SYNOPSIS

Research Goal and Significance:

Water is exposed to numerous natural and anthropogenic influences in the form of pollutants. Urban storm waters, eroded soils and runoff waters, untreated domestic wastewaters, leachates from uncontrolled solid waste dumpsites and landfills, mining operations and use of petroleum products accelerate the loading of various inorganic and organic contaminants in surface water and sediments of lakes (Mwamburi, 2015). Fresh water bodies are important ecosystems providing various services constituting 65% of freshwater ecosystems worldwide and are regarded as the most vulnerable globally (Tan *et al*., 2015). Stressors such as eutrophication or climate change, threaten their ecological functions (Dornhofer *et al*., 2016). Anthropogenic activities degrade fresh water bodies thereby affecting ecological integrity, functioning and subsequently their use for domestic, industrial and agricultural purposes (Venkatachalapathy and Karthikeyan, 2015). Water provides shelter, oxygen, food, nutrient and other requirements necessary for the growth of aquatic community. The quality of water arises from physical, chemical and biological interactions which are changed with seasonal variations of temperature, amount of rainfall, transformation and accumulation of matter of living things, agricultural residues into the water body (Barman *et al*., 2015). Water quality has direct influence on the type and distribution of community in the water body. Excessive changes in water quality may threaten the aquatic life by changing the community structure as well as losing biodiversity (Goswami *et al.*, 2012). Freshwater communities are very sensitive to the environmental variables (Darchambeau *et al.,* 2014). In limnological studies, it is very important to determine the water quality in lake, pond and stream, so also to identify phytoplanktons. Some of the species can be indicators of status of aquatic body (Rani and Sivakumar, 2012). Phytoplanktons are used as indicators mainly due to their sensitivity and strong response to physical and chemical changes in waters (Sharma *et al.,* 2013). Biological monitoring is a fast and cost-effective approach for assessing the effects of environmental stressors, making it a essential tool (Bere and Tundisi, 2010a). Among the several groups of phytoplanktons that occur in fresh waters, diatoms have been used as the most common indicators. Various indices have been developed for monitoring pollution in water body. One of the simplest and effective water quality indexes, utilizing diatom population is IDSE/5 - the index of Saprobity- Eutrophication (Louis Leclercq, 2008, Lecoinite *et al.,* 1993). This index is obtained from the OMNIDA GB 5.3 software which indicates the quality of water in terms of organic pollution as well as anthropogenic eutrophication. Pollution of trace metals in aquatic ecosystem is a growing problem worldwide. Currently it has reached an alarming rate and has become a problem of great concern. These metals may accumulate to a very high toxic levels and causes severe impact on the aquatic organisms without any visible sign (Giguere *et al.,* 2004).

Trace metals originate from anthropogenic activities like draining of sewerage, dumping of wastes and recreational activities. Metals also occur in small amounts naturally and may enter into aquatic system through leaching of rocks, airborne dust and forest fires (Fernandez and Olalla, 2000). As trace metals cannot be degraded, they are continuously being deposited and incorporated in water, sediment and aquatic organisms (Linnik and Zubenko, 2000). During their transportation, the trace metals undergo numerous changes in their speciation due to dissolution, precipitation and sorption which affect their bio availabilities (Dassenakis, 1997; Akcay, 2003 and Nicolau, 2006). Aquatic plants as producers play key role in protecting water quality there by providing habitat for aquatic organisms. They are known as good indicators of trace metal contamination in aquatic ecosystems and they also act as good bio-filters as they accumulate metals from the surrounding environment (Vardanyan *et al*., 2007). Phytoremediation is a promising, cost effective and eco-friendly technology for water quality restoration in lakes (Xu *et al*., 2014). Over the past 50 years, a large body of literature has been developed to identify the principle impacts and sources of increased nutrient levels on the quality of receiving waters (Smith, 2003).

Pollution of fresh water bodies is a global problem, as the deterioration of water quality and excessive biological productivity causes significant damage to aquatic ecosystems and also to society. A large number of standing water bodies is available in India and in the state of Goa for fishery management, irrigation, recreational, drinking water purpose. The conservation of these lakes is in the interest of man in its ecological, cultural and touristic values. As these water bodies are important for mankind in various ways it is imperative as well as challenging to assess their present condition and study the associated pollution problems. Many lakes in Goa suffer from the deterioration of the water quality due to accumulation of toxic chemicals, shrinkage of area, and above all, a loss of the aesthetic value. The local residents generally complain of bad odors around the lake. There is a need for continuous evaluation of the pollution level in order to promote better living conditions around these water bodies as they are subjected to anthropogenic stress and receive inputs of domestic waste and sewage.

Present work is carried out by analysing water samples on monthly basis from four water bodies in the State of Goa. Two water bodies from North Goa and two from South Goa are selected for comparing the impact of biotic activities on physico-chemical characteristics of water. Syngenta Lake - is in the premises of M/s Syngenta Agro Chemicals, Corlim Ilhas Goa, Khandola Pond - is in Marcela village which serves as a source of irrigation to areca nut plantation. Lotus Lake - is in Benaulim village while Curtorim Lake - is situated in Curtorim village. Both water bodies from south Goa serve as source of irrigation for paddy crop. Sampling was carried out on monthly basis from January 2014 to December 2015 using plastic water samplers.

The thesis comprises of 9 chapters that are listed below.

Chapter 1: Introduction

This chapter introduces the research objectives and highlights the importance of water and the scenario of water pollution along with the importance of phytoplanktons as pollution indicators. It also focuses on contamination of water bodies by trace metals and their accumulation by aquatic macrophytes and their role in phyto - remediation.

Chapter 2: Review of Literature

In this chapter an update of literature pertaining to the research objectives is highlighted. Pioneering studies in the field of Limnology in different parts of world and in India are reviewed. Research work related to physico chemical parameters, phytoplankton population and their use as pollution indicators, trace metals and their influence on aquatic ecosystems, macrophytes and their role in metal accumulation, use of modern techniques like remote sensing in water pollution studies has also been reviewed.

Chapter 3: To study the various sources of eutrophication of water bodies in the state of Goa. (Objective 1)

In this chapter the observations related to degradation of water bodies in the state due to several reasons are enlisted.

Observations:

State of Goa has number of standing fresh water bodies which serve as a source of irrigation, recreation, used for fishing purpose and some serve as source of drinking water. It has been observed that processes like agriculture and livestock runoff, septic tank lechete, dumping of solid waste, residential runoff and urban runoff are responsible for choking several water bodies to death.

Chapter 4: To determine physical, chemical and biological characteristics of water body and to identify the trophic status of selected water bodies. (Objective 2)

This chapter focuses on the study physicochemical parameters that were analysed along with the trophic state of the selected water bodies.

Key findings:

Trophic state was eutrophentic in Syngenta, Lotus and Curtorim Lakes and mesotrophantic in Khandola Pond.

Chapter 5: To understand the seasonal variations in water quality in the water bodies as affected by pollutants. (Objective 3)

This chapter deals with the various parameters analysed during two years study period.

Methodology:

Parameters analyzed:

pH, temperature, total dissolved solids, turbidity, DO, BOD, nitrates ($N0_3^-$), phosphates ($P0_4^-$) and total chlorophyll were analysed on monthly basis. Macro- and microphytes were identified using standard bibliographies. Trace metals from water, sediment and aquatic macrophytes were analyzed during pre-monsoon, monsoon and post-monsoon seasons.

pH was determined by using a digital pH meter, while water temperature was recorded by using a thermometer. Total dissolved solids were measured gravimetrically. Turbidity was determined by using a Turbidity meter, DO was analysed by Winkler method, BOD analysis was carried out by titration method using sodium thiosulphate. Nitrates were determined by spectrophotometric method using stock nitrate solution (PDA method). Total phosphorus (P) was determined by using stannous chloride (APHA, 2012). Total chlorophyll was estimated by acetone extraction and optical density was read at required wavelength using spectrophotometer (Arnon, 1949).

Statistical analysis of the data was done using modern softeware programmes. Data was analysed for Principal Component Analysis, Bray Curtis similarity index using PAST, one way ANNOVA and Tukey's (HSD) was done using VASSAR STATS, Pearson's correlation Matrix was calculated using SPSS-19 software, for, CCME water quality index was calculated using CCME WQI Calculator.

Key findings:

Monthly analysis showed seasonal variations in the parameters. In the present study, the pH of water ranged from acidic to alkaline; *viz.*, Syngenta Lake (5.9 - 6.8), Khandola Pond (6.0 - 7.1), Lotus Lake (5.4 - 7.8) and Curtorim Lake (5.4 - 7.6). Phytoplankton population showed variations which may be attributed to the change in pH values. Water temperature ranged from 25 to 32^{o}C, with maximum in summer and minimum in winter. Water temperature plays an important role in controlling occurrence and abundance of phytoplanktons (Nazneen, 1980). The Total Dissolved Solids (TDS) were least at Khandola Pond (32.60 to 54.40 mg/L), while they were much higher at Syngenta Lake (538 to767 mg/L), Lotus Lake (616 to 1410 mg/L) and at Curtorim Lake (922 to 1465 mg/L). According to Beeton (1965), oligotrophic lakes have TDS less than 100 ppm, while eutrophic lakes have TDS values more than 100 ppm. Soil particles, planktonic algae, microbes and other organisms contribute to turbidity. Higher values were recorded during monsoon season while low values were recorded during winter season. *viz.,* 53-22 NTU in Syngenta Lake, 31-15.4 NTU in Khandola Pond, 54.78-29 NTU in Lotus Lake and 56.7-26 NTU in Curtorim Lake. Increased turbidity levels in monsoon may be due to rainfall and surface runoff of water bringing a lot of sediments from the surrounding area. DO ranged between 5.97 to 12.06 mg/L at Syngenta Lake, 7 to 11.97 mg/L at Khandola Pond, 5.14 to 10.30 mg/L at Lotus Lake and 5.65 to 12.77 mg/L at Curtorim Lake. Increased DO during monsoon is known to be due to increased solubility of oxygen while lower levels of DO in summer is due to higher temperature and low solubility of oxygen in water (Kaushik, 1994). BOD varied from 6.07 to 18.34 mg/L at Syngenta Lake, 18.79 to 47.83 mg/L at Lotus Lake, 21.89 to 59.9 mg/L at Curtorim Lake. As BOD increased there was rapid depletion of DO. Sankar *et al.,* (2002) suggested that high BOD may be due to the increase demand of oxygen for the degradation of the organic wastes dumped into the water. Nitrate levels in the selected water bodies varied; ranged from 0.20 to 0.59 mg/L in Syngenta Lake, 0.21 to 0.58 mg/L in Khandola Pond, 1.43 to 4.55 mg/L in Lotus Lake and, 0.80 to 2.76mg/L in Curtorim Lake. Phosphate concentrations showed variations and ranged from 0.07 to 0.31 mg/L in Syngenta Lake, 0.01 to 0.30 mg/L in Khandola Pond, 0.01 to 2.41 mg/L in Lotus Lake and 0.01 to 1.72 mg/L in Curtorim Lake. During monsoon season, nutrients like nitrates and phosphates enter the water bodies from the surrounding area, especially from farmlands and sewage, resulting in their elevation (Sawaiker and Rodrigues, 2016). Monitoring chlorophyll levels is a direct way of tracking algal growth. Surface waters that have high chlorophyll conditions are typically high in nutrients, generally P and N. Chlorophyll concentration varied from 10.76-23.43 mg/m^3 at Syngenta Lake, 2.7-5.25 mg/m^3 at Khandola Pond , 16.52-39.23 mg/m^3 at Lotus Lake and 19.04-54.4 mg/m^3 at Curtorim Lake. High chlorophyll content was observed during late summer and during October. CCME WQI results show that overall water quality of the water bodies selected for study is poor and water is not suitable for drinking, aquatic life, recreation, irrigation purpose and for livestock.

Chapter 6: To survey the macrophytes and phytoplanktons present in polluted and non polluted water bodies. (Objective 4)

Methodology:

Macrophytes were handpicked from the water body. The identification of the macrophytes was carried using the available literature. (Almeida, 1990; Biswas, 1936; and Cook, 1968).One liter of water sample was collected for the study of phytoplanktons in sterile plastic bottle and Lugol solution (0.7ml/100ml of sample, APHA, 2012) was added immediately for sedimentation and left undisturbed for 24 hours. The phytoplanktons settled at the bottom of the container were collected and preserved in 4% formaldehyde. After decanting the supernatant fluid and remaining sample was concentrated by centrifugation at 1500 rpm. The total volume was made to 10 ml. Phytoplanktons were examined immediately after fixation using calibrated student research microscope. Dimensions were measured using micrometry technique and photomicrographs were taken using Nikon DS Fi 2 camera. Counting was done by Laky drop method. Identification was carried out using standard bibliographies and monographs (APHA, 2012; Krishnamurthy, 2000; Prasad and Misra, 1992; Prescott, 1969; Edmondson, 1966; Desikachary, 1959; Iyengar, 1940). Biomonitoring using diatoms was done by OMNIDA GB 5.3 software and IDSE/5 index was calculated. Nestedness index for diatoms was calculated by using Nestedness temperature calculator.

Key findings:

Macrophytes were found growing in all sites except in Khandola Pond. In all, 15 macrophytes have been identified from three water bodies. A total of 128 phytoplanktons were indentified - Chlorophyceae (77), Bacillariophyceae (21), Euglenophyceae (16) and Cyanophyceae (14). IDSE/5 index ranged from 3.31-3.47 in Syngenta Lake, 3.52 in Khandola Pond during both years of study, 3.16-3.53 in Lotus Lake and 3.46-3.47 in Curtorim Lake indicating low to moderate degradation of all water bodies. (IDSE index range is between 1- 5 {1 - worse and 5 - best}). Indicator species of diatoms for organic pollution *viz., Gomphonema parabolum, Navicula halophila*, *N. microcephala, N. mutica* and anthropogenic pollution *viz., Amphora ovalis, Stauroneis phoenicenteron, Synedra ulna* were recorded from Syngenta, Lotus and Curtorim Lakes. Indicator species for organic pollution *viz., Navicula mutica* and anthropogenic pollution *viz., Navicula microcephala* were recorded from Khandola Pond. Diatoms documented in this study showed highly packed matrix thereby proving maximum nestedness, by reordering entire rows and columns. Present study reveals that Syngenta, Lotus and Curtorim Lakes greatly supported the growth of diatoms compared to Khandola Pond. Eight species of diatoms *viz., Navicula halophila, N. mutica, N. radiosa, N. rhynococephala, Synedra ulna, Pinnularia gibba, P. dolosa* and *P. graciloidis* were common to all the study sites indicated a common niche requirement. These forms were present throughout the study and hence described as *autochthonous* species. Species occupying lower rows in the tables were appearing occasionally. The matrix fill of the species in the Syngenta Lake was 79% with system temperature of 12.73°, at Lotus Lake it was 78.7% with temperature 4.73°, while at Curtorim Lake it was 71.2% matrix fill with 12.86° system temperature with high nestedness index. Even though lesser number of species was recorded in Khandola Pond, the matrix fill was 66.6% with highly nested species having cooler system temperature of 2.12°C. This may be attributed to lack of species distribution in the water body. From nestedness index it is concluded that, Syngenta, Lotus and Curtorim Lakes, are judged as most hospitable sites; while Khandola Pond is placed at bottom position in supporting the growth of diatoms. During study it was observed that for *Pinnularia graciloids, Navicula halophila, N. mutica,, N. radiosa N. rhynococephala, Synedra ulna,* and *Pinnularia gibba* niche requirements were most common and prevalent.

Chapter 7: To analyse the trace metals present in the water bodies and their accumulation by aquatic macrophytes. (Objective 5)

Methodology:

Total metals from water were extracted using APDC and MIBK (APHA, 2012). Digestion of sediment for total metal analysis was done by using Hydrofloric acid, Nitric acid and Perchloric acid in the proportion of 7:3:1(APHA, 2012). Dominant macrophytes from three water bodies were selected for trace metal accumulation. Trace metal extraction from water, sediment and bioaccumulation was studied during three seasons' *viz.*, pre-monsoon, monsoon and post-monsoon.

Aquatic macrophytes like *Salvinia*, *Eichhornia* and *Pistia* were handpicked from the habitat and were sorted species-wise following standard taxonomic manuals. One set was kept for preparation of herbarium and confirmation of taxonomic identification. Individual species were washed carefully. Roots and shoots were washed in distilled water and dried at 70 $^{\circ}$C in hot air oven for 48 hours. Dried samples were homogenized and ground to yield fine powder.

Nitric acid digestion:

One gram of powdered sample was taken to which 10 ml of concentrated HNO_3 was added. The sample was heated for 45 min at 90°C, and then the temperature was increased to 150°C at which the sample was boiled for at least 8 hours until a clear solution was obtained. Concentrated $HNO_3$was added to the sample (5 ml, three times). Digestion was carried out until the volume was reduced to 1 ml. After cooling, 5 ml of 1% $HNO_3$was added to the sample. The solution was filtered using Whatman No. 42 filter paper and < 0.45 mm Millipore filter paper. It was then transferred to a 25 ml volumetric flask by adding distilled water (Zheljazkov and Nielson, 1996). The digested samples were analysed for trace metals using Atomic Absorption Spectrophotometer.

Key findings:

The concentration of trace metals varied from one water body to another. The difference among all water bodies in metal content is significant. According to Trivedi and Gurudeepraj (1992), surface water generally contain less than 1 mg/l of iron.Water containing more than 2 mg/L iron cause staining, and imparts a bitter astringent taste to water. Iron content in water ranged from 0.38 - 4.60 ppm at Syngenta Lake; 0.26 - 3.37 ppm at Khandola Pond; 1.03 - 8.61 ppm at Lotus Lake; and 0.42 - 3.31 ppm at Curtorim Lake. Maximum concentration was recorded at Lotus Lake while minimum concentration was recorded at Khandola Pond. Carrol (1958) stated that iron appears in the Lake sediments as an essential component of clay minerals. **Fe** concentration in sediment ranged from 7.75 - 9.56 ppm at Syngenta Lake; 2.16 - 5.78 at Khandola Pond; 2.94 - 22.46 ppm at Lotus Lake and 0.83 - 6.19 ppm at Curtorim Lake. The highest concentration was recorded in Lotus Lake. This may be attributed to the huge amounts of raw sewage, discharged into the lake (Abdel-Moati and El-Sammak, 1997). Sediments act as traps for most of heavy metals by forming stable complexes with sediment organic matter, carbonates, and iron (Fe)–manganese (Mn) oxides (Duzzin *et al*., 1988; Rajendran *et al*., 1992).

Manganese is an essential micronutrient throughout all stages of plant development. It is important for vital plant functions and act as a cofactor in various enzymes as well as in the structure of chlorophyll and major it's sources in air and water are burning of fuels. (Abbasi *et al*., 1998). **Mn** concentration in water ranged from 0.01 - 0.42 ppm at Syngenta Lake; 0.03 - 0.20 ppm at Khandola Pond; 0.004 - 0.22 ppm in Lotus Lake; and 0.40 - 0.60 ppm in Curtorim Lake. Highest concentration was recorded at Curtorim Lake while lowest at Lotus Lake. **Mn** concentration in sediment varied from 4.40 - 10.07 ppm at Syngenta Lake; 2.74 - 3.0 ppm at Khandola Pond; 0.88 - 7.75 ppm at Lotus Lake and 1.05 - 7.93 ppm at Curtorim Lake. According to Khaled (2005), metals enter the aquatic environment through geological weathering and human activities, and due to the removal of topsoil.

Copper enters the aquatic environment through wet and dry depositions, mining activities, and storm water run-offs, industrial, domestic, and agricultural waste disposal. Among industrial sources include copper plating, e-waste, sewage and other forms of waste waters (Jumbe and Nandini, 2009). **Cu** concentration in water varied from 0.04 - 0.40 ppm at Syngenta Lake; 0.03 - 0.20 ppm at Khandola Pond; 0.014 - 1.72 ppm at Lotus Lake; and 0.018 - 1.47 ppm at Curtorim Lake. Highest concentration was found at Lotus Lake while lowest was at Khandola Pond. The maximum permissible range was exceeded as BIS (Bureau of Indian Standards) limit is 0.05 ppm. **Cu** concentration in sediment was recorded as 0.31 - 7.36 ppm at Syngenta Lake; 0.26 - 6.10 ppm at Khandola Pond; 0.02 - 5.14 ppm at Lotus Lake; and 0.24 - 7.29 ppm at Curtorim Lake. WHO guidelines for maximum permissible limit of Copper is 0.05mg/L. The range obtained was higher than the WHO value; hence adverse effects from domestic use are expected (Puttaiah and Bhadravati, 2007).

Nickel is used extensively in Nickel plating and alloy manufacture. High nickel alloys are used in chemical, marine, electrical, oil refining, and other industrial processes (Jumbe and Nandini, 2009). **Ni** concentration in water varied from 0.019 - 0.30 ppm at Syngenta Lake; BDL - 2.50 ppm at Khandola Pond; BDL - 1.32 ppm at Lotus Lake; BDL - 1.40 ppm at Curtorim Lake respectively. Lowest concentration was reported at Syngenta Lake (0.019 ppm) and highest at (2.50 ppm) at Khandola Pond. This was above drinking water standards stipulated for Nickel by WHO (i.e. 0.1ppm). Sediment concentration showed the variations as 0.45 - 2.49 ppm at Syngenta Lake; 1.86 - 9.25 ppm at Khandola Pond; 0.26 - 3.03 ppm at Lotus Lake and 0.52 - 6.41 ppm at Curtorim Lake. Possible sources of Ni in sediment include antropogenic activities, combustion of fossil fuels, old battery wastes, components of automobiles etc (Merian, 1984).

Zinc is an essential nutrient for humans and animals for the functioning of a large number of metallo-enzymes, like alcohol dehydrogenase, alkaline phosphatase etc. (Chambers, and Prepas, 1994). Zn can enter the aquatic environment from a number of sources, including industrial discharges, liquid manure, composted materials, sewage effluent, and agrochemical runoff landfill leachates, urban storm water, poultry sewage, and compost (Boxall *et al.,* 2000). **Zn** concentration in water ranged from 0.09 - 4.45 ppm at Syngenta Lake;0.09 - 3.35 ppm at Kahndola Pond; BDL - 2.52 ppm at Lotus Lake; 0.26 - 0.90 pmm at Curtorim Lake. Highest concentration was reported in Syngenta Lake which exceeded the FAO limit (food and agricultural organization - 2ppm). Sediment of Syngenta Lake showed **Zn** concentration from 0.95 - 8.47 ppm; at Khandola Pond - 0.96 - 5.25 ppm; at Lotus Lake - 0.02 - 3.25 ppm ; while at Curtorim Lake it was 0.41- 3.53 ppm respectively. Sediment of Syngenta Lake showed the maximum concentration of Zinc. In this sampling site Zinc must have been originated from agrochemical sewage from the vicinity.

Lead and its compounds from industrial effluents, sewage sludge, domestic wastes, pigments, petrol (gasoline) additives, steel products, and combustion of fossil fuels are likely to reach the aquatic environment (Fergusson, 1990; Mathew *et al.*, 2003). Lead concentration in water ranged from BDL - 0.16 ppm at Syngenta Lake; BDL - 1.65 ppm at Khandola Pond; BDL - 0.32 ppm at Lotus Lake; BDL - 0.21 ppm at Curtorim Lake. The concentration exceeded the WHO limit of 0.01 ppm. In sediment the concentration varied from 2.71 - 3.32 ppm at Syngenta Lake; 0.76- 3.02 ppm at Khandola Pond;1.45 - 2.11 ppm at Lotus Lake and 0.30 - 2.00 ppm at Curtorim Lake. Highest concentration was seen in Syngenta Lake. Dust holds a huge amount of lead from the combustion fuel may lead to increase Pb content (Hardman *et al*,. 1994).

Positive correlation was observed between trace metals like**:** Mn - Fe, Cu - Fe, Pb - Fe, Mn - Pb, Ni - Pb at **Syngenta Lake,** Mn - Fe, Pb - Cu, Zn - Cu , Ni - Pb, Zn - Pb at **Khandola Pond,** Mn - Cu, Ni - Mn, Ni - Cu, Zn - Cu, Ni - Zn, Pb - Fe, Ni - Pb at **Lotus Lake** and Ni - Fe, Pb - Fe, Zn - Cu, Ni - Pb at **Curtorim Lake** respectively**.**

Chapter 8: To study the restoration measures using phyto remediation process in selected water bodies. (Objective 6)

Methodology: The bioaccumulation factor was calculated according to (Klavins *et al.*, 1998) as follows:

BAF= Metal concentration in plant tissue / Metal concentration in water

Key findings: Bioaccumulation factor for metals analysed (in ppm)

Metal	*Salvinia molesta*	*Eichhornia crassipes*	*Pistia stratiotes*
Fe	2.28	**2.33**	0.77
Mn	**32.32**	7.86	5.4
Cu	1.60	4.12	**5.22**
Ni	**2.51**	1.14	0.03
Zn	**1.07**	0.73	0.85
Pb	**3.06**	2.94	2.48

Observations:

Aquatic plants growing in the study area exhibited variations in trace element concentrations. It was observed that the metal uptake is more during dry season than in the monsoon. Agricultural, industrial and other anthropogenic activities around the study sites have contributed to high levels of metals in the selected water bodies. These metals occur as impurities in fertilizers, metal-based pesticides, compost, manure, solid waste dumped in the water bodies. The absorption of metals depends upon the degree and extent of exposure of the water body to anthropogenic activities, size of the water body, amount of rainfall, life cycle of an exposed plant species and even the age of the sampled plant species from that sampling point. Light intensity, temperature, oxygen and pH also play important role in metal uptake. Selected species of macrophytes were found suitable for phyto remediation process. They may be called as hyperaccumulators of the metals. Absorption of metals was in the following order:-

Fe - *Eichhornia* > *Salvinia*> *Pistia*

Mn - *Salvinia* > *Eichhornia* > *Pistia*

Cu - *Pistia* > *Eichhornia* > *Salvinia*

Ni- *Salvinia* > *Eichhornia* > *Pistia*

Zn - *Salvinia* > *Pistia* > *Eichhornia*

Pb- *Salvinia* > *Eichhornia* > *Pistia*

Chapter 9: Summary

Fresh water bodies provide us with number of environmental benefits. They influence the quality of our life and also strengthen economy. Ground water recharge and conservation of biodiversity are major benefits to human beings from fresh water resources. Many water bodies are used in recreation and tourism; some are sources of drinking water to local residents in the state of Goa. The nutrient load into the selected water bodies has increased and in some cases has gone beyond permissible limits. As a result of increased total maximum daily load, the plankton and macrophyte biomass has accumulated and created nuisance to the people living in surrounding areas.

The main findings of the entire work are summarized as follows:

1. The physico chemical parameters analysed showed seasonal variations in their concentrations.

2. Bio monitoring of the selected water bodies was done using diatoms as ecological indicators suggested that three water bodies namely - Syngenta, Lotus and Curtorim Lakes are eutrophentic while Khandola Pond is mesotrophentic.
3. Indicator species of diatoms for organic pollution *viz., Gomphonema parabolum, Navicula halophila, N. microcephala, N. mutica* and anthropogenic pollution *viz., Amphora ovalis, Stauroneis phoenicenteron, Synedra ulna* were recorded from Syngenta, Lotus and Curtorim Lakes. Indicator species for organic pollution *viz., Navicula mutica* and anthropogenic pollution *viz., Navicula microcephala* were recorded from Khandola Pond.
4. *Navicula halophila, N. mutica, N. radiosa, N. rhynococephala, Synedra ulna, Pinnularia gibba, P. dolosa* and *P. graciloidis* were autochthonous forms and showed high nestedness index.
5. Trace metals were analysed using standard protocols showed seasonal variations.
6. Bioaccumulation factor was calculated for metal accumulation. *Salvinia, Eichhornia, Pistia* proved to be the hyper accumulators of these metals.

From the study it is concluded that these water bodies are important sources of irrigation, their conservation can be done by reducing waste inputs, harvesting biomass, by aeration, by reforestation, de-siltation and most important is by Peoples Participation. Selected water bodies are under anthropogenic stress and their conservation is the need of the hour.

Conferences/Seminars attended

- Presented research paper entitled "Physico-chemical characteristics and diversity of phytoplankton observed in some fresh water bodies of Goa." at 7th International Congress of Environmental Research (ICER 14) at Bangalore jointly organized by R. V. College of Engineering and Journal of Environment Research and Development from 26 -28th December 2014.
- Presented research paper entitled "Biomonitoring of selected freshwater bodies using diatoms as ecological indicators" at 6th International congress on Biodiversity and Conservation held at Dubai UAE from 27th to 28th April 2017.

Research papers published

- Sawaiker, R. U. and B. F. Rodrigues (2016). Physico-chemical Characterisitcs and Phytoplankton diversity in some fresh water bodies of Goa, India. *Journal of Environment Research and Development*, 10(4): 706 - 711.
- Sawaiker, R. U. and B. F. Rodrigues (2017). Biomonitoring of selected freshwater bodies using diatoms as ecological indicators. *Journal of Ecosystem & Ecography* (In Press).

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Prof. B. F. Rodrigues — Guide