora*	38015	NF	42135	22905	NF	28459
7	*Limnocharis flava*	955	NF	NF	15.5	NF	NF
8	*Nelumbo nucifera*	4595	4415	4181	363.3	297	149
9	*Panicum repens*	3910	4835	4220	1759	197	156
10	*Pistia stratiotes*	6025	5978	NF	104	104	NF
11	*Nymphaea odorata*	5435	5218	5003	520	444	448
12	*Nymphoides indicus*	5500	5333	5050	210	198	172
13	*Eleocharis dulcis*	12599	11000	12500	10250	9900	11132
14	*Ipomea aquatica*	NF	5535	4110	NF	4350	3950

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon; NF= Not found

K content of aquatic macrophytes are presented in the Table 37. K content of macrophytes was much lower compared to N and P. The plants viz., *Colocasia esculenta* and *Eichhornea crassipes* showed higher concentration for K in root comparied to other macrophytes. In the pre monsoon season the highest value for shoot K was showed by *Limnocharis flava.* In the monsoon and post monsoon season it was showed by *Pistia stratiotes* and *Scirpus grossus* respectively. Regarding the K content in root, the highest value was showed by *Echinocloa colona* in the pre monsoon season. *Eichhornea crassipes* showed the highest value for monsoon and post monsoon seasons. In general the shoot K content of aquatic macrophytes ranged from 32 to 192 mg kg^{-1} and root content ranged from 14 to 166 mg kg^{-1}.

Table 37. K content of aquatic macrophytes during different seasons of 2010

Sl No	Scientific Name of the Plant	Shoot (mg kg^{-1})			Root (mg kg^{-1})		
		Pre-M	M	Post-M	Pre-M	M	Post-M
1	*Brachiaria mutica*	128	NF	NF	25	NF	NF
2	*Colocasia esculenta*	101	NF	NF	115	NF	NF
3	*Scirpus grossus*	113	87	142	93	63	56.7
4	*Echinocloa colona*	169	NF	NF	166	NF	NF
5	*Eichhornea crassipes*	NF	89	93	NF	128	119
6	*Dryopteris erythrosora*	97	NF	89	69	NF	89
7	*Limnocharis flava*	192	NF	NF	39	NF	NF
8	*Nelumbo nucifera*	145	134	132	53	43	58
9	*Panicum repens*	69	48	55	62	27	35
10	*Pistia stratiotes*	150	138	NF	47	32	NF
11	*Nymphaea odorata*	131	121	130	31	31	32
12	*Nymphoides indicus*	65	59	70	21	14	15
13	*Eleocharis dulcis*	70	61	70	65	45	70
14	*Ipomea aquatica*	NF	40	32	NF	35	19

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon ; NF= Not found

Data on Ca content of aquatic macrophytes are presented in the Table 38. The macrophytes of the area showed a very high variation in their Ca content. *Panicum repens* showed the highest value for shoot Ca content and *Dryopteris erythrosora* for root Ca content. In the pre monsoon season, *Panicum repens* showed the highest value for shoot Ca content. In the monsoon and post monsoon seasons, the highest value was showed by *Pistia stratiotes* and *Dryopteris erythrosora* respectively. Regarding root Ca content, *Dryopteris erythrosora* showed the highest value for both pre monsoon and post monsoon seasons. In the monsoon season, the highest value was showed by *Eleocharis dulcis.* Shoot Ca content ranged between 0.12 to 2.01 % and root Ca content, from 0.03 to 0.80 % for various aquatic macrophytes.

Table 38. Ca content of aquatic macrophytes during different seasons of 2010

Sl No	Scientific Name of the Plant	Shoot (%)			Root (%)		
		Pre-M	M	Post-M	Pre-M	M	Post-M
1	*Brachiaria mutica*	0.34	NF	NF	0.03	NF	NF
2	*Colocasia esculenta*	1.33	NF	NF	0.59	NF	NF
3	*Scirpus grossus*	0.72	0.12	0.80	0.20	0.10	0.09
4	*Echinocloa colona*	0.95	NF	NF	0.65	NF	NF
5	*Eichhornea crassipes*	NF	0.25	0.21	NF	0.11	0.09
6	*Dryopteris erythrosora*	1.68	NF	4.10	0.68	NF	0.80
7	*Limnocharis flava*	1.00	NF	NF	0.10	NF	NF
8	*Nelumbo nucifera*	0.35	0.29	0.34	0.16	0.21	0.14
9	*Panicum repens*	2.01	0.43	0.35	0.42	0.15	0.06
10	*Pistia stratiotes*	0.96	0.73	NF	0.40	0.40	NF
11	*Nymphaea odorata*	0.50	0.40	0.62	0.30	0.27	0.16
12	*Nymphoides indicus*	0.40	0.36	0.22	0.06	0.04	0.03
13	*Eleocharis dulcis*	0.50	0.40	0.50	0.08	0.45	0.30
14	*Ipomea aquatica*	NF	0.12	0.15	NF	0.08	0.07

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon; NF= Not found

Data on Mg content in aquatic macrophytes are presented in the Table 39. Most of the plants recorded higher values for shoot content of Mg compared to the root, except for *Limnocharis flava*. The highest value for shoot Mg content was showed by *Nymphaea odorata* and that for root was showed by *Eichhornea crassipes. Nelumbo nucifera* recorded the highest value for shoot Mg content during pre monsoon and monsoon seasons and *Nymphaea odorata* in the post monsoon season. While the root Mg content was highest for *Nelumbo nucifera* in all the three seasons. Shoot Mg content ranged between 0.08 and 1.90 % and root Mg content between 0.001 and 1.05 % for the aquatic macrophytes identified in the study area.

Table 39 Mg content of aquatic macrophytes during different seasons of 2010

Sl No	Scientific Name of the Plant	Shoot (%)			Root (%)		
		Pre-M	M	Post-M	Pre-M	M	Post-M
1	*Brachiaria mutica*	1.70	NF	NF	0.03	NF	NF
2	*Colocasia esculenta*	0.94	NF	NF	0.50	NF	NF
3	*Scirpus grossus*	0.46	0.21	0.40	0.18	0.03	0.07
4	*Echinocloa colona*	0.08	NF	NF	0.03	NF	NF
5	*Eichhornea crassipes*	NF	0.70	0.60	NF	0.001	0.008
6	*Dryopteris erythrosora*	1.10	NF	0.62	0.58	NF	0.20
7	*Limnocharis flava*	0.06	NF	NF	0.08	NF	NF
8	*Nelumbo nucifera*	1.90	1.58	1.40	1.05	0.90	0.90
9	*Panicum repens*	0.23	0.12	0.43	0.20	0.11	0.35
10	*Pistia stratiotes*	0.86	0.78	NF	0.51	0.39	NF
11	*Nymphaea odorata*	1.60	1.25	1.74	0.90	0.70	0.80
12	*Nymphoides indicus*	0.50	0.53	0.34	0.07	0.04	0.06
13	*Eleocharis dulcis*	0.70	0.50	0.7	0.05	0.02	0.55
14	*Ipomea aquatica*	NF	0.50	0.6	NF	0.08	0.08

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon; NF= Not found

Data on S content of aquatic macrophytes are presented in Table 40. In general, the S content of plants identified in the study area was more in shoot compared to the root. However, *Colocasia esculenta* and *Limnocharis flava* showed higher root S content compared to the shoot. Among the different aquatic macrophytes, the highest shoot S content (5694 ppm) was found for *Echinocloa colona* and for root, the highest value was showed by *Limnocharis flava* in the pre monsoon season. *Scirpus grossus* and *Panicum repens* showed highest S content in shoot during monsoon and post monsoon seasons respectively. *Pistia stratiotes* and *Dryopteris erythrosora* showed the highest value for root S content in the monsoon and post monsoon season respectively.

Table 40. S content of aquatic macrophytes during different seasons of 2010

Sl No	Scientific Name of the Plant	Shoot (mg kg^{-1})			Root (mg kg^{-1})		
		Pre-M	M	Post-M	Pre-M	M	Post-M
1	*Brachiaria mutica*	3781	NF	NF	1198	NF	NF
2	*Colocasia esculenta*	2651	NF	NF	4094	NF	NF
3	*Scirpus grossus*	5071	4200	4268	3362	2100	4291
4	*Echinocloa colona*	5694	NF	NF	4116	NF	NF
5	*Eichhornea crassipes*	NF	3600	5300	NF	2956	2500
6	*Dryopteris erythrosora*	5086	NF	5200	4449	NF	4563
7	*Limnocharis flava*	5394	NF	NF	5436	NF	NF
8	*Nelumbo nucifera*	4170	3210	4207	1021	952	926
9	*Panicum repens*	4598	3706	5317	2587	1377	1277
10	*Pistia stratiotes*	4513	4000	NF	4506	3425	NF
11	*Nymphaea odorata*	3600	2663	3348	1000	875	945
12	*Nymphoides indicus*	2500	1329	2168	990	776	824
13	*Eleocharis dulcis*	3500	2200	3500	1250	990	2308
14	*Ipomea aquatica*	NF	2500	2156	NF	1786	1655

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon; NF= Not found

Data on Na content of aquatic macrophytes during different seasons are presented in the Table 41. In general the Na content in shoot was higher compared to the root Na content except for *Brachiaria mutica, Scirpus grossus* and *Nymphaea odorata.* In the pre monsoon and post monsoon seasons, Na content in shoot was highest for *Pistia stratiotes. Eichhornea crassipes* also recorded the same shoot Na content during monsoon season and it recorded the highest value for post monsoon season also. Root Na content was highest for *Scirpus grossus* for all the three seasons.

Table 41. Na content of aquatic macrophytes during different seasons of 2010

Sl No	Scientific Name of the Plant	Shoot (mg kg^{-1})			Root (mg kg^{-1})		
		Pre-M	M	Post-M	Pre-M	M	Post-M
1	*Brachiaria mutica*	3.20	NF	NF	4.90	NF	NF
2	*Colocasia esculenta*	4.75	NF	NF	4.00	NF	NF
3	*Scirpus grossus*	4.20	2.80	5.10	8.40	5.10	7.30
4	*Echinocloa colona*	2.50	NF	NF	3.80	NF	NF
5	*Eichhornea crassipes*	NF	8.50	9.10	NF	3.60	3.10
6	*Dryopteris erythrosora*	4.65	NF	2.70	4.50	NF	1.90
7	*Limnocharis flava*	9.80	NF	NF	4.00	NF	NF
8	*Nelumbo nucifera*	4.26	1.97	4.65	1.96	1.03	1.75
9	*Panicum repens*	3.88	2.20	3.33	2.80	1.65	1.33
10	*Pistia stratiotes*	10.2	8.50	NF	6.80	2.10	NF
11	*Nymphaea odorata*	4.50	3.60	3.99	5.00	3.75	4.50
12	*Nymphoides indicus*	5.00	3.33	4.50	0.90	0.30	0.65
13	*Eleocharis dulcis*	3.00	1.10	3.00	2.10	1.70	2.50
14	*Ipomea aquatica*	NF	3.00	2.10	NF	1.20	1.50

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon; NF= Not found

Data on Al content of aquatic macrophytes are presented in the Table 42. The Al content of shoot was higher for all the plants present in the lake compared to root. Among the aquatic macrophytes, the Al content of shoot was highest for *Dryopteris erythrosora* and *Nelumbo nucifera* recorded the highest value for root Al content. The Al content in shoot was highest for *Dryopteris erythrosora*, *Eichhornea crassipes* and *Nelumbo nucifera* during pre monsoon, monsoon and post monsoon seasons respectively. *Nelumbo nucifera* recorded the highest value for root Al content during pre and post monsoon seasons and *Eichhornea crassipes* during monsoon season.

Table 42. Al content of aquatic macrophytes during different seasons of 2010

Sl No	Scientific Name of the Plant	Shoot (mg kg^{-1})			Root (mg kg^{-1})		
		Pre-M	M	Post-M	Pre-M	M	Post-M
1	*Brachiaria mutica*	115	NF	NF	105	NF	NF
2	*Colocasia esculenta*	622	NF	NF	396	NF	NF
3	*Scirpus grossus*	595	538	533	367	399	423
4	*Echinocloa colona*	470	NF	NF	368	NF	NF
5	*Eichhornea crassipes*	NF	716	735	NF	675	535
6	*Dryopteris erythrosora*	822	NF	715	596	NF	453
7	*Limnocharis flava*	346	NF	NF	257	NF	NF
8	*Nelumbo nucifera*	808	607	748	740	567	667
9	*Panicum repens*	545	454	531	354	402	309
10	*Pistia stratiotes*	635	536	NF	457	387	NF
11	*Nymphaea odorata*	751	466	637	467	400	450
12	*Nymphoides indicus*	650	493	600	351	244	318
13	*Eleocharis dulcis*	346	231	359	311	199	328
14	*Ipomea aquatica*	NF	545	550	NF	421	395

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon; NF= Not found

The data on Fe content of different aquatic macrophytes presented in Table 43 revealed that most of the plants concentrate Fe in their roots. However, there are exceptions like *Brachiaria mutica*, *Limnocharis flava*, *Nelumbo nucifera*, *Panicum repens*, *Nymphaea odorata*, *Nymphoides indicus* and *Ipomea aquatica.* Among the aquatic macrophytes, *Eichhornea crassipes* recorded the highest Fe content in both shoot and root. The Fe content in shoot was lowest for *Panicum repens* and in the case of root it was for *Brachiaria mutica.*

Table 43. Fe content of aquatic macrophytes during different seasons of 2010

Sl No	Scientific Name of the Plant	Shoot (mg kg^{-1})			Root (mg kg^{-1})		
		Pre-M	M	Post-M	Pre-M	M	Post-M
1	*Brachiaria mutica*	1727	NF	NF	445	NF	NF
2	*Colocasia esculenta*	928	NF	NF	1249	NF	NF
3	*Scirpus grossus*	1341	834	1737	1911	856	1879
4	*Echinocloa colona*	1404	NF	NF	2630	NF	NF
5	*Eichhornea crassipes*	NF	1985	2135	NF	2675	2350
6	*Dryopteris erythrosora*	1233	NF	1788	2182	NF	1911
7	*Limnocharis flava*	1865	NF	NF	750	NF	NF
8	*Nelumbo nucifera*	1176	796	1417	581	342	496
9	*Panicum repens*	1380	576	1244	810	490	453
10	*Pistia stratiotes*	1166	1036	NF	2034	1980	NF
11	*Nymphaea odorata*	1350	1211	1287	755	650	679
12	*Nymphoides indicus*	1099	824	1082	855	672	737
13	*Eleocharis dulcis*	1543	1250	1543	2031	1990	1747
14	*Ipomea aquatica*	NF	851	769	NF	750	655

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon; NF= Not found

The aquatic macrophytes did not show a general accumulation pattern for Zn in their plant parts (Table 44). In certain plants Zn accumulation was more in shoot region while in certain others a reverse trend was observed. *Pistia stratiotes* recorded the highest value for both shoot and root content for Zn. The Zn content in shoot was lowest for *Nymphaea odorata* and for root *Nymphoides indicus* showed the lowest value. *Pistia stratiotes*, *Panicum repens* and *Ipomea aquatica* recorded the highest values for shoot Zn content during pre monsoon, monsoon and post monsoon seasons respectively. The Zn content in root was highest for *Pistia stratiotes* in the pre monsoon and monsoon seasons and for *Dryopteris erythrosora* in the post monsoon season.

Table 44. Zn content of aquatic macrophytes during different seasons of 2010

Sl No	Scientific Name of the Plant	Shoot (mg kg^{-1})			Root (mg kg^{-1})		
		Pre-M	M	Post-M	Pre-M	M	Post-M
1	*Brachiaria mutica*	71	NF	NF	67	NF	NF
2	*Colocasia esculenta*	72	NF	NF	84	NF	NF
3	*Scirpus grossus*	52	59	50	57	61	57
4	*Echinocloa colona*	70	NF	NF	65	NF	NF
5	*Eichhornea crassipes*	NF	28	21	NF	26	21
6	*Dryopteris erythrosora*	79	NF	70	56	NF	69
7	*Limnocharis flava*	46	NF	NF	45	NF	NF
8	*Nelumbo nucifera*	44	22	65	14	10.91	34
9	*Panicum repens*	74	82	68	69	78	62
10	*Pistia stratiotes*	83	79	NF	101	88	NF
11	*Nymphaea odorata*	1	0.45	0.78	1.2	1.05	1.5
12	*Nymphoides indicus*	1.1	0.90	1.65	1	0.61	0.78
13	*Eleocharis dulcis*	25	15	25	31	25	27
14	*Ipomea aquatica*	NF	75	79	NF	55	41

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon; NF= Not found

Data on Cu content of aquatic macrophytes collected during different seasons are presented in Table 45. *Eichhornea crassipes* was found to accumulate highest content of Cu for both shoot and root. The plants did not show a uniform pattern of higher accumulation either in shoot or root. However, *Limnocharis flava* was found to contain very high amount of Cu in root compared to shoot. In general, the Cu content of shoot varied between 2.10 and 30.5 mg kg^{-1} and for root it varied between 2.40 and 24.5 mg kg^{-1} for different aquatic macrophytes.

Table 45. Cu content of aquatic macrophytes during different seasons of 2010

Sl No	Scientific Name of the Plant	Shoot (mg kg^{-1})			Root (mg kg^{-1})		
		Pre-M	M	Post-M	Pre-M	M	Post-M
1	*Brachiaria mutica*	9.50	NF	NF	4.60	NF	NF
2	*Colocasia esculenta*	8.45	NF	NF	10.4	NF	NF
3	*Scirpus grossus*	9.90	15.2	6.50	9.16	12.1	4.20
4	*Echinocloa colona*	5.25	NF	NF	12.9	NF	NF
5	*Eichhornea crassipes*	NF	30.5	13.0	NF	24.5	12.1
6	*Dryopteris erythrosora*	12.6	NF	25.0	11.7	NF	10.8
7	*Limnocharis flava*	3.60	NF	NF	15.0	NF	NF
8	*Nelumbo nucifera*	9.20	7.50	7.35	19.6	15.2	21.5
9	*Panicum repens*	8.90	15.3	7.33	9.42	16.5	9.00
10	*Pistia stratiotes*	18.2	15.0	NF	7.05	7.60	NF
11	*Nymphaea odorata*	17.0	12.9	14.2	12.0	8.00	10.0
12	*Nymphoides indicus*	16.0	17.3	18.9	14.2	13.5	14.9
13	*Eleocharis dulcis*	2.50	2.10	3.50	3.90	2.40	3.75
14	*Ipomea aquatica*	NF	19.0	16.0	NF	11.0	14.0

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon; NF= Not found

Data on the Cd content of aquatic macrophytes presented in Table 46 revealed that there are certain plants like *Pistia stratiotes* and *Scirpus grossus* did not accumulate Cd in their plant parts. *Scirpus grossus* was found to contain Cd in root portion only. *Nelumbo nucifera* recorded the highest value for both shoot and root content of Cd among the different aquatic macrophytes. During the pre and post monsoon periods, *Nelumbo nucifera* recorded the highest value for shoot Cd and in monsoon season, it was for *Eichhornea crassipes.* While for root Cd content, *Eichhornea crassipes* was showing highest values during monsoon and post monsoon seasons and *Nelumbo nucifera* in pre monsoon season.

Table 46. Cd content of aquatic macrophytes during different seasons of 2010

Sl No	Scientific Name of the Plant	Shoot (mg kg^{-1})			Root (mg kg^{-1})		
		Pre-M	M	Post-M	Pre-M	M	Post-M
1	*Brachiaria mutica*	2	NF	NF	0.09	NF	NF
2	*Colocasia esculenta*	0.9	NF	NF	2	NF	NF
3	*Scirpus grossus*	0	0	0	2	1.1	0.9
4	*Echinocloa colona*	1.5	NF	NF	0.04	NF	NF
5	*Eichhornea crassipes*	NF	3.10	2.1	NF	4	3.5
6	*Dryopteris erythrosora*	0.025	NF	0.05	1	NF	0.009
7	*Limnocharis flava*	0	NF	NF	0.008	NF	NF
8	*Nelumbo nucifera*	4	2.08	3.45	3.8	2.1	3.4
9	*Panicum repens*	1	0.97	1.1	0.5	0.2	0.8
10	*Pistia stratiotes*	0	0	NF	0	0	NF
11	*Nymphaea odorata*	2.5	1.5	2.1	0.9	0.78	1.3
12	*Nymphoides indicus*	2.1	1.9	2	1	0.87	1.2
13	*Eleocharis dulcis*	0.8	0.5	0.4	0.6	0.3	0.3
14	*Ipomea aquatica*	NF	1.8	1.2	NF	0.6	0.8

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon; NF= Not found

Data on Pb content of aquatic macrophytes are presented in the Table 47. The plants in general contained more Pb in shoot compared to root. But *Colocasia esculenta, Scirpus grossus, Eichhornea crassipes* and *Dryopteris erythrosora* showed the higher concentration of Pb in their root. *Pistia stratiotes* recorded the highest Pb content in both the shoot and root. The Pb content of shoot ranged between 1.90 and 47 mg kg^{-1} for different aquatic macrophytes. For root it ranged between 0.80 and 29 mg kg^{-1}. *Ipomea aquatica* recorded the lowest value for Pb content in both shoot and root.

Table 47. Pb content of aquatic macrophytes during different seasons of 2010

Sl No	Scientific Name of the Plant	Shoot (mg kg^{-1})			Root (mg kg^{-1})		
		Pre-M	M	Post-M	Pre-M	M	Post-M
1	*Brachiaria mutica*	15	NF	NF	5.4	NF	NF
2	*Colocasia esculenta*	5	NF	NF	6	NF	NF
3	*Scirpus grossus*	5	3	2.3	7	4.1	5.4
4	*Echinocloa colona*	10	NF	NF	8	NF	NF
5	*Eichhornea crassipes*	NF	11.8	8.9	NF	12	9
6	*Dryopteris erythrosora*	2.05	NF	3.5	3.2	NF	4.1
7	*Limnocharis flava*	12	NF	NF	4.6	NF	NF
8	*Nelumbo nucifera*	29	5.8	8.3	11.8	2.5	8.8
9	*Panicum repens*	12	10	8	4.5	5	7.5
10	*Pistia stratiotes*	47	17	NF	29	6.5	NF
11	*Nymphaea odorata*	21	19	23	8	9	9.5
12	*Nymphoides indicus*	15	19	19	7.5	5.6	7.6
13	*Eleocharis dulcis*	3	2	4	1.1	0.9	2.1
14	*Ipomea aquatica*	NF	1.9	2	NF	0.8	0.8

Pre-M= Pre monsoon, M=Monsoon, Post-M=Post monsoon; NF= Not found

4.3.3. Bio concentration factor

Bio concentration factor for N, P and K are presented in the Table 48. In general the macrophytes showed a higher BCF for shoot compared to root with regard to N. But *Colocasia esculenta* and *Limnocharis flava* did not differ in their BCF for shoot and root. The highest value was showed by *Eichhornea crassipes* for both shoot and root. *Pistia stratiotes* also recorded the same value for root.

Table 48. Bioconcentration factor of aquatic macrophytes for N, P and K

Sl No	Scientific Name of the Plant	N		P		K	
		Shoot	Root	Shoot	Root	Shoot	Root
1	*Brachiaria mutica*	11.9	0.1	24483	70	9	2
2	*Colocasia esculenta*	100	100	10037	4177	4	4
3	*Scirpus grossus*	43	37	1211	73	8	5
4	*Echinocloa colona*	100	50	131	35	10	10
5	*Eichhornea crassipes*	10000	1500	799	5400	26	36
6	*Dryopteris erythrosora*	125	45	22295	14246	10	9
7	*Limnocharis flava*	80	80	1144	19	14	3
8	*Nelumbo nucifera*	120	50	1665	103	12	5
9	*Panicum repens*	70	10	1659	237	6	4
10	*Pistia stratiotes*	2500	1500	21341	368	46	12
11	*Nymphaea odorata*	107	10	2205	197	13	3
12	*Nymphoides indicus*	64	0.67	2535	93	5	1
13	*Eleocharis dulcis*	36	5.77	6617	5849	5	5
14	*Ipomea aquatica*	130	0.84	4018	3298	3	2

P was also mainly accumulated in shoot as evidenced by the higher BCF values for shoot compared to root. *Brachiaria mutica* recorded the highest BCF value for shoot and *Dryopteris erythrosora* for root.

The plants mainly concentrated K in their shoot compared to the root. However, for *Eichhornea crassipes* it was mainly concentrated in the root since BCF values were higher for root. But *Colocasia esculenta* , *Echinocloa colona* and *Eleocharis dulcis* showed equal BCF values for shoot and root.

Bio concentration factor for Ca, Mg and S are presented in the Table 49. In general the macrophytes showed a higher BCF for shoot compared to root with regard to Ca, Mg and S except *Limnocharis flava*. *Pistia stratiotes* showed the highest BCF for shoot and root in the case of Ca and Mg. In the case of S, the BCF for shoot was highest for *Eichhornea crassipes* and for root *Pistia stratiotes* recorded the highest value.

Table 49. Bioconcentration factor of aquatic macrophytes for Ca, Mg and S

Sl No	Scientific Name of the Plant	Ca		Mg		S	
		Shoot	Root	Shoot	Root	Shoot	Root
1	*Brachiaria mutica*	6	1	157	3	62	20
2	*Colocasia esculenta*	20	10	80	40	36	56
3	*Scirpus grossus*	11	3	57	10	61	49
4	*Echinocloa colona*	20	20	5	2	72	52
5	*Eichhornea crassipes*	285	125	2500	15	273	169
6	*Dryopteris erythrosora*	115	25	100	45	72.5	64
7	*Limnocharis flava*	30	3	10	10	124	125
8	*Nelumbo nucifera*	13	7	200	133	74	19
9	*Panicum repens*	25	5	40	37	58	22
10	*Pistia stratiotes*	950	450	6500	3500	232	217
11	*Nymphaea odorata*	13	10	200	100	38	11
12	*Nymphoides indicus*	10	1	97	13	16	7
13	*Eleocharis dulcis*	13	7	137	40	25	13
14	*Ipomea aquatica*	4	2	55	10	90	66

Bio concentration factor for Na, Al and Fe are presented in the Table 50. Almost all the macrophytes showed a higher BCF for shoot compared to root with regard to Na except *Brachiaria mutica* and *Scirpus grossus.* Al was mainly translocated to shoot in all the macrophytes identified in the study area as evidenced by higher BCF for shoot. In case of Fe several plants viz., *Colocasia esculenta, Scirpus grossus, Echinocloa colona, Pistia stratiotes, Eichhornea crassipes* and *Eleocharis dulcis* showed the highest BCF for root.

Table 50. Bioconcentration factor of aquatic macrophytes for Na, Al and Fe

Sl No	Scientific Name of the Plant	Na		Al		Fe	
		Shoot	Root	Shoot	Root	Shoot	Root
1	*Brachiaria mutica*	0.20	0.30	3	3	104	27
2	*Colocasia esculenta*	0.30	0.30	15	9	59	80
3	*Scirpus grossus*	0.30	0.53	13	9	79	92
4	*Echinocloa colona*	0.20	0.30	10	8	83	155
5	*Eichhornea crassipes*	0.80	0.30	125	104	137	166
6	*Dryopteris erythrosora*	0.45	0.35	21	14	91	57
7	*Limnocharis flava*	0.60	0.20	7	5	108	0
8	*Nelumbo nucifera*	0.40	0.16	18	16	73	30
9	*Panicum repens*	0.33	0.20	12	8	66	36
10	*Pistia stratiotes*	0.80	0.40	115	83	66	121
11	*Nymphaea odorata*	0.27	0.27	16	11	80	43
12	*Nymphoides indicus*	0.37	0.08	13	7	60	45
13	*Eleocharis dulcis*	0.27	0.20	9	8	92	122
14	*Ipomea aquatica*	0.20	0.10	15	11	51	44

Bio concentration factor for Zn, Cu, Cd and Pb are presented in the Table 51. Several macrophytes showed higher BCF for shoot compared to root with regard to Zn. The exceptions are *Colocasia esculenta, Scirpus grossus, Eichhornea crassipes, Pistia stratiotes, Nymphaea odorata* and *Eleocharis dulcis.* Cu was mainly accumulated in shoot for almost all the macrophytes identified in the study area as evidenced by higher BCF for shoot except *Colocasia esculenta, Echinocloa colona* and *Panicum repens*. In case of Cd several plants viz., , *Colocasia esculenta, Scirpus grossus Eichhornea crassipes* and *Limnocharis flava* showed the highest BCF for root. Pb was mainly translocated to the shoot for most of the macrophytes except, *Colocasia esculenta, Scirpus grossus Eichhornea crassipes,* and *Dryopteris erythrosora* as evidenced by higher BCF for shoot.

Table 51. Bioconcentration factor of aquatic macrophytes for Zn, Cu, Cd and Pb

Sl No	Scientific Name of the Plant	Zn		Cu		Cd		Pb	
		Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
1	*Brachiaria mutica*	169	160	14	7	100	5	31	11
2	*Colocasia esculenta*	118	138	15	19	51	114	11	13
3	*Scirpus grossus*	80	86	36	29	0	89	9	13
4	*Echinocloa colona*	69	64	8	20	120	3	91	73
5	*Eichhornea crassipes*	50	51	62	52	15570	20117	31	32
6	*Dryopteris erythrosora*	84	70	33	19	251	95	8	11
7	*Limnocharis flava*	72	70	6	23	0	0.8	120000	46000
8	*Nelumbo nucifera*	78	36	21	49	333	323	32	18
9	*Panicum repens*	108	100	23	26	3348	741	43	26
10	*Pistia stratiotes*	161	190	38	18	0	0	723	313
11	*Nymphaea odorata*	1.1	1.8	29	20	13403	5643	84	36
12	*Nymphoides indicus*	2	1.2	94	79	1409	659	39	15
13	*Eleocharis dulcis*	25	32	4	5	32	23	6	3
14	*Ipomea aquatica*	64	40	19	15	6023	4008	6	2

4.3.4. Translocation index

Translocation index which is an indication of the ability of plants to translocate nutrients/metals from root to the above ground portion were calculated for different aquatic macrophytes found in the study area and presented below.

Table 52. Translocation index for macro and secondary nutrients

Sl No	Scientific Name of the Plant	N	P	K	Ca	Mg	S
1	*Brachiaria mutica*	317	933	12	16	140	8
2	*Colocasia esculenta*	2	5	2	4	4	1
3	*Scirpus grossus*	3	33	4	7	12	3
4	*Echinocloa colona*	3	6	2	2	4	2
5	*Eichhornea crassipes*	15	0.3	1	4.6	425	3
6	*Dryopteris erythrosora*	2	1	1	2	1	1
7	*Limnocharis flava*	9	201	16	33	3	3
8	*Nelumbo nucifera*	2	12	2	0.95	1	3
9	*Panicum repens*	8.8	30	3	8	2	5
10	*Pistia stratiotes*	4	117	8	4	4	2
11	*Nymphaea odorata*	4	4	2	1	1	1
12	*Nymphoides indicus*	17.2	22	4	8	6	2
13	*Eleocharis dulcis*	88.6	3	3	9	26	6
14	*Ipomea aquatica*	140	2	3	3	10	3

Translocation index for macro and secondary nutrients are presented in Table 52. The various aquatic macrophytes found in the area showed a translocation index above one for N, P, K, Ca, Mg and S. However, there are certain exceptions like *Eichhornea crassipes* for P and *Nelumbo nucifera* for Ca recording translocation indices of 0.30 and 0.95 respectively. In the case of N and P and S, the highest value was observed for *Brachiaria mutica.* For K and Ca, *Limnocharis flava* showed the highest translocation index. For Mg, *Eichhornea crassipes* recorded the highest value.

Table 53. Translocation index for Na, Al, micro nutrients and heavy metals

Sl No	Scientific Name of the Plant	Na	Al	Fe	Zn	Cu	Cd	Pb
1	*Brachiaria mutica*	2	3	10	3	6	59	7
2	*Colocasia esculenta*	2	3	2	2	2	1	2
3	*Scirpus grossus*	1	3	2	2	3	NT	1
4	*Echinocloa colona*	1	2	1	2	1	56	2
5	*Eichhornea crassipes*	6	2	2	2	2	1	2
6	*Dryopteris erythrosora*	1	1	0.5	1	1	1	0.4
7	*Limnocharis flava*	10	5	2.5	3	1	NT	9
8	*Nelumbo nucifera*	1	1	2	2	0.3	0.6	1.2
9	*Panicum repens*	3	2	3	2	2	5	3
10	*Pistia stratiotes*	5	3	1	2	5	NA	5
11	*Nymphaea odorata*	0.9	1	1	0.5	1	1	1
12	*Nymphoides indicus*	5	2	1	1	1	2	2
13	*Eleocharis dulcis*	3	3	2	2	2	4	6
14	*Ipomea aquatica*	4	3	2	3	3	4	5

NT= Not translocated to shoot; NA= Not absorbed

Translocation index for Na, Al, Fe, Cu, Zn, Cd and Pb are presented in Table 53. The various aquatic macrophytes found in the area generally accumulated the metals in the shoot as evidenced by a translocation index above one. But for each metal, certain plants showed an index value below one. Such plants are viz., *Nymphaea odorata* for Na and Zn, *Dryopteris erythrosora* for Fe and Pb, *Nelumbo nucifera* for Cu and Cd. For Al, all the plants showed a value above one. *Limnocharis flava* showed the highest translocation indices for Na and Al. *Brachiaria mutica* showed the highest translocation indices for Fe, Cu, Cd and Pb.

Discussion

5. DISCUSSION

This chapter encompasses a critical appraisal of the salient findings of the study "Evaluation of aquatic pollution and identification of phytoremediators in Vellayani lake" and the discussion is presented below.

5.1 Impact of spatial and seasonal variation on water characteristics

5.1.1 Physical characteristics

Water temperature is important in terms of its effect on aquatic life and its influence on self purification process in a stream. No variation was observed for water temperature within a season. The seasonal variation (Fig.2) was also very narrow ranging from 26-28^{0}C recording the highest value during pre monsoon season, reflecting the influence of air temperature. This was in confirmity with the results of Radhika *et al.* (2004). Increased temperature reduces the solubility of oxygen in water. High temperature enhances the growth of micro organisms.

The colour of lake water ranged from pale blue to yellowish brown during pre and post monsoon periods. During the monsoon period the colour was yellowish brown only. The variation in colour was observed mainly due to the mixing up of water during the down pour with the suspended particles such as clay, silt, finely divided organic and inorganic matters and planktons.

Turbidity (Fig.3) and suspended solids (Fig.4) which determines the clarity of water also followed the same pattern as that of colour showing the higher values during the monsoon period, probably due to the mixing up of suspended particles and decaying vegetation with water during the monsoon showers. Both the values showed an increasing trend towards the monsoon season. Krishnakumar *et al.* 2005, also reported the variation for TSS in lake water of Vellayani.

5.1.2. Electrochemical characteristics

Water in Vellayani lake is slightly acidic. The pH of a water body is very important in determination of water quality since it affects other chemical reactions such as solubility and metal toxicity. An increase in pH (Fig. 5) was observed during the monsoon season definitely due to the dilution effect of increased quantity of water received and low evaporation rates. A reverse trend was observed in the case of EC (Fig.6) where the lowest values were noted during monsoon period. The large volume of water present might have diluted the salt concentration of the lake water leading towards low EC values. However, certain locations showed values, much deviated from the mean probably due to dumping of wastes in those particular sites occasionally. Radhika *et al*. 2004, also reported similar results.

5.1.3. Nutritional characteristics

The content and variation of the important nutritional parameters viz., N, K, Ca, Mg, Na, S, Fe, Cu and Zn in water with reference to the different locations and seasons are discussed here.

N is present mainly in the form of ammonia and nitrate with small quantities of nitrite. The rate of oxygenation decides the transformation of ammonia to nitrate. Nitrogen in any form is toxic to aquatic organism and to human population when its limit exceeds the maximum permissible limit (Lindau *et al.*, 1988). NH_4-N (Fig.8) was found to be highest during post monsoon season and the locations differed widely in their NH_4-N content. Agriculture together with municipal waste water is the most important source of anthropogenically derived ammonia and nitrate to surface waters (Moore, 1991). The area surrounding Vellayani lake is an intensively cultivated area. Banana, cassava, vegetables etc are the major crops which are mainly raised with heavy fertilisation. The residues from N fertilisers reaching the lake water might be responsible for the increase in NH_4-N during post monsoon season which coincide with the peak vegetable cultivation season.

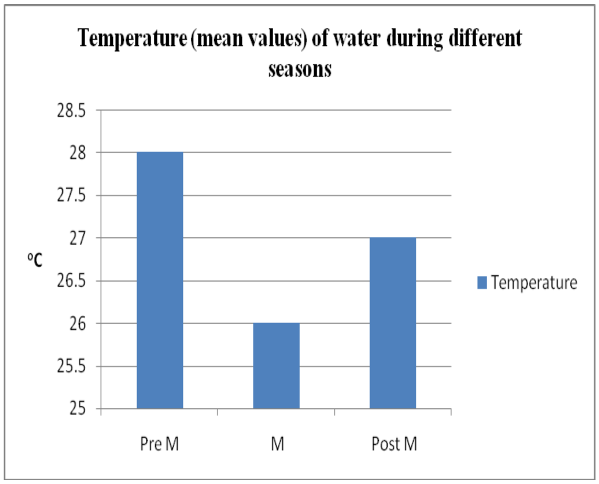

Fig. 2

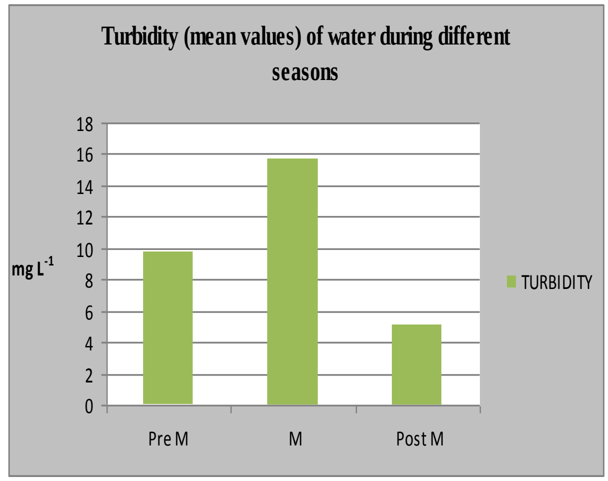

Fig. 3

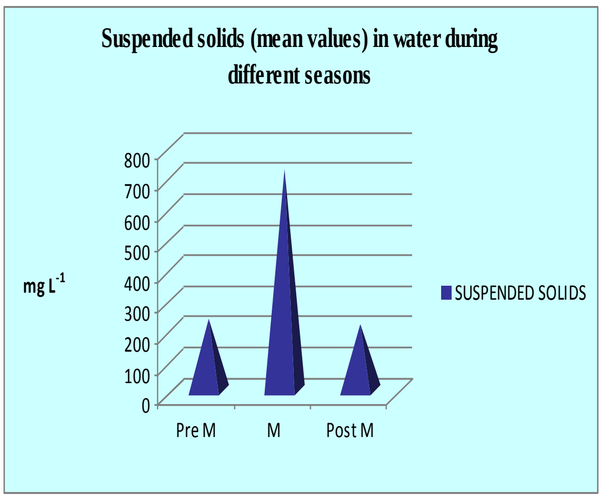

Fig. 4

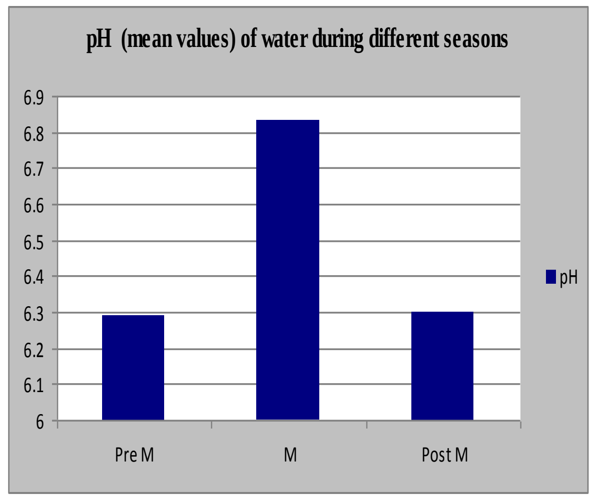

Fig. 5

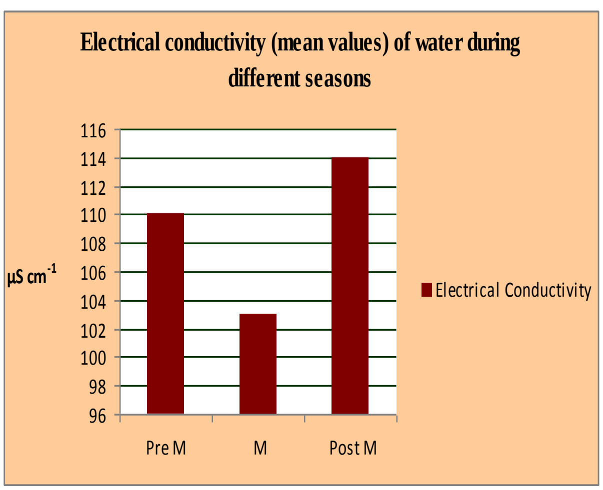

Fig. 6

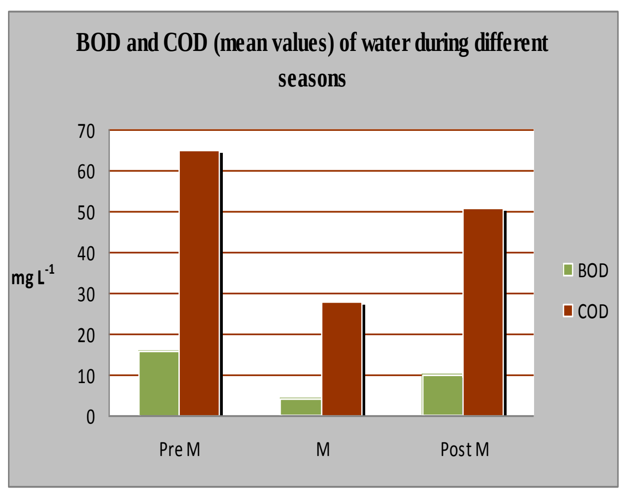

Fig. 7

NO3-N content (Fig.8) was lowest during the monsoon season and several sites even did not record NO3-N during this period. The continuous receipt of monsoon showers might have reduced the nitrification process and even facilitate denirification. NO3-N was more during the pre monsoon season probably due to better oxidation status of water. Krishnakumar et al. 2005, reported the absence of nitrate in Vellayani lake while Radhika et al. 2004, reported its presence in very low concentrations during different seasons.

P content in water was negligible and in many of the sites it was not detected. Due to the high P fixing capacity of the sediment, its release to the over lying water is restricted. The absorption by the macrophytes are also responsible for very low content of P. The data on P content of aquatic macrophytes (Table 36) also support the above observation.

The cationic nutrients K (Fig.9), Mg (Fig.11) and Na (Fig.13) were higher during post monsoon season. The above three nutrients are highly water soluble and the monsoon showers have brought down considerable amount of these nutrients to the water. The decrease in volume of water coupled with comparatively high evaporation rates during the post monsoon season have contributed towards the above increase. The receipt of pre monsoon and monsoon showers have resulted in lower values for above nutrients in the corresponding periods. While Ca showed a different pattern with highest values during monsoon season. Ca showing better adsorption power might have retained in the exchange sites itself during pre and post monsoon periods. The heavy rains during the monsoons have pushed it out of the exchange sites, which may reach the water bodies resulting an enhancement in Ca content. This was not in tune with the results of Radhika et al. (2004).

The S content of Vellayani water (Fig.10) was comparatively high, ranging from 16.8 to 19.4 mg L-1 showing low degree of seasonal variation. S occurs abundantly in natural waters and the anthropogenic emissions to the atmosphere

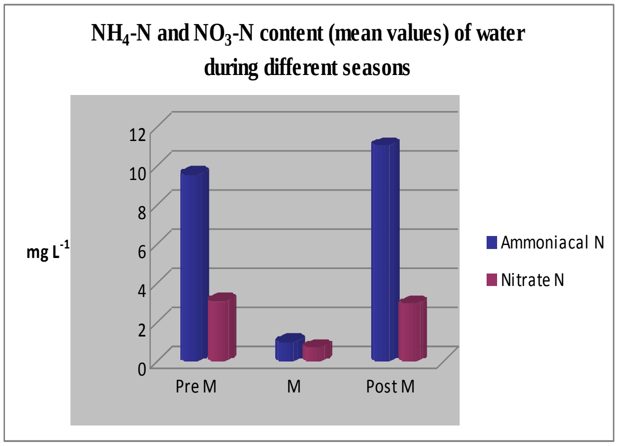

Fig. 8

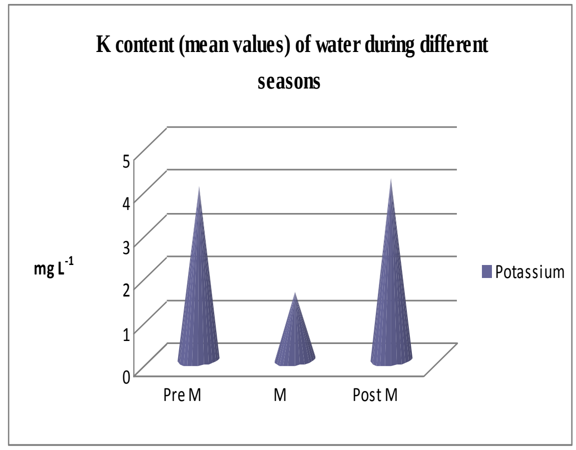

Fig. 9

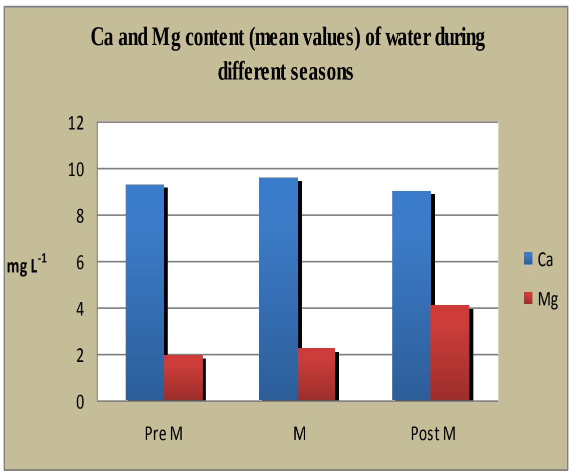

Fig. 10

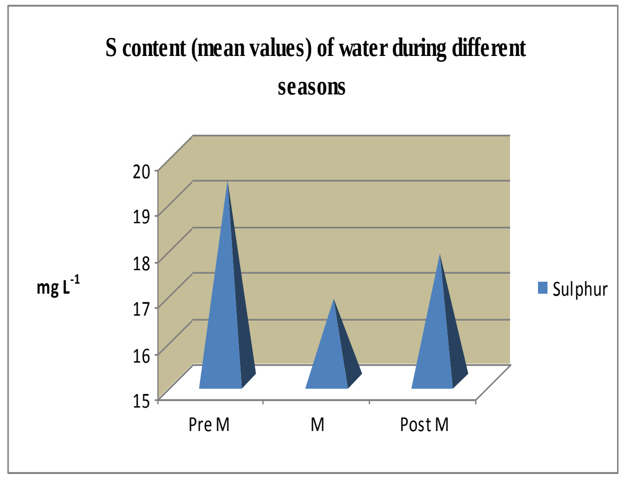

Fig. 11

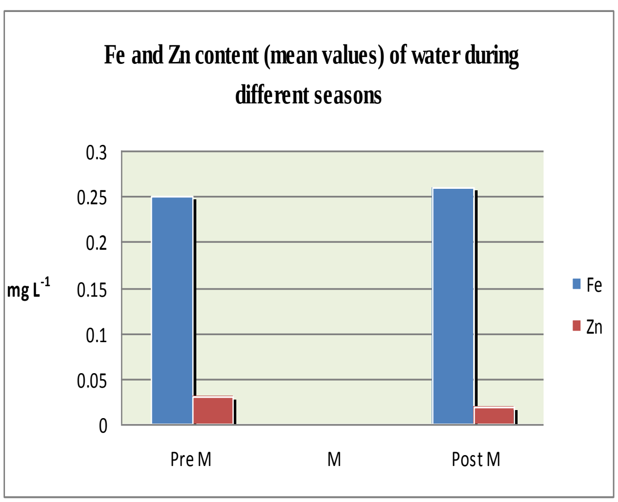

Fig. 12

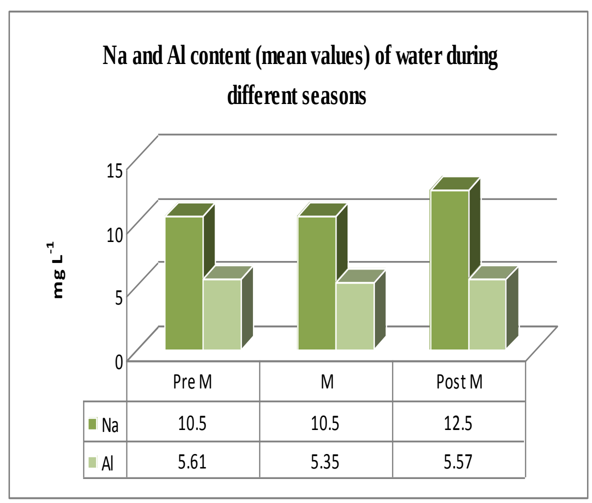

Fig. 13

contribute towards further increase in S content of the environment (Moore, 1991). The decaying vegetation, organic matter and planktons might be responsible for higher values of S. Probably, the difference in their decomposition rate have influenced the varying S content of water during different seasons.

Among the micro nutrients, only Fe and Zn (Fig.12) were detected in water and that too in very low concentrations. They were not detected during the monsoon season. The receipt of large quantity of fresh water in response to the monsoon showers might have improved the water quality considerably. Fe residues in surface waters are extremely variable and the oxidation- reduction cycle controls the fate of Fe. The cycle varies seasonally depending on the availability of oxygen resulting, the absence of Fe in water due to deposition of insoluble Fe^{3+} in sediments. The concentration of Zn in fresh waters usually ranges from < 0.001 to approximately 0.05 mg L^{-1}. The pH of the water is one of the main factors that decide the Zn concentration in water (Moore, 1991). The near neutral pH (Table 9) and low Zn content of parent material might have resulted in low concentration of Zn in water.

5.1.4. Toxicity characteristics

Al content of lake water ranged from 5.35 to 5.61 05 mg L^{-1}. Relatively large amount of Al was found in surface water in dissolved form due to the decrease in pH of surface water (Goenaga and Williams, 1988). The above result also indicated the influence of pH on Al content of water by showing the lowest values during monsoon season when the water pH was at its maximum. Dissolved Al is highly toxic to crop plants.

Cadmium is contributed to the surface waters through paints, pigments, glass enamel, deterioration of the galvanized pipes etc. is toxic to fish and other aquatic organisms even when present in very low concentration (Moore, 1991). Vellayani lake water showed the presence of Cd and Pb (Fig.14 and 15) in small concentrations with lowest values during monsoon season, evidently due to the dilution effect of

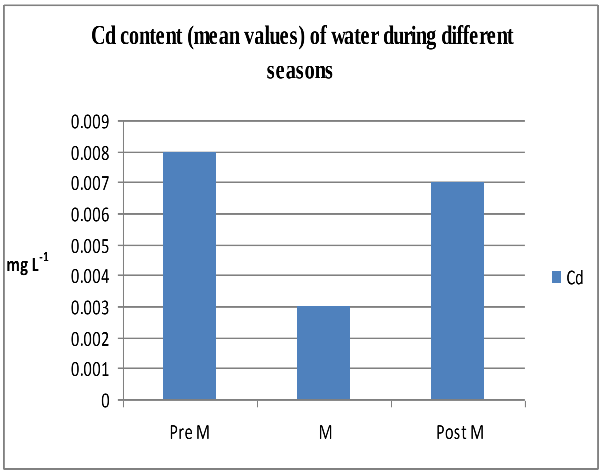

Fig. 14

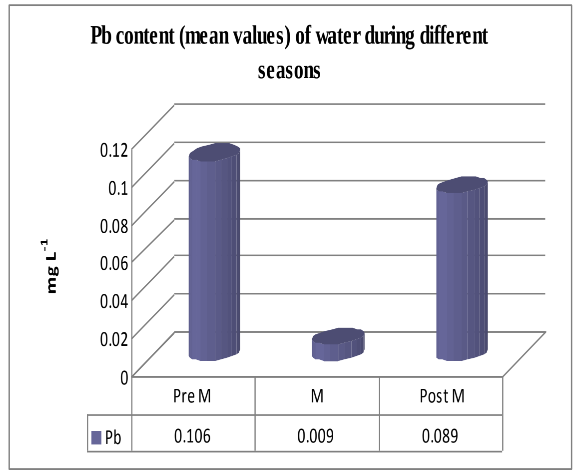

Fig.15

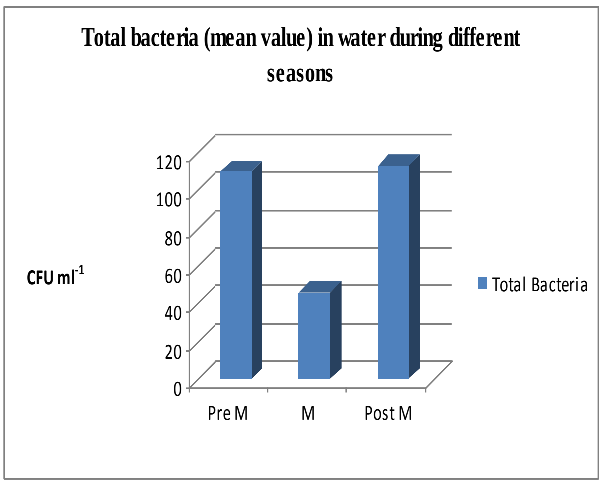

Fig. 16

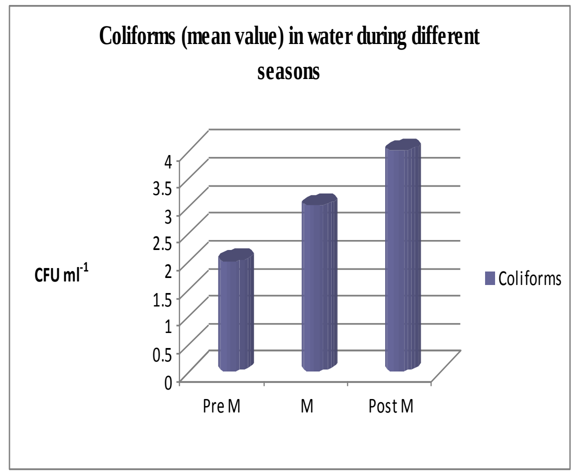

Fig. 17

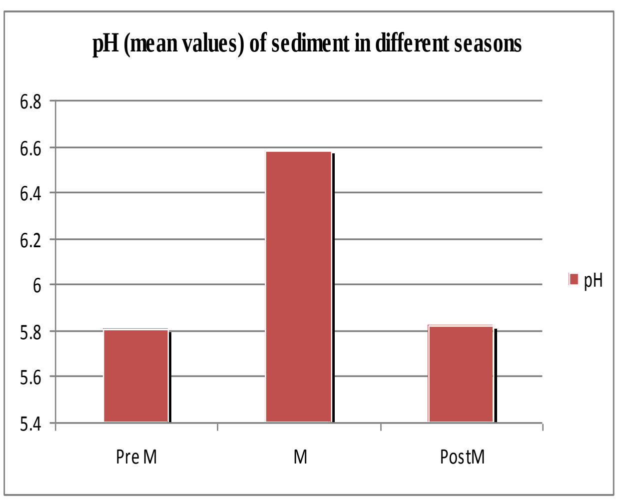

Fig. 18

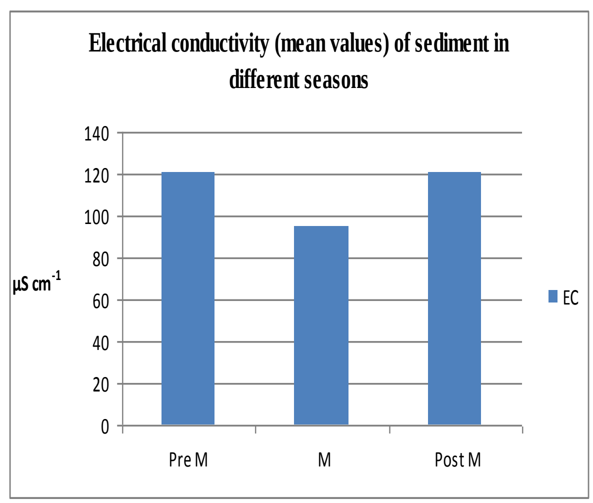

Fig. 19

heavy monsoon showers. In the pre monsoon season the Cd content was higher which might be due to the concentration of Cd in water in response to the increased rate of evaporation.

The behaviour of Pb was also similar to that of Cd showing the lowest values during the monsoon and highest values in pre monsoon season. The change in volume of lake water is the major factor that controls the level of Pb in water. Pb is discharged in the lake water through paints, pipes, building material, gasoline etc. The discharge of heavy metals in the environment has much obvious impact on aquatic systems. There may be an increase in residue levels in water, sediments and biota, decreased productivity and increase in exposure of humans to harmful substances.

5.1.5. Biologically related chemical characteristics

Both BOD and COD (Fig.7) were lowest during monsoon and highest during pre monsoon period. Low values of BOD and COD during monsoon may be due to low temperature and the presence of fresh water on receipt of monsoon showers. As the oxidisable organic matter increases, there will be a corresponding increase in the oxygen demand of water. During pre monsoon and post monsoon periods, the more number of aquatic macrophytes were found in the lake which may contribute to the decomposable organic matter. Radhika *et al.* 2004, also reported similar results.

5.1.6. Biological characteristics

The mean bacterial count of Vellayani lake varied from 46 to 113 CFU ml^{-1} (Fig.16) with lowest during monsoon season and highest during post monsoon season. Plenty of fresh water received during monsoon season might have diluted the bacterial counts. After the cessation of monsoon showers, the bacterial growth also might have increased in tune with that of macrophytes. In the post monsoon season, leachates from the soil increased the bacterial population. Agarwal and Govind

(2010) also observed higher bacterial count during summer and rainy seasons and minimum during winter.

Regarding the Coliform count (Fig.17), a gradual increase in number from pre monsoon to post monsoon season was observed. The presence of coliform bacteria in aquatic environments is indicative of contamination with animal and sewage wastes. The lower values during monsoon season might be due to the receipt of continuous heavy showers which might have helped to maintain good water quality. The human intervention and waste disposal to the lake might be more during the post monsoon season in response to the enhanced tourist activities and water sports. The above activities were also responsible for increasing the coliform count.

5.2. Impact of spatial and seasonal variation on sediment characteristics

5.2.1. Electrochemical properties

Electrochemical properties viz., pH and EC (Fig.18 and 19) showed site wise and season wise variation which was significant. With regard to the pH it showed an increase towards the monsoon season and there after a decrease. The value of pH was highest during the monsoon season and lowest during the post monsoon season. The high value was definitely due to the large volume of water added to the lake by the monsoon showers which leads to dilution of water. During the post monsoon season the rate of evaporation rate will be higher than that of monsoon and that coupled with non receipt of showers lower the water level which in turn reduce the value of pH (Radhika *et al*., 2004). The lowest value for pH (3.45) was shown by Panangode (Site 1) during the pre monsoon period (Table 19). This was attributed by the dumping of waste in that particular site occasionally. During the monsoon season normal pH was observed in that site. Monsoon showers diluted and washed off the toxicity from that area.

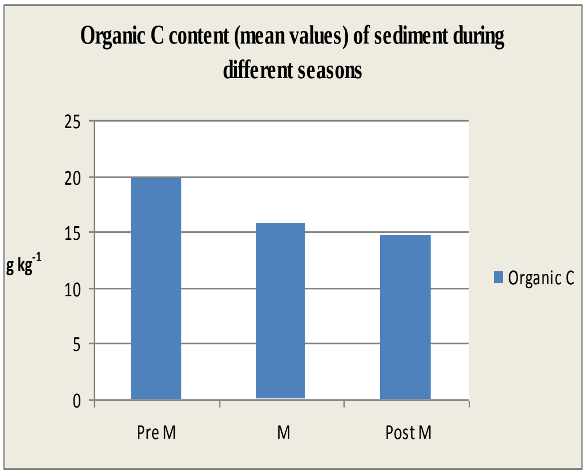

Fig. 20

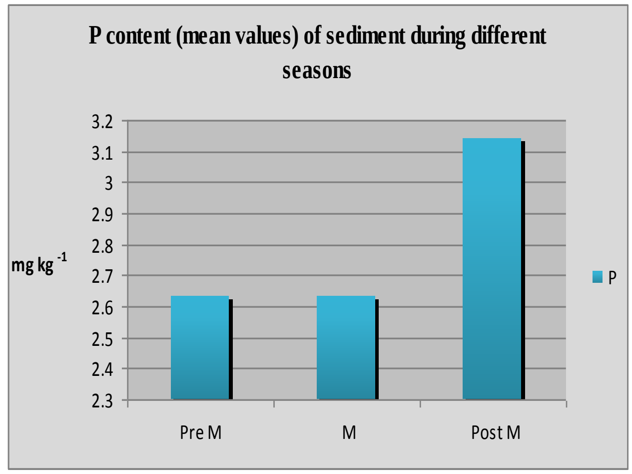

Fig.21

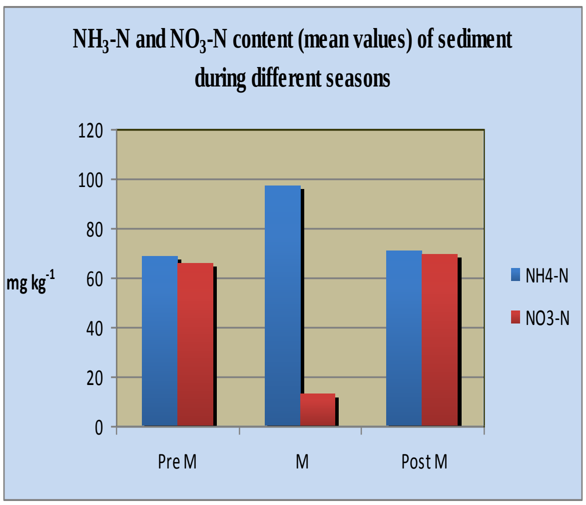

Fig. 22

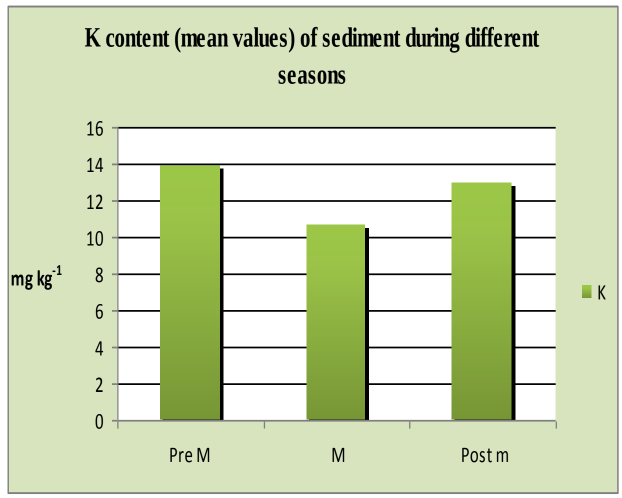

Fig.23

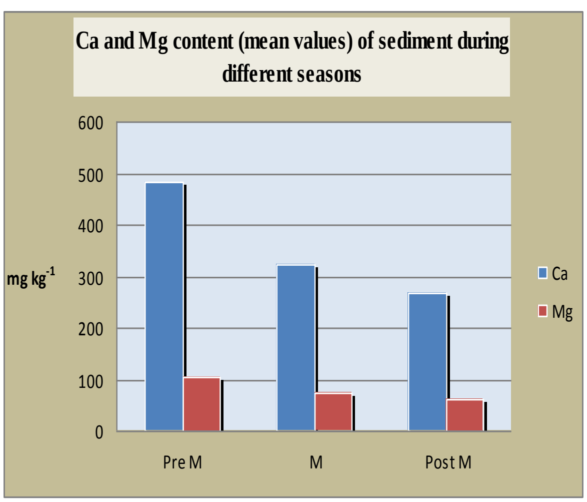

Fig. 24

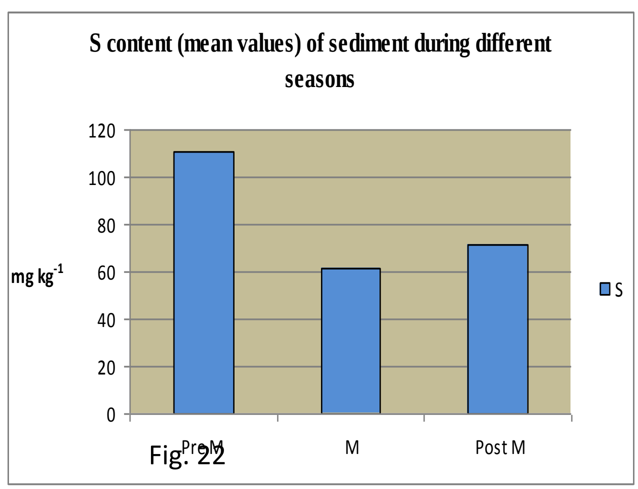

Fig.25

Electrical conductivity showed a reverse trend as that of pH. The EC decreased towards the monsoon season and there after increased. The decrease in EC during monsoon season was due to the dilution effect of monsoon showers (Radhika *et al*., 2004).

5.2.2. Nutritional parameters

OC content (Fig.20) of the sediment showed a gradual decrease towards the post monsoon season. OC content in the sediment is directly linked to the texture of the soil and it was observed that areas with sandy texture have low OC (Sobha *et al*., 2009). The low microbial activity might be one of the major reasons for the season wise variation in OC content.

Ammoniacal nitrogen content of sediment (Fig.22) showed an increasing trend towards the monsoon season. Nitrification process may be at a very low rate during the monsoon season as the water level is more and an anaerobic condition prevails. The data on NO_3-N also support this observation (Table 21). So the ammoniacal nitrogen will not get converted to nitrate nitrogen and high value was shown in the monsoon season (Santhosh, 1999).

During the post monsoon season the water level lowers and the nitrification process will be much more faster which leads to the conversion of ammoniacal nitrogen to nitrate nitrogen.

Available P content of the sediment (Fig.21) was very low, might be due to the high P fixing capacity of the sediment (Sanjeev, 1994). The highest value was observed for the post monsoon season. The available P content in the sediment was very low. Though the highest value was observed during the post monsoon season, and was statistically significant, the difference from the other two seasons is very low. The average P content of different sites showed wide variation and this might have resulted in non uniformity in seasonal variation. Since the surrounding

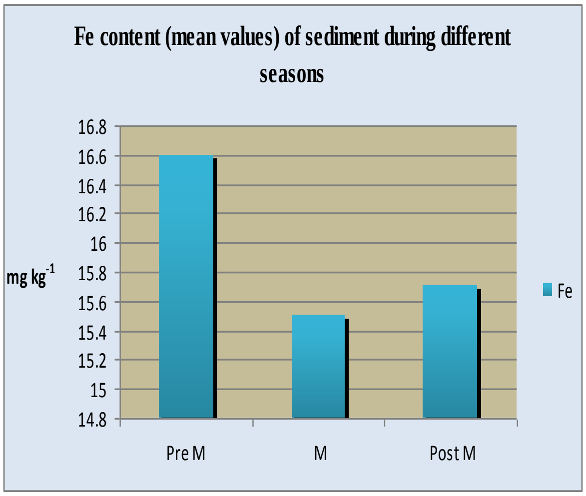

Fig.26

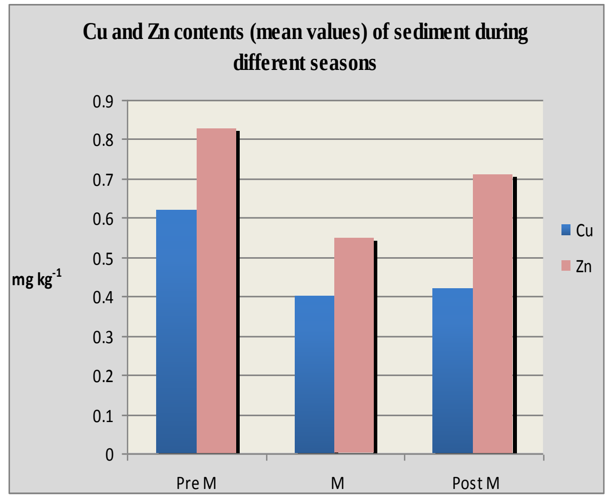

Fig.27

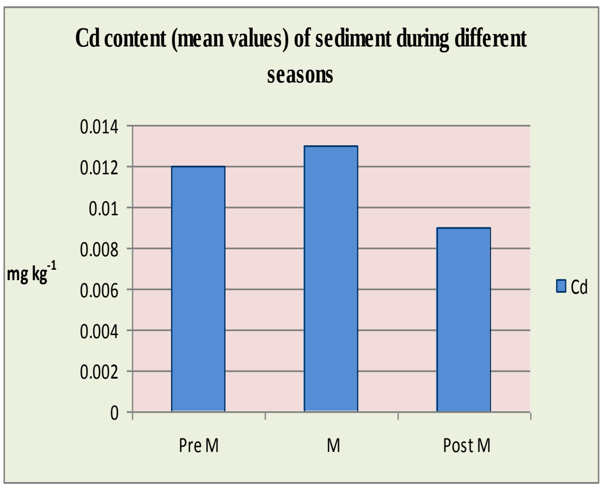

Fig. 28

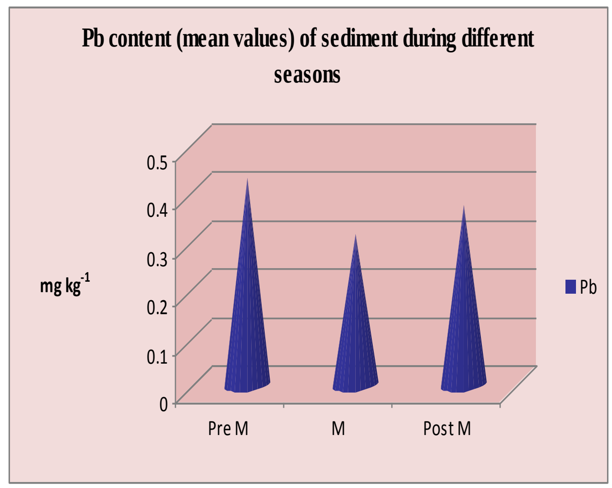

Fig. 29

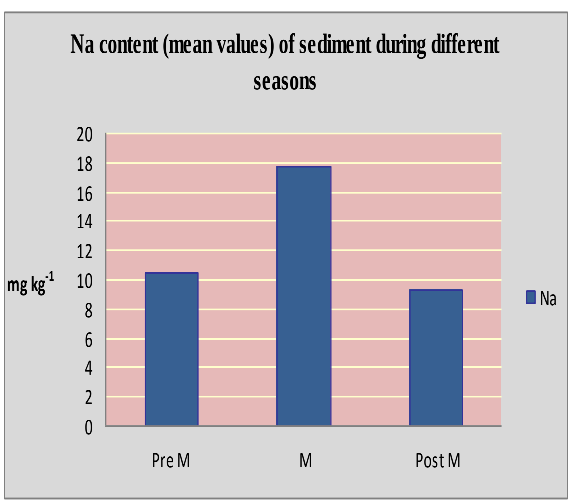

Fig. 30

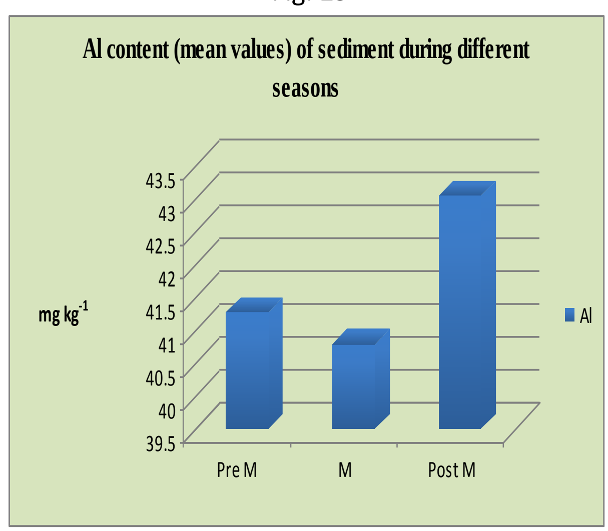

Fig. 31

areas of the lake are intense vegetable cultivating areas, part of fertilizers applied might have washed to the lake and has resulted the increased value during the post monsoon season; which is major vegetable growing season (Sobha *et al.,* 2009).

Available K (Fig.23), Ca and Mg contents (Fig.24) were highest during pre monsoon season which coincides with summer. Since evaporation rate was highest during this season, the volume of lake water will be low which result in an increase in concentration of different soluble cations. For available K, lowest value was noted during the monsoon season, while available Ca and available Mg were at their lowest values during post monsoon. Since K is very loosely attached to the exchange sites, it was completely leached off during the monsoon season. Since the bonding strength of Ca and Mg are higher than that of K, it might have taken more time for their removal from sediment, showing the lowest values during post monsoon season. More than 80 per cent of available K, 60 per cent of exchangeable Mg and 50 per cent of exchangeable Ca is in water soluble form and can be easily removed from the exchange sites (Thampatti, 1997). However, the behaviour of available Na (Fig.30) was quite different from the above three cations.

The contents of available S (Fig.25), Fe (Fig.26), Cu and Zn (Fig.27) were also highest during the pre monsoon season, mainly due to the decrease in volume of lake water in this season, compared to other seasons (Table 24 and 25).

Aluminium content in the sediment was at its lowest during the monsoon season. The increase in pH might have reduced the solubility of Al (Table 27, Fig.31). The highest value was seen during the post monsoon season. Al concentrations are directly related to the soil pH and toxic concentrations can occur only at pH values below 5. Free Al is commonly found in water above such soils (van Mensvoort *et al.,* 1985).

5.2.3. Toxicity parameters

Heavy metals like Cd and Pb were present in the sediment (Fig.28 and 29). The Cd content of sediment was very low, but Pb was present in sizeable amounts. Available Pb content was also highest during pre monsoon season, definitely due to the high evaporation rate. However, Resmi *et al.* 2007 reported high content of Cd in sediments of Vellayani lake. Cd is primarily used in electroplating of other metals or alloys for protection against corrosion, and in the manufacture of storage batteries, glass ceramics, and some biocides.

The Pb content of Vellayani lake varied from 0.0001 to 1.2 mg Kg^{-1}. Pb reaches the aquatic sediment through precipitation, erosion and leaching of soil as well as municipal and industrial waste. Pb continues to be used in large amounts in storage batteries, metal products, pigment, chemicals and hydro carbon fuels (Abbasi *et al.*, 1998). The Pb released by such materials might have reached the lake, contaminating the water. Pb reaches the aquatic sediment through precipitation, erosion and leaching of soil as well as municipal and industrial waste. The different aquatic systems of Thiruvananthapuram showed a Pb content ranged from 21.1 to 99.4 mg kg^{-1} during post monsoon season and from 0.4 to 29.4 mg kg^{-1} during pre monsoon season (Sobha *et al.*, 2009).

5.3 Extent of pollution in lake water

According to Indian standards (IS: 2296), the maximum permissible pH for drinking water is 8.5 and minimum pH is 6.5. The water of Vellayani lake comes within the limit only at the monsoon season. In other two seasons, some of the sites showed high acidity, below the maximum allowable lower limit. During those seasons, the water from such sites cannot be used for drinking and even domestic purposes. In the case of conductivity, the maximum permissible limit for domestic purposes as well as irrigation is 0.75 dS m^{-1} (Ayers and Westcot, 1985 and WHO, 1971). As per the above criteria, the lake water is safe for use. Regarding BOD, the maximum permissible limit for drinking water is 2 mg L^{-1} and 3 mg L^{-1} for domestic purposes. The different locations of Vellayani lake recorded values ranging from 0 to 39 mg L^{-1}. During pre monsoon season, the BOD for all the sites and 14 sites during post monsoon season were above the MPL. During monsoon season only 7 sites recorded higher BOD values than MPL. This indicated that the lake water is highly contaminated with organic load.

NH_4-N content of the area ranged from 0.1 to 44.3 mg L^{-1}. The permissible maximum concentration for NH_4-N is 16 mg L^{-1} in water and a concentration above this is lethal to the marine lives like fish and prawn (Sebastian, 1994). During the monsoon season, there is no threat of contamination by NH_4-N. But during pre monsoon and post monsoon periods, Reservoir bund (Site 5), Palapoor (Site 7) and Kaattukulam (Site 15) recorded NH_4-N content above this limit. This might be due to the leachate of N fertilisers from these sites which were intensively cultivated with vegetables. N content as nitrates should not exceed 45 mg L^{-1} for drinking and for other domestic purposes. In all the three seasons, NO_3-N content of lake water was below the above limit and can be safely used.

As per ISO standards the desirable limits for Ca and Mg are 75 and 30 mg L^{-1} respectively for drinking water. Both the elements come within the permissible limits. Vellayani lake water is safe with regard to the sulphate content since it can go up to a maximum value of 400 mg L^{-1}. Here, maximum sulphate content recorded may come to 66 mg L^{-1} (22 mg S L^{-1}). No specific guidelines are issued with regard to the safe limits of P, K and Na in connection with drinking/ domestic purposes. Al content of water did not vary much during different seasons and with locations with a range of 4.43 to 5.89 mg L^{-1}. As per WHO standards, permissible limit is upto 0.2 mg L-1 only. The entire lake water is unfit for drinking purpose as per the above criteria. Remediation measures for reducing the Al level in water should be advocated.

For Fe, the permissible limit is 0.3 mg L^{-1}. Fe was absent in all the sites during the monsoon season. In the pre monsoon and post monsoon season, only Venniyoor (Site 14) exceeded the MPL. Otherwise the water is safe with regard to its Fe content (Table 14). The maximum permissible limit for Zn and Cu is 1.5 mg L^{-1}. Zn was absent in all the sites in the monsoon season. In other two seasons, it was below the maximum permissible limits. Cu was not detected in the lake water in any of the three sampling seasons. Vellayani lake water is within safe limits with regard to Zn and Cu since the values were below MPL.

With regard to Cd, the MPL is 0.01 mg L^{-1}. The lake water exceeded this limit at six locations. Two locations viz., Manamukku (Site 4) and Reservoir bund (Site 5) were contaminated with Cd throughout the year. Hence decontamination treatments should be advocated. In the case of Pb the MPL is 0.1 mg L^{-1}. During monsoon season, the entire locations recorded values below this limit. But during pre monsoon season, 9 sites and during post monsoon 8 sites exceeded the MPL. Hence Vellayani lake water is contaminated with Pb at several locations and proper treatments have to be undertaken to remove Pb from water since it is highly toxic to human beings, aquatic organisms and macrophytes.

On evaluating the extend of aquatic pollution in Vellayani lake, it was observed that the water is contaminated with organic residues. With regard to the heavy metals, one location is contaminated with Fe, six locations with Cd and eight locations with Pb. During monsoon season, the water quality is generally good. But in the case of Al, the whole area is above the MPL.

5.4 Impact of spatial and seasonal variation on occurrence macrophytes

On evaluating the spatial and seasonal variation of macrophytes within the lake area, it was observed that fourteen species of aquatic macrophytes were found within the lake. Maximum number of plant species (12) was found during pre monsoon and minimum (9) during monsoon season more number of macrophytes were found in the pre monsoon season (Table 29). In the monsoon season macrophytes were absent in two sites viz., Kulangara (Site 11) and Mannamvarambu (Site 12). The water level may have increased and most of the macrophytes might have drowned during the monsoon season. *Panicum repens* was the most abundantly distributed macrophyte followed by fern, *Dryopteris erythrosora* and *Nelumbo nucifera.* No definite relation was observed between the spread of macrophytes and location since the macrophyte found in a location at one season may not be present there in the next season. Removal of macrophytes by human intervention may be the major reason for this erratic occurrence of plants in the lake.

5.5 Suitability of macrophytes as hyperaccumulators/phytoremediators

Hyperaccumulators are conventionally defined as species capable of accumulating metals at levels 100 fold greater than those typically measured in common non-accumulator plants. This ability of plants is widely exploited under phytoremediation for the clean up of environment. N is the prime essential element required for plant growth and many plants especially leguminous group contain very high quantities of N. Among the macrophytes 8 species recorded a N content above 1%. BCF was highest for *Eichhornea crassipes* (10000) followed by *Pistia stratiotes* (2500). The plants with such high BCF could be generally used as phytoremediators for N and can be widely employed for treatment of water contaminated with NO_3-N especially in constructed wetlands.

Among the macrophytes, *Brachiaria mutica*, *Colocasia esculenta* and *Dryopteris erythrosora* contained more than 3.5 % of P in shoot reflecting their ability to accumulate P, while some other plants recorded a low P content of 0.006 %.

BCF values were also very high for the above three species, indicating their ability for the removal of P from water and can be used as phytoremediators.

K removal by the macrophytes was comparatively low though *Eichhornea crassipes* and *Pistia stratiotes* recorded BCF of 26 and 46 respectively. The low content of K in water and sediment may be the reason for the low K concentration. Further experiments have to be conducted for the confirmation of the above.

Among the macrophytes, *Colocasia esculenta*, *Dryopteris erythrosora* and *Panicum repens* showed high Ca and Mg content with high BCF. But the BCF was highest for *Pistia stratiotes* for Ca and Mg followed by *Eichhornea crassipes*. The high Ca content of *Eichhornea crassipes* has already been reported (KAU, 2009).

Many of the macrophytes found in the area were found to remove substantial quantities of S from the sediment/water. This has clearly indicated their phytoextraction ability for S. Among the macrophytes, *Limnocharis flava*, *Eichhornea crassipes*, *Echinocloa colona* and *Scirpus grossus* can be used as phytoremediators since their S content has showed a positive relation with S content of sediment/water. For S, *Eichhornea crassipes* recorded the highest BCF followed by *Pistia stratiotes.* The difference showed by macrophytes in element content and accumulation ability might be due to the seasonal and temporal variation, nutrient content in water/sediment and occurrence of plants. Hence with this observation, the phytoremediation activity cannot be evaluated. Hyperaccumulation of S from acid sulphate soils of Kuttanad by *Eichhornea crassipes* and *Scirpus grossus* has been reported (KAU, 2009).

Na content of macrophytes was very low definitely due to the low content in water/ sediment (Table 15). None of the macrophytes showed a BCF greater than 10 and cannot be used as a phytoremediator. For a successful phytoremediator BCF should be greater than 10 (Chaney et al., 1995; Prasad *et al.*, 2005).

Regarding Al content *Dryopteris erythrosora* recorded the highest value. But the BCF was highest for *Eichhornea crassipes* followed by *Pistia stratiotes*. The hyperaccumulation ability of *Eichhornea crassipes* and *Pistia stratiotes* for Al has been already confirmed in experiments conducted at COA Vellayani in acid sulphate soils (KAU, 2009). Thus the above plants, though they are noxious weeds are doing a favour to the nature by maintaining water quality by the uptake of potentially toxic elements.

In general Vellayani lake water was within the safe limits with regard to Fe content except Venniyoor (Site 14). Almost all the macrophytes found in the area removed considerable quantity of Fe from sediment/water either in one or other season (Table 43). Their removal of Fe might have already helped to maintain a low Fe concentration in the lake water (Table 14). Among the macrophytes, *Eichhornea crassipes* had removed highest quantity of Fe. BCF was also highest for the same plant. This has clearly indicated the suitability of *Eichhornea crassipes* for the clean up of the water/sediment contaminated beyond the toxic levels with Fe. Similar result has been already reported for removing Fe from water bodies of Kuttanad (KAU, 2009).

Zn content of the macrophytes found in the area ranged from 0.45 to 83 mg kg^{-1} in shoot and from 0.61 to 101 mg kg^{-1} in root. In both cases *Pistia stratiotes* showed the highest value indicating its capacity to remove Zn from water and recorded the highest BCF (190). Exceptionally low contents of Zn were noticed for *Nymphaea odorata* and *Nymphoides indicus* and hence they cannot be used as phytoremediators.

Cu content of the water was below detectable limits. Even then, several macrophytes showed Cu content above 5.0 mg kg^{-1} with *Eichhornea crassipes* showing the highest value followed by *Pistia stratiotes* and *Nymphoides indicus*. The macrophytes present in the lake might have absorbed the soluble Cu, making it completely absent in water. Highest BCF was showed by *Nymphoides indicus* followed by *Eichhornea crassipes.* Both the above could be used as phytoremediators. The phytoremediation capacity of *Eichhornea crassipes* has already reported for wetland ecosystems of Kuttanad (KAU, 2009). In the case of *Nymphoides indicus*, this has to be further confirmed.

Cd was found in all the macrophytes of the lake except *Pistia stratiotes*. For *Scirpus grossus*, it was present only in root and not translocated to shoot. *Nelumbo nucifera* recorded the highest Cd content followed by *Eichhornea crassipes*, *Nymphaea odorata* and *Nymphoides indicus*. All the above macrophytes showed higher values for BCF and hence they can be suggested for the removal of Cd from lake water through phytoremediation. *Pistia stratiotes* cannot be used for phytoremediation of Cd since it is not taking up Cd from water/sediment.

The Vellayani lake was contaminated with Pb and in eight locations, the level exceeded safe limits. Pb was noticed in all the macrophytes found in the lake with *Pistia stratiotes* recording the highest content followed by *Nymphaea odorata.* But *Limnocharis flava* recorded the highest BCF followed by *Pistia stratiotes.* The very high BCF for *Limnocharis flava* indicated its high phytoextraction ability for Pb. Even with very small concentration of Pb in water/sediment, the plant was able to extract and translocate to different plant parts.

In general, the macrophytes found in the lake were seemed to be good translocators of various nutrient elements and heavy metals as evidenced by showing translocation indices >1. However there are certain exceptions. *Eichhornea crassipes* which was found to be a good hyperaccumulator of various elements was found to retain most of the P absorbed in the root itself. Similarly *Nelumbo nucifera* was found to retain more of Ca, Cu and Cd in the root itself. *Dryopteris erythrosora* showed similar behaviour for Fe and Pb and *Nymphaea odorata* for Na and Zn.

Among the macrophytes, *Eichhornea crassipes* was found to be a good phytoextractor for N, K, S, Al, Fe, Cu and Cd and *Pistia stratiotes* for N, K, S, Al, Zn, Cu and Pb. *Nymphaea odorata* was found to phytoextract Cu and Cd and *Nymphoides indicus* for Cd and Pb. For S, *Limnocharis flava* and *Scirpus grossus* can be used as phytoextractors.

As per the study, it was found that Vellayani lake was contaminated with organic and inorganic residues. Hence urgent action may be taken for the restoration and maintenance of water quality of the lake. The following measures can be advocated to tackle the problem.

1. Appropriate administrative action may be undertaken to demarcate 100 m from the water front as the ecotone.

2. All along the margins of the lake, soil holding plants with phytoremediation capacity can be planted. Vetiver (*Vetiveria zizanoides*) is a suitable option for soil and water conservation.

3. Exposed bund along the shore line of the lake should be covered by vegetative barriers to prevent soil erosion and further silt deposition in the lake.

4. At the same time farmers of the area as well as the public should be made aware of the adverse effect of unscientific cultivation and anthropogenic developmental activities on this fragile ecosystem.

SUMMARY

6. SUMMARY

A study entitled "Evaluation of aquatic pollution and identification of phytoremediators in Vellayani lake" has been carried out at the College of Agriculture, Vellayani the year 2009-2010 with an objective to assess the extent of pollution and to identify the phytoremediators in Vellayani lake. The study was conducted as two parts viz., 1. Evaluation of aquatic pollution in Vellayani lake and 2. Identification of hyper accumulators / phytoremediators found in the Vellayani lake.

A reconnaissance survey was carried out along the banks of Vellayani lake and 15 locations were selected for the collection of water, sediment and macrophytes during pre monsoon (April), monsoon (Sep) and post monsoon (Dec) periods. The samples were analyzed for various physical, chemical and biological properties to assess the extent of pollution in the aquatic system as well as to identify the macrophytes having phytoremediation capacity.

6.1. Water

1. The physical properties of the lake water showed significant variation among seasons and with locations except water temperature which ranged from 26 to 28^0 C. The colour ranged from pale blue in pre and post monsoon to yellowish brown in monsoon season. The turbidity and the amount of suspended solids in water showed an enhancement towards the monsoon from pre monsoon season.

2. All the chemical properties of lake water were significantly influenced by the season and location. The water pH was highest during monsoon season (6.83) and the mean values were almost same for both pre monsoon and post monsoon periods. EC

of lake water was comparatively low, recording the minimum during monsoon and then increased towards post monsoon season. As per the ISI criteria, pH of the lake water was within safe limits only at the monsoon season while EC was within the permissible limit throughout the year.

3. BOD of water ranged from 0 to 39 mg L^{-1} and COD from 4 to 126 mg L^{-1}, both recording their lowest values during monsoon and highest during pre monsoon. As per the ISI criteria the lake water is highly contaminated with organic load.

4. The NH_4-N content of water ranged from 0.1- 44.3 mg L^{-1} with highest values during the post monsoon. There was no threat of contamination by NH_4-N during monsoon season where the lowest values were observed. In other seasons, three sites exceeded the MPL. The NO_3-N content was highest during pre monsoon season and was undetectable in most of the sites during the monsoon season. In all the three seasons, NO_3-N content of lake water was below the above limit and can be safely used.

5. The P content of water was below detectable limits. K and S contents showed lowest values during the monsoon season and there after a gradual increase were observed. The S content of water was highest during pre monsoon season and lowest during monsoon season. All the above elements come within the permissible limits.

6. There was only a slight variation in the mean value of Ca during the three seasons with highest during the monsoon season. Mg content was highest during post monsoon season and lowest during pre monsoon season. For both, site wise variation was high. Ca and Mg content of water were also within safe limits.

7. Both Fe and Zn contents were below detectable levels during the monsoon season. Their values showed only a slight variation between pre monsoon and post monsoon seasons. Cu was not detected in water. In the pre monsoon and post

monsoon seasons, the Fe content of water of one location (Venniyoor-Site 14) alone exceeded the MPL. For Zn it was within safe limits.

8. Na content of water ranged from 6.2 to 25.4 mg L^{-1} with highest values during post monsoon season. Al content of water did not vary much during different seasons and with locations (4.43 to 5.89 mg L^{-1}). As per WHO standards, Al content of lake water exceeds the MPL throughout the year, indicating the need for Al decontamination treatment. Carbonates and Bicarbonates were not detected in any of the sites during three sampling periods.

9. In general, the Cd content of water was very low except at six locations. It was highest in the pre monsoon season and lowest in the monsoon season.. At the above six locations, Cd content of water exceeded the MPL. Pb content of water was comparatively high and it followed the same trend as that of Cd for seasonal variation. Pb content of entire locations was below the MPL during monsoon season. But at pre monsoon season, 9 sites and at post monsoon 8 sites exceeded the MPL.

10. With regard to the microbiological properties, the bacterial count was lowest during monsoon and highest during post monsoon season. Regarding the Coliform count, a gradual increase in number from pre monsoon to post monsoon season was observed. Algal population was seen uniformly distributed in all the 15 sites throughout the three seasons. Algae do not showed any significant difference between the sites.

6.2. Sediment

11. All the chemical properties of lake sediment were significantly influenced by the season and location. The pH was highest during the monsoon season and lowest during the pre monsoon season, while EC was lowest during monsoon season.

12. Organic carbon content ranged from 4.5 to 41.5 g Kg^{-1}. It was highest during the pre monsoon season and lowest during the post monsoon season. The extractable P content was generally low with highest values during post monsoon which was significantly higher than other two seasons.

13. NH_4-N content was highest during the monsoon season (254 mg kg^{-1}) and lowest during the pre monsoon season. For NO_3-N a reverse trend was observed.

14. Extractable K also followed the same trend as that of NO_3-N. But the behaviour of extractable Na was quite different showing higher values during monsoon season. Ca content showed a decreasing trend towards the monsoon with highest values during pre monsoon season. Regarding extractable Mg, it followed the same trend as that of Ca. Extractable S content of the sediment showed a decreasing trend towards the monsoon season and thereafter a slight increase in the value was seen.

15. With regard to extractable Fe, a decreasing trend towards the monsoon season was observed with the highest values during pre monsoon season. The values of extractable Cu and Zn showed almost same trend as that of Fe.

16. Extractable Cd and Pb contents of sediment also followed the same trend as that of Fe and Cu, showing highest values during pre monsoon and decrease towards

post monsoon. For Cd, the highest values of 0.025 mg kg-1 and for Pb 1.2 mg kg-1 were noted during the pre monsoon season.

17. The extractable Al content showed a decreasing trend towards the monsoon season and thereafter an increase was observed recording the highest value during post monsoon season. Carbonates and bicarbonates were not detected in the sediment samples.

18. The texture of sediment ranged from sandy to sandy clay loam. Out of the 15 locations, four locations were sandy, five locations were sandy clay loam, three locations were loamy sand and the remaining were sandy loam in texture.

6.3. Aquatic macrophytes

19. Fourteen species of aquatic macrophytes were found within the lake. Maximum number of plant species (12) was found during pre monsoon and minimum (9) during monsoon season. The macrophytes viz., *Scirpus grossus Panicum repens, Nelumbo nucifera, Nymphoides indicus*, *Nymphaea odorata* and *Eleocharis dulcis* were found during the three seasons. While *Brachiaria mutica*, *Colocasia esculenta, Echinocloa colona* and *Limnocharis flava* were found only during the pre monsoon season. Among the macrophytes, *Panicum repens* was observed at maximum number of sites (7) followed by *Dryopteris erythrosora* (4) and *Nelumbo nucifera* (4). *Panicum repens, Scirpus grossus, Ipomea aquatica, Eichhornea crassipes* and *Eleocharis dulcis* recorded 100 per cent growth intensity.

20. All the macrophytes showed higher N content in shoot compared to root. *Eichhornea crassipes* recorded the highest value. The P content was also higher for shoot in almost all the plants, except *Eichhornea crassipes*. The highest value was showed by *Dryopteris erythrosora.* K content of macrophytes was much lower

compared to N and P. The plants viz., *Colocasia esculenta* and *Eichhornea crassipes* showed higher concentration for K in root compared to other macrophytes.

21. Ca content was also higher for shoot compared to root with *Panicum repens* showing the highest value. Most of the plants recorded higher values for shoot content of Mg compared to the root, except for *Limnocharis flava*. In general, the S content of plants was also higher for shoot except *Colocasia esculenta* and *Limnocharis flava*. Na also followed the same trend as that of S with exceptions like *Brachiaria mutica*, *Scirpus grossus* and *Nymphaea odorata.*

22. The Al content of shoot was higher for all the plants present in the lake compared to root. Among the aquatic macrophytes, the Al content of shoot was highest for *Dryopteris erythrosora* and *Nelumbo nucifera* recorded the highest value for root Al content.

23. Out of the 14 macrophytes identified seven viz., *Brachiaria mutica, Limnocharis flava*, *Panicum repens, Pistia stratiotes, Nymphae odorata*, *Nymphoides indicus* and *Eleocharis dulcis* concentrated Fe in their roots. *Eichhornea crassipes* recorded the highest Fe content in both shoot and root. For Zn, the aquatic macrophytes did not show a definite accumulation pattern.

24. The plants did not show a uniform pattern of accumulation for Cu. *Eichhornea crassipes* was found to accumulate highest content of Cu for both shoot and root. Cd was not present in all macrophytes identified in the area. It was not detected in *Pistia stratiotes* and *Scirpus grossus. Nelumbo nucifera* recorded the highest value for both shoot and root Cd content. The plants in general contained more Pb in shoot compared to root. *Pistia stratiotes* recorded highest Pb content in both shoot and root. The Pb content of shoot ranged between 1.90 and 47 mg kg^{-1} for different aquatic macrophytes. For root it ranged between 0.80 and 29 mg kg^{-1}.

25. The macrophytes showed a higher BCF for shoot compared to root for N, P, K and Al. The same trend was followed by Ca, Mg and S except in the case of *Limnocharis flava*.

26. BCF for Na was also higher for shoot compared to root except in the case of *Brachiaria mutica* and *Scirpus grossus.* In case of Fe several plants viz., *Colocasia esculenta, Scirpus grossus, Echinocloa colona, Pistia stratiotes, Eichhornea crassipes* and *Eleocharis dulcis* showed the highest BCF for root.

27. In the case of Zn, Cu, Cd and Pb, BCF was generally higher for shoot compared to root with certain exceptions.

28. The various aquatic macrophytes found in the area showed a translocation index above one for N, P, K, Ca, Mg and S. However, there are certain exceptions like *Eichhornea crassipes* for P and *Nelumbo nucifera* for Ca recording translocation indices of 0.30 and 0.95 respectively. In the case of N and P and S, the highest value was observed for *Brachiaria mutica.* For K and Ca, *Limnocharis flava* showed the highest translocation index. For Mg, *Eichhornea crassipes* recorded the highest value.

29. Translocation indices for Na, Al, Fe, Cu, Zn, Cd and Pb showed that various aquatic macrophytes found were > 1. But for each metal, certain plants showed an index value below one. Such plants are viz., *Nymphaea odorata* for Na and Zn, *Dryopteris erythrosora* for Fe and Pb, *Nelumbo nucifera* for Cu and Cd. For Al, all the plants showed a value above one. *Limnocharis flava* showed the highest translocation indices for Na and Al. *Brachiaria mutica* showed the highest translocation indices for Fe, Cu, Cd and Pb.

Conclusion

On evaluating the extend of aquatic pollution in Vellayani lake, it was found that the water was contaminated with organic residues as evidenced by high BOD; NH_4-N, Al and heavy metals. With regard to the heavy metals, one location was contaminated with Fe, six locations with Cd and eight locations with Pb. During monsoon season, the water quality is generally good. Al content of water was always above the safe limits fixed by ISI/WHO. Hence suitable treatments for improving water quality should be advocated for its use as drinking water/ for domestic purposes.

Among the macrophytes, *Eichhornea crassipes* was found to be a good phytoextractor for N, K, S, Al, Fe, Cu and Cd and *Pistia stratiotes* for N, K, S, Al, Zn, Cu and Pb. *Nymphaea odorata* was found to phytoextract Cu and Cd and *Nymphoides indicus* for Cd and Pb. For S, *Limnocharis flava* and *Scirpus grossus* can be used as phytoextractors.

Future line of work:

From the present study, the contamination of lake water and presence of phytoremediators in the lake were confirmed. Hence more thrust should be given for restoration of the water quality using green technologies. With this in view, the following future line of work is being proposed.

1. The phytoremediation capacity of different macrophytes should be evaluated for various inorganic contaminants.
2. Characterise the Vellayani lake area and its catchments in terms of physical, chemical, biological and anthropogenic parameters. Develop a suitable technology based on phytoremediation for the restoration and maintenance of water quality of the lake.

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EVALUATION OF AQUATIC POLLUTION AND IDENTIFICATION OF PHYTOREMEDIATORS IN VELLAYANI LAKE

by

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THESIS

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8. ABSTRACT

A study entitled "Evaluation of aquatic pollution and identification of phytoremediators in Vellayani lake" has been carried out at the College of Agriculture, Vellayani during the year 2009-2011 to assess the extent of pollution and to identify the phytoremediators in Vellayani lake. Vellayani wetland ecosystem comprising a fresh water lake and surrounding padasekharams, extends through three panchayaths viz., Kalliyoor, Pallichal, Venganoor and two zones of Thiruvananthapuram Corporation namely Nemom and Thiruvallam. It is the sole drinking water source for the above area. Vellayani and adjoining areas is undergoing drastic reduction in area and water quality. Samples of water, sediment and macrophytes found in the lake were collected during pre monsoon, monsoon and post monsoon seasons, from 15 sites within the lake and were subjected to physical, chemical and biological analysis.

The physical properties of the lake water viz., colour, turbidity and the amount of suspended solids showed significant variation among seasons and with locations showing higher values during monsoon season. All the chemical properties of lake water were also significantly influenced by the season and location. On evaluating the water as per ISI/WHO criteria, it was found that the chemical characteristics like EC, NO_3-N, K, Ca, Mg, S and Zn were within the maximum permissible limits. P and Cu were not detected in water in any of the seasons. pH of the lake water was within safe limits only during the monsoon season and it was highly contaminated with organic load. The NH_4-N content of water exceeded the MPL at certain locations during pre and post monsoon seasons. With regard to the heavy metals, one location was contaminated with Fe, six locations with Cd and eight locations with Pb. During monsoon season, the water quality is generally good. Al content of water was always above the safe limits fixed by ISI/WHO. Hence suitable

treatments for improving water quality should be advocated for its use as drinking water/ for domestic purposes.

With regard to the microbiological properties, the bacterial count was lowest during monsoon and highest during post monsoon season. Regarding the Coliform count, a gradual increase in number from pre monsoon to post monsoon season was observed. Algal population was seen uniformly distributed in all the 15 sites throughout the three seasons.

All the chemical properties of lake sediment were significantly influenced by the season and location. Among the chemical characteristics organic carbon, extractable K, Ca, Mg, S, Fe, Cu, Zn and Pb were higher during pre monsoon season while pH and NH_4-N were higher during monsoon season. Most of the chemical characteristics like EC, NO_3-N, extractable K, S, Fe, Cu, Zn and Pb recorded their lowest values during monsoon season, while organic carbon, extractable Ca, Mg and Cd were at their lowest during post monsoon. NO_3-N and extractable Al recorded their highest value during post monsoon season. Carbonates and bicarbonates were not detected in the sediment samples. The texture of sediment ranged from sandy to sandy clay loam.

Fourteen species of aquatic macrophytes were found within the lake. Maximum number of plant species (12) was found during pre monsoon and minimum (9) during monsoon season. All the macrophytes showed higher elemental composition in shoot compared to root. Among the macrophytes, *Eichhornea crassipes* was found to be a good phytoextractor for N, K, S, Al, Fe, Cu and Cd and *Pistia stratiotes* for N, K, S, Al, Zn, Cu and Pb. *Nymphaea odorata* was found to phytoextract Cu and Cd and *Nymphoides indicus* for Cd and Pb. For S, *Limnocharis flava* and *Scirpus grossus* can be used as phytoextractors.

Appendices

APPENDIX – I

I. Media compositon

a) Tryptone glucose extract agar (1 L)

Tryptone	-	20g
Glucose	-	5g
KH_2PO_4	-	0.20g
K_2HPO_4	-	0.35g
$MgCl_2.6H_2O$	-	0.10g
$CaCl_2.2H_2O$	-	0.07g
Agar	-	18g
Distilled water	-	1L

b) Endo agar (1L)

Peptone	-	10g
Lactose	-	10g
K_2HPO_4	-	3.5g
Sodium sulfite	-	2.5g
Basic fuchsin	-	0.4g
Agar	-	18g
Distilled water	-	1L

APPENDIX- II

II. Forel-ule Colour scale

Colour scale	Colour
1-5	Pale blue
6-10	Greenish blue
11-16	Pale green
17-21	Yellowish brown
22	Brown