SUMMARY

Only 3% of the total water present on earth constitutes fresh water that is utilized by billions of people for agriculture and other purposes. Clean water is essential for human survival as they rely mostly on inland waters including rivers, lakes and wetlands, and to a greater extent on the ground water resources. These sources provide mankind with fisheries, recreation, drinking water and scenic splendor. Pollution and waste generation due to industrialization and population explosion are serious threat to fresh water resources and have resulted in degradation and eutrophication of many fresh water bodies. With a view of understanding the quality of water and pollution status, four fresh water bodies were selected for the present study. Two water bodies located in north Goa (Syngenta Lake and Khandola Pond) and south Goa (Lotus Lake and Curtorim Lake) districts were studied to understand variations in their physico-chemical and biological parameters, besides trace metal contamination and phytoremediation. The selected water bodies differed in size and shape, nature of pollution, aquatic vegetation and usage. Nine physico-chemical parameters *viz.*, pH, temperature, TDS, turbidity, DO, BOD, nitrates, phosphates and total chlorophyll were analyzed on monthly basis for a period of two years from January 2014 to December 2015. Trace metals from water, sediments and aquatic plants were analyzed during pre-monsoon, monsoon and post-monsoon seasons. The analyzed physico-chemical parameters governed growth of a variety of phytoplanktons and macrophytes. The study revealed definite relationship between physico-chemical parameters and phytoplanktons in the selected water bodies. Variations in pH were responsible for the existence of biological life and influenced the biological activity of water microflora. Variation in temperature was responsible for the occurrence of variety and abundance of phytoplanktons. The water temperature played an important role in the solubility and uptake of metals. High TDS concentration resulted in aesthetically unsatisfactory

condition of the water bodies. Turbidity resulted due to the large volume of suspended sediments that reduced the light penetration and depletion of DO in the selected water bodies. DO values were found maximum during rainy season and minimum during summer season. These variations may be due to natural turbulence in the rainy season and active utilization in bacterial decomposition of organic matter. The results of BOD showed significant monthly variations during the study period. BOD was recorded below detectable level at Khandola Pond. Negative correlation was observed between DO and BOD at Syngenta, Lotus and Curtorim Lakes. The growth of phytoplanktons and macrophytes was stimulated mainly by nutrients such as nitrates and phosphates. High amount of chlorophyll was observed during late summer and during October. Significant monthly variations in total chlorophyll were observed during the study period. This is due to an increase in the water temperature that accelerates primary production. The analyses of water quality suggest that most of the parameters are above desirable limits. The Lotus and Curtorim Lakes are influenced by domestic activities, sewage flow, cattle washing by rural communities and small scale industrial effluents, while the Syngenta Lake is affected by organic pollution. Khandola Pond however, is affected to a lesser extent by above anthropogenic stresses.

In all, 15 macrophytes have been identified from the three water bodies, while no macrophytes were recorded from Khandola Pond. *Salvinia molesta, Eichhornia crassipes* and *Pistia stratiotes* were dominant in Syngenta, Lotus and Curtorim Lakes respectively. These plants were selected to study trace metal accumulation and the process of phytoremediation. A total of 125 phytoplanktons were indentified from all the study sites. Seventy four species of Chlorophyceae belonging to 26 genera that dominated all the water bodies were recorded during the study period. Sixteen species of Euglenphyceae belonging to four genera were identified. Of these two species *viz.*

Euglena minuta and *E. oxyuries* were recorded from Khandola Pond. Fourteen species of Cyanophyceae belonging to seven genera were recovered from the study sites out of which only *Chroococcus various* and *Merismopedia* sp. were recorded from Khandola Pond. Twenty one species of Bacillariophyceae belonging to 12 genera were recorded from the study sites. *Cocconeis placentula, Navicula halophila, N. radiosa, N. rhynochocephala, N. mutica* and *Pinnularia dolosa* were found growing in Khandola Pond. Among the four sites, least phytoplankton diversity was recorded from Khandola Pond. This may be attributed to the lesser degree pollution observed in this water body. Diatoms encountered were used for biomonitoring and nestedness study, as they are ubiquitous in habit and are considered key organisms in ecological quality analyses of water. α-mesosaprobous forms were found occurring in Syngenta, Lotus and Curtorim Lakes while β-mesosaprobous forms were recorded from Khandola Pond. Both α- and β-mesosaprobous organisms indicate the presence of moderately polluted water. Trophic state was eutrophentic in Syngenta, Lotus and Curtorim Lakes and mesoeutrophantic in Khandola Pond indicating the deteriorating water quality. This deteriorating water quality of water bodies is mainly because of organic and anthropogenic pollution caused due to disturbances created by human activities such as cattle washing, fishing, unrestricted entry of sewage and effluents from the surrounding residential areas and industries.

From nestedness study it is concluded that, the three Lakes *viz.*, Syngenta, Louts and Curtorim are the most hospitable sites, while Khandola Pond is placed at bottom position in supporting the growth of diatoms. The niche requirements were common for *Navicula halophila, N. mutica, N. radiosa, N. rhynococephala, Synedra ulna, Pinnularia gibba, P. dolosa* and *P. graciloidis.* These forms were present throughout the study period and thus are described as *autochthonous* species. The nestedness

shown by the diatom community was highly significant, even though there were idiosyncratic species like *Gomphonema subtiles, G. parabolum, Pinnularia graciloids, Eunotia tumida, Melosira islandica and Navicula microcephala*. Among the environmental variables analyzed during this study, PCA identified turbidity, temperature, nitrates, and phosphates as principal components that controlled diatom community structure and were possible drivers of nested patterns in the selected water bodies.

Trace metals *viz.*, Fe, Mn, Cu, Ni, Zn and Pb were extracted seasonally from water, sediments and macrophytes to ascertain that whether the selected water bodies are contaminated with these metals and the ability of the naturally growing aquatic macrophytes present in the study sites to absorb them. Three dominant species *viz., S. molesta, E. crassipes* and *P. stratiotes* were selected to compare differences in accumulation of trace metals and to evaluate the suitability of individual plant species in phytoremediation process. Variations were seen in the trace metal concentrations of water and sediments. Concentration of metals in water was higher than the permissible limits of WHO, BIS (Bureau of Indian Standards), FAO (Food and Agricultural Organization), whereas concentration in sediments was either higher or lower than the Sediment Protection Guidelines of MoE, Ontario Canada. Metal concentration in the selected macrophytes was in the following order-

- *Salvinia molesta*: Mn >Fe> Zn >Cu>Ni >Pb
- *Eichhornia crassipes*: Fe>Cu>Mn>Zn>Ni>Pb
- *Pistia stratiotes* : Cu>Mn>Fe> Zn>Pb>Ni

Suitability of selected aquatic macrophytes for trace metal accumulation and their potential to remediate the unhealthy lake ecology was tested by calculating the

bioaccumulation factor (BAF) while capability of metal translocation in their aerial parts was analyzed by calculating Translocation factor (TF).

Aquatic plants growing in the study area exhibited seasonal variations in the uptake of trace element. Study revealed that the metal uptake was more during dry season than in the monsoon. The results showed difference in BAF and TF values which indicated preferential accumulation/uptake and translocation of metals. Both BAF and TF were higher than 1 in selected metal accumulator species. Trace metals form one of largest category of contaminants that are efficiently removed by aquatic plants. Selected plant species studied for phytoremediation accumulated considerable amounts of metals and thus proved to be highly potential for phytoremediation of aquatic bodies contaminated with metal pollution.

Despite few disadvantages, the phytoremediation technology is used as an efficient method for environmental cleaning. With the advancement in the field of genetic recombination technology, genetically engineered plants can be instrumental in the phytoremediation approaches towards environmental cleaning. Future studies are needed to focus on the combined use of more than one phytoremediation approach for the successful remediation of the polluted areas. Fresh water bodies provide number of environmental benefits like replenishing ground water; preserve biodiversity, opportunities for recreation and tourism, source of irrigation, supply water for drinking purpose, *etc*. In a small state like Goa, discharge of nutrient loads into fresh water bodies has increased resulting in their degradation.

Aquatic ecosystems have been heavily influenced by human activity over the years. Lakes have intrinsic ecological and environmental controls in moderating temperatures

that affect micro-climate of the surroundings. To make sustainable use of a lake ecosystem one need to consider integrated approaches like biomonitoring and phytoremediation, and modify the social approach by humans. Water pollution in the State of Goa can be reduced by control of major sources of nutrient loading, phytoremediation and aeration. In order to restore the lakes and to mitigate bad conditions and water quality can be improved by using these technologies. As the main cause of eutrophication is anthropogenic stress, participation of local people is important to combat lake eutrophication. To achieve this success, cooperation between local inhabitants and small scale industries accompanied by reduced P discharge, and farmers who choose agriculture method with reduced P release from the farmland, is essential.

The co-ordinated role of local experts, scientists, NGO's, municipalities and village panchayats, environmentalists and interested citizens can help in the restoration of the lakes. In order to conserve the fresh water bodies there is need for reduction and prevention of water pollution from point and non-point sources. Further research can be carried out by using Remote sensing and GIS, harvesting biomass, reforestation and de-siltation.