LIMNOLOGICAL STUDIES OF WATERBODIES IN GOA

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GOA UNIVERSITY

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IN

BOTANY

BY

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Research Guide

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December 2017

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DECLARATION

I hereby declare that the matter embodied in this thesis entitled **“LIMNOLOGICAL STUDIES OF WATERBODIES IN GOA”** submitted to Goa University, for the award of the degree of **Doctor of Philosophy in Botany** is a record of original and independent work carried out by me during July 2013 - December 2017, under the supervision of Prof. B. F. Rodrigues, Department of Botany, Goa University and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship or any other similar title.

Goa University | **Mrs. Ranjita U. Sawaiker**

December 2017 | Candidate

CERTIFICATE

This is to certify that the thesis entitled "**LIMNOLOGICAL STUDIES OF WATERBODIES IN GOA"** submitted to Goa University, by Mrs. Ranjita U. Sawaiker for the award of the degree of **Doctor of Philosophy in Botany** is a record of original and independent work carried out by her during the period of July 2013 - December 2017, under my supervision and the same has not previously submitted for the award of any degree, diploma, associateship or fellowship or any other similar title.

Goa University | **Prof. B. F. Rodrigues**

December 2017 | (Research Guide)

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Those who are truly grateful are deeply moved by the privilege of living." Auliq

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Ranjita U. Sawaiker

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LIST OF ABRREVATIONS

APDC	Ammonium Pyrorolidene dithio Carbamate
BAF	Bioaccumulation Factor
BDL	Below Detectable Level
BIS	Bureau of Indian Standards
BOD	Biological Oxygen Demand
CCME -WQI	Canadian Council of Ministers for Environment - Water Quality Index
Cu	Copper
$^{\circ}$C	Degree Celsius
DO	Dissolved Oxygen
EWFD	European Water Frame-work Directives
ESA	Ecological Society of America
Fe	Iron
GDWQI	Global Drinking Water Quality Index
$HClO_4$	Perchloric Acid
HCl	Hydrochloric Acid
HF	Hydrofloric acid
HNO_3	Nitric Acid
IDSE	Index of Saprobity - Eutrophication
MIBK	Methyl Isobutyl Ketone
Mn	Manganese
MoE	Ministry of Environment (Ontario Canada)
Ni	Nickel

NGO's	Non Government Organisations
NO_3^-	Nitrate
NSF	National Sanitation Foundation
OWQI	Oregon Water Quality Index
Pb	Lead
PCA	Principal Component Analysis
PO_4-	Phosphates
TC	Total chlorophyll
TDS	Total Dissolved Solids
TF	Translocation Factor
USEPA	United Nation Environment Protection Agency
WHO	World Health Organisation
WQI	Water Quality Index
Zn	Zinc

CHAPTER - 1

Introduction

A necessary feature of sustainable development is to take care of the planet, protect the environment and make proper use of natural resources (Mansourri *et al.*, 2016). Lakes are important ecosystems that provide various services, and stress factors such as eutrophication and climate change threaten their ecological functions (Dornhofer *et al.*, 2016). Ponds, lakes and reservoirs constitute 65% of freshwater ecosystems worldwide and are regarded as vulnerable globally (Tan *et al.*, 2015). Anthropogenic activities degrade freshwater ecosystems thereby affecting ecological integrity and functioning, and subsequently their use for domestic, industrial and agricultural purposes (Venkatachalapathy and Karthikeyan, 2015). Lakes supply water for irrigation, drinking, fisheries, recreation, thus has significant economic and recreational value. Water provides shelter, oxygen, food, nutrients and all other necessary requirements for the growth and maintenance of aquatic communities. In limnetic ecosystems, water quality depends upon physical, chemical, and biological factors (Upadhyay *et al.*, 2012). The quality alters with seasonal variations in temperature, amount of rainfall, transformation and accumulation of biotic matter and agricultural residues (Barman *et al.*, 2015). Water quality has a direct influence on the type and distribution of community. Excessive changes in water quality may threaten the community structure as well as lead to loss of valuable biodiversity. Aquatic resources possess enormous potential to contribute towards remediation of polluted waters (Goswami *et al.*, 2012).

Availability of good quality water is an indispensable feature for preventing disease and improving quality of life. Deterioration in water quality is known to affect human interests directly. Access to safe drinking-water is essential for human health. Thus adequate and potable supply of water must be available to all (WHO, 2011). Suitability of potable water is evaluated using water quality indices (WQI) that serve as tools for management strategies and improvement of water quality. The WQI are numeric expressions used to transform large quantities of ecological data related to water quality into a single number that represents the water quality level (Abbasi, 2002). Monitoring of water quality has the highest priority in Environmental Protection Policy (Simeonov *et al.,* 2002) as it helps to control and minimize the incidence of pollutant-oriented problems, and provides water of appropriate quality for drinking, irrigation, recreation and industry. Traditional approaches to assess water quality are based on a comparison of certain experimentally determined parameters with existing guidelines (Debels *et al.*, 2005). Water Quality Index provides a tool for simplifying the report of water quality data (Liou *et al.,* 2003). The index ranges from 0 to 100 and is widely used to solve problems pertaining to data management. It is also used to evaluate successes and failures in management strategies for improving water quality. A large number of effective indices have been developed to assess water quality data that can be communicated to the general public (Salmoni *et al.*, 2011). The need for clean water is considered as one of the biggest problems of the global environment (Xhelal *et al.*, 2014).

Water quality assessment involves the analysis of physico-chemical, biological and microbiological parameters that reflect the biotic and abiotic status of the ecosystem (Verma *et al.,* 2012). Parameters such as temperature, turbidity, nutrients, hardness, alkalinity, DO are some of the important factors that determine the growth of living organisms in aquatic ecosystems and provide valuable information on water quality (Smitha *et al.*, 2013; Khare and Shukla, 2013). These properties of water help in identification of sources of pollution, for conducting further investigations on the eco-biological impacts and also for initiating necessary steps for remedial actions in case of polluted water bodies (Ekwenye *et al.,* 2008). Over the years discharge of urban, industrial, and agricultural wastes has added the quantum of various harmful chemicals to the water bodies considerably altering their inherent physico-chemical characteristics (Kim *et al.*, 2001). The alteration in physico-chemical parameters leading to eutrophication has become a widely recognized problem of water quality deterioration (Jayakumar *et al.*, 2009). The monitoring of quality in such surface waters by estimating physico-chemical parameters is among the major environmental priorities, as it permits direct assessment of the status of ecosystems that are exposed to deleterious anthropogenic factors (Vandysh, 2004; Kalyoncu and Serbetci, 2013). In the past 50 years, a considerable literature is available to identify impacts and sources of increased nutrient levels on the quality of receiving waters (Smith, 2003).

Ecological studies have shown that chemical measurement reflects water quality at a given time while biological assessment reflects conditions that have existed in a given environment over a long period of time (Odiete *et al.*, 2003). The health of lakes and their biological diversity are directly related to health of almost every component of the ecosystem (Kumar *et al.*, 2011).

Planet earth is endowed with a rich variety of life forms. Water is the principal medium for living beings and the teaming millions of living organisms are the first life forms originated in water (Wetzel, 1995). Aquatic ecosystems are the one of the diverse ecosystems in the world. Water is considered as a universal solvent as it has the ability to dissolve many organic and inorganic compounds (Qureshimatva and Solanki, 2015). The quality of water generally refers to the component of water present at the optimum level that is suitable for the growth of aquatic plants and animals. Aquatic organisms need a healthy environment to live and adequate nutrients for their growth. The productivity of aquatic ecosystem depends on the physico-chemical characteristics of the water body (Agbaire and Obi, 2009). It can be obtained in aquatic ecosystem only when the physico-chemical parameters are present at optimum level (Verma *et al.*, 2012). Phytoplankton communities are widely distributed in aquatic as well as terrestrial ecosystems. In aquatic ecosystems phytoplankton forms the first ring of food chain, affecting the efficiency of this environment (Ozedon, 2013). Phytoplankton composition is a trophic indication of the water mass. In addition, phytoplankton species are used as an indicator for determining the nutrient level which is the basis for preparing and monitoring the strategies towards lake management (Buzzi, 2002). In modern times, phytoplanktons are important as a means of controlling pollution in aquatic ecosystem, bio-fertilizers for crops, in sewage treatment and in purification of eutrophic waters (Kumar *et al.*, 2011). These organisms are very sensitive to the aquatic environment in which they live and any change in the properties of water can cause alteration in their community structure and functioning (Jafri and Gunale, 2006). Therefore, studies on phytoplankton populations serve as a reliable tool in biomonitoring to assess the pollution status of aquatic water bodies (Mathivanan *et al.*, 2007). Among phytoplanktons, diatoms are potential indicators of water quality due to their sensitivity and strong response to physico-chemical and biological changes (Suphan *et al.*, 2012). Fluctuation of diatom species to various environmental changes can be an early indication of freshwater ecological problems and hence small changes in water quality make diatoms very powerful indicators of pollution (Van Dam *et al.*, 1994).

Water is an essential natural resource for sustaining life and is likely to become critically scarce in the coming decades due to continuous increase in demand by a rapidly increasing population and expanding economy of the any nation (Sridhar *et al.*, 2006). Greater emphasis is being laid on its economic use and better management. Unplanned management has resulted in tremendous disarray development of industry, agriculture and disposal of untreated public sewage water, and other human and animal wastes into rivers, lakes and reservoirs. Thus there is a continuous deterioration of water quality and biotic resources (Elmaci *et al.*, 2008).

Hydrobiological study is a pre-requisite in any aquatic system for assessing its potentialities and to understand the differences between trophic levels and food webs. Furthermore, environmental conditions such as topography, water movement, oxygen, temperature and nutrients that characterize particular water mass also determine its biotic composition. Thus, the nature and distribution of flora and fauna in the aquatic system are mainly controlled by the fluctuations in its physico-chemical characteristics (Vijayakumar and Subramaniyan, 2013). Poor water quality is often associated with increased trophic state which in turn disturbs numerous ecosystem services (Meybeck and Helmer, 1996).

Natural eutrophication is a slow and gradual process, occurring over centuries due to nutrient-rich soil washing into lakes. In contrast, human-induced eutrophication can occur over time frames as short as a decade (Addy and Green, 1996). Although it has taken only six decades for anthropogenic influence to turn many freshwater lakes eutrophic, studies suggest that recovery may take 1000 years, even under the best of circumstances (Carpenter and Lathrop, 2008). There are two sources of eutrophication *viz.*, point and non point sources. The term ‘point source’ refers to any visible confined transportation like a channel, a discrete fissure or pipe, a tank *etc.* from which pollutants are leached. ‘Non-point sources’ are grouped into agricultural and live stock runoff, residential and urban runoff (Carpenter *et al.*, 2011). Runoff, especially from urban and agricultural areas, carries fertilizers, pesticides, sediment and/or industrial effluents when discharged into a water body accelerate eutrophication (Smith *et al.*, 1999). Severe eutrophication, often results in hypoxic conditions, disrupting normal food web and ecosystem processes by creating a dead zone where no animal life can sustain (Smaya, 2008).

In recent years, accumulation of trace metals from natural sources and anthropogenic activities in the aquatic ecosystem has become a major problem throughout the world. These metals may accumulate to toxic levels and can cause severe impact on the aquatic organisms without any visible sign (Giguere *et al.*, 2004). Trace metals occur at very low levels in a given system and are among the most harmful of the elemental pollutants (Lee *et al.*, 2007). Trace elements such as copper (Cu), iron (Fe), chromium (Cr), manganese (Mn), zinc (Zn) and nickel (Ni) are essential metals since these elements play important roles in biological systems, whereas cadmium (Cd) and lead (Pb) are non-essential metals, and are toxic, even in trace amounts (Fernandes *et al.*, 2008). These metals or their compounds discharged from industries, farmlands, municipal urban water runoffs and agricultural activities enter into surface water. Trace Metals may also enter into aquatic system through leaching of rocks, airborne dust, forest fires and vegetation (Fernandez, 2000). Metal pollutants when compared with other aquatic pollutants, are less visible but their effects on the ecosystem and humans are extensive due to their toxicity and ability to accumulate in the aquatic organisms (Edem *et al*., 2008). Due to slow degradation, metals are continuously being deposited and incorporated in water, sediment and aquatic organisms (Linnik, 2000). During transportation, metals undergo numerous changes due to dissolution, precipitation, sorption and complexation phenomena which affect their bioavailability (Akcay *et al.*, 2003; Nicolau *et al*., 2006). Thus, contamination with metals may cause devastating effects on the ecological balance of aquatic environments and the diversity of aquatic organisms (Suziki *et al.,* 1988). Metals are bio-concentrated or bio-accumulated in one or several compartments across food webs (Otitoloju and Don-Pedro, 2004).

Metal bio-accumulation can be of importance from the public health point of view, especially for humans at the end of food chain. An important link in the transfer of metals from soil/sediment to man is plants (Lozak *et al.,* 2001). The distribution of metals in sediments can provide evidence of the anthropogenic impact on aquatic ecosystems and therefore aid in assessing the risks associated with discharged waste (Tsai, 2003). The entry of metallic pollutants into a water body, either natural or artificial, can occur in dissolved and particulate form. Depending on physico-chemical conditions, the pollutants in dissolved form can precipitate. Some of the widely used metals include automobiles, mining industries, pesticides, house-hold appliances, dental amalgams, paints, photographic papers and photo chemicals (Hutchinson *et al.,* 1993). Some metals are also essential as micronutrients for life processes in animals and plants. Concentrations of trace elements in water vary due to physiological, environmental and other factors. Bio-accumulation of metals can take place only when the rate of uptake by the organism exceeds the rate of elimination, and may cause cytotoxic, mutagenic and carcinogenic effects in the organism. Measurement of trace metal concentrations in water helps the evaluation of water quality. The concentration of pollutants in an aquatic environment depends upon the chemical composition of sediment as well as the type and amount of absorbed pollutants (Chambers and Prepas, 1994).

Environmentally benign and sustainable biological measures have become attractive options for the *in situ* remediation of polluted surface waters (Wu *et al.,* 2014). The distribution and behaviour of many aquatic macrophytes are often correlated with water quality (Romero and Onaindia, 1995). Detecting environmental pollution by using biological material is a cheap, reliable and simple alternative to the conventional sampling methods (Zurayk *et al.*, 2001). A number of organisms such as mosses, periphyton, fish and vascular plants have been successfully used in remediation of water bodies (Porvari, 1995). Aquatic macrophytes accumulate considerable amounts of heavy metals in their tissues and are proposed as pollution-monitoring organisms (Shine *et al.*, 1998). Metal bio-accumulation depends upon numerous biotic and abiotic factors, such as temperature, pH and dissolved ions in water (Lewander *et al.*, 1996).

Aquatic macrophytes play a role in oxygen production, nutrient cycling, water quality control, and sediment stabilization. These plants play important role in providing habitat and shelter for aquatic life and are considered as efficient heavy metal accumulators. As a result they have been successfully used as biological monitors and remediates of environments contaminated with heavy metals (Vardanyan and Ingole, 2006). Phytoremediation is considered an effective, low cost and preferred clean-up option for moderately contaminated areas. Although the capacity of aquatic macrophytes to accumulate metals is well documented their potential to accumulate heavy metals differs markedly among species (Demirezen and Aksoy, 2004). Uptake and accumulation of elements by plants may follow two different paths, *i.e.* the root system and the foliar surface (Sawidis *et al.*, 2001). Plant species vary in their capability to remove and accumulate heavy metals. Some species may accumulate specific heavy metals, such as the *Spirodela polyrhiza* is known to accumulate Zn (Markert, 1993).

Macrophytes act as good bio-filters by accumulating heavy metals from the surrounding environment and also have the tendency to bio-accumulate heavy metal residues present in water or the sediment stratum. All these released pollutants have a great ecological impact on the water quality and especially on environmental resistance of aquatic macrophytes. According to Ikem *et al.* (2003) sediments are important sinks for various pollutants like heavy metals and play a significant role in the remobilization of contaminants in aquatic systems under favourable conditions and in interactions between water and sediment. Unlike organic pollutants, natural processes of decomposition do not remove heavy metals. Instead they accumulate in aquatic biota and can be converted to organic complexes, which may be even more toxic (Edward *et al.,* 1998).

According to the Indian environmental managers and researchers the condition of freshwater resources in India and their management as a serious environmental problem which includes nutrition enrichment, acidification, domestic and agricultural waste, sewage and industrial effluents (Parashar *et al.,* 2008; Laskar and Susmita, 2009). Almost 70% of surface and ground water reserves in India have been contaminated by biological, organic and inorganic wastes (Shekhar *et al.,* 2008).

Standing water bodies in Goa and in the country in general are used for various activities *viz.,* fishery management, recreation and drinking purpose. There is an urgent need to conserve these water bodies in the interest of mankind for ecological, cultural and touristic purposes. As these water bodies are important in various ways, it is imperative as well as challenging to assess their present status and to study pollution problems associated with them. Despite human interference, freshwater systems have hardly been studied in the state of Goa. In light of this lacuna, present study was initiated in selected water bodies with the following aims and objectives.

Aims and objectives:

1. To survey the sources of eutrophication of water bodies in Goa,
2. To determine physical, chemical and biological characteristics of water body and to identify their trophic status,
3. To study seasonal variations in water quality parameters in the water bodies as affected by pollutants,
4. To survey macrophytes and phytoplanktons from polluted and non polluted water bodies,
5. To analyze trace metals present in water bodies and their accumulation by aquatic macrophytes and
6. To study restoration measures using phytoremediation process in selected water bodies.

CHAPTER - 2

Review of Literature

2.1: General limnology

Water is called elixir of life and its importance was realized way back in 640-546 B.C. Limnology deals with the structural and functional interrelationships of organisms of inland waters as their dynamic physical, chemical, and biotic environments affect them. The pioneering work in limnology was initiated by Forel (1869) on Lake Geneva and published a list of bottom fauna. Hence he is regarded as the '*Father of Modern Limnology*' as he gave an impetus to study this subject intensively. Forbes (1887) worked on Lake Microcosm and described interaction between biota and environmental factors. The above studies laid a firm foundation for Limnology and Hydrobiology. First Fresh Water Biological station was established by Fritsch (1888), to study various lakes, as a result of which limnology flourished in Europe and America. A number of reports are available on Limnobiotic studies of water. Different physico-chemical parameters of surface water yielded useful data towards understanding of the nature of water environment and the changes that occur due to intense human interference. Broad based ecological assessment of fresh water ecosystems with interdisciplinary approach has been followed by many limnologists. Literature on ecology of fresh water systems is available in the reviews (Alley, 1949; Hutchinson, 1957). In India limnological studies were initiated in 1930's. Extensive work has been carried on fresh water reservoirs (Pruthi, 1933; Iyangar, 1940; Bhardwaja, 1940; Gonsalves and Joshi, 1946; Rao, 1953; Gulati ans Wurtz, 1980).

In recent years, increase in human population, demand for food, land conversion, and use of fertilizer have led to faster degradation of many freshwater resources (Jayakumar *et al.*, 2009; Venkata Subba, 2012). Urban, industrial, and agricultural wastes have altered physico-chemical characteristics of water bodies (Kim *et al.*, 2001). The monitoring of quality of such surface waters by estimating physico-chemical parameters is among the major environmental priorities (Vandysh, 2004).

2.2: Physico chemical and diversity studies

Victor Hensen's discovery of plankton in 1887 opened up a new vista in the field of limnology. West and West (1907), Hodgetts (1921) and Pearsall (1921) published a detailed account of the factors controlling the periodicity of fresh water algae. Storm (1924), Howland and Lucy (1931) and Yoshimura (1932) studied several fresh water lakes with respect to various parameters and distribution of phytoplanktons. Fritsch and Rich (1937) recorded 14 new species and 25 new varieties of desmids, from Belfast Pan in Pretoria, among which unicellular forms were present in abundance, while filamentous forms were relatively scarce. Objectionable phytoplanktons and their control in lakes were dealt by Prescott (1938) and reported that nitrates, phosphates, oxidizable organic matter and pH were responsible for their distribution. Bailey (1938) studied the ecology of phytoplankton of Lake Michigan and reported that the diatoms showed considerable seasonal variation especially *Synedra*. Gonzalves and Joshi (1946) worked on the seasonal occurrence of algae in a tank at Bandra, Mumbai and recorded four new taxa. Patrick (1948) studied the factors affecting distribution of diatoms and reported that the chemical and physical analyses of the sediments corresponded with the changes indicated by diatom communities. Thresh *et al.* (1949) analyzed chloride of surface waters and attributed its higher amounts to chloride to pollution. Krishnamurthy (1954) worked on the diatomic flora of south Indian lakes and recorded four new diatoms species. Gandhi (1955) studied and identified various species of fresh water diatoms *viz.*, *Achnanthes elata*, *Achnanthes fasciata*, *Ceratoneis iyengarii*, *Cymbella powaiana*, *Diploneis subsmithii* and *Eunotia cholnokyi* from Pratabgad, Rajastan. Singh

(1960) recorded the phytoplankton ecology of inland waters of Uttar Pradesh and attributed high percentage of Euglenophyceae to high amount of carbon di-oxide. George (1966) made a comparative study of phytoplankton ecology of fish tanks from Delhi and reported that compared to temperate waters, the tanks in Delhi showed richer variety of organisms. The largest number of genera was noted among the green algae. Desmids were poorly represented in the tanks. Munnawar and Zafar (1967) studied the distributional pattern of phytoplanktons of polluted and unpolluted lakes of Hyderabad and pointed out the importance of chemical parameters and their impact on algal growth. Bharathi and Hosmani (1973) made an extensive survey of hydrobiology of ponds and lakes of Dharwad and observed that heavily polluted ponds showed decreased production during summer, and recorded different species of algae that appeared as blooms. Dellon and Rigler (1975) studied correlation between total N, P and phytoplanktons and concluded that these two nutrients were important for algal blooms. Bharathi and Hosmani (1976) studied and reported that increased P, Ca, low pH and high degree of organic pollution accelerated the bloom of Cyanophyceae. Singh and Swamp (1979) studied Lake Surah (Ballia) with special reference to the periodicity of sewage contamination on fresh water ecosystems. The Central Amazon Lakes were analyzed for physico-chemical and microbiological parameters by Rai and Hill (1982) and classified them as oligotrophic and eutrophic, based on the bacterial density, electrical conductivity, pH, dissolved, oxygen, silica and P content. Koschel *et al.* (1983) while studying Lake Breiber in Germany pointed out that calcite precipitation decreases the phytoplankton population DO and total phosphates. Raina *et al.* (1984) pointed out that nutrients like nitrates and phosphates play an important role in determining the trophic status of water bodies. Zutshi *et al.* (1984) revealed that low DO in Dal Lake was related to enhance microbial activity and increased rate of decomposition. Chtranshi and Bilgram (1986) investigated lentic ecosystems stressing importance of physico-chemical parameters in relation to the distribution pattern of phytoplanktons. Singh and Mahajan (1987) investigated the primary production in Ox-bow Lake and recorded that high temperature coupled with higher concentrations of P enhanced the rate of reproduction of *Microcystis aeruginosa*.

Puttaiah and Somasheker (1987) observed that high concentrations of carbon dioxide and low concentrations of oxygen significantly contributed to the abundance of Euglenoids in fresh waters of Mysore. Kurata and Yuji (1987) studied seasonal changes of various physico-chemical parameters in Lake Notoro, in Japan. The relationship between phytoplankton density in fish ponds and the level of DO at dawn was demonstrated by Daniel and Piedrahita (1988). Their study suggested that aqua culturists can raise DO levels by increasing algal biomass and not by reducing it.

Ikommikov (1990) observed that Ladoge Lake in Russia was polluted due to increased discharge of toxic substances that caused water quality deterioration, changes in species composition and other deleterious effects on the aquatic ecosystem.

Goel *et al.* (1994) reported that P and N ratio enhances the growth of blue green algae. Shaji and Patel (1994) highlighted phytoplankton ecology of a polluted pond at Anand in Gujarat and stressed that the physico-chemical parameters were responsible for increasing the phytoplankton populations. Boris *et al.* (1996) reported toxicity of Cyanobacterial blooms in Lake Lodoga formed by *Anabaena circinalis, A. flosaquae, A. lemmemani, Gleotrichia cichimilata and Microcystis aeruginosa*. Takans and Hino (1997) opined that high temperature promoted growth of diatoms in a hypertrophic Lake Barato in Japan. The importance of P in eutrophication of fresh waters and production of abundant phytoplanktons mainly by Cyanophyceae members was discussed by Correl (1998).

According to the study of Yoh *et al.* (1999) to succeed in combating Lake Eutrophication, cooperation of local inhabitants, small factories and farmers in reducing P discharge is essential. But the willingness of each one to cooperate would depend on the cooperation of other members and on the level of environmental concern of the society in general. They observed that the lake pollution increases with the total P released due to any of the above activities, and results in high pollution level in the lake. They reported that, with a greater cooperation among the people the water can remain clean.

Frank *et al.* (1999) studied the medium shallow Lake Grimnitzsee in Germany and characterized the lake as eutrophic. The Lake was restored by fast recovery of silicon concentration in the water column after diatom sedimentation, the re-suspension of planktonic diatom populations was implemented, after which there was moderate correlation between chlorophyll a concentration and light attenuation. Borse and Bhave (2000) analyzed dissolved carbon dioxide from a lake near Jalgaon and reported that it was maximum in summer and minimum in winter and was dependent on carbonates and bicarbonate levels in the water. They also observed that carbon dioxide and pH of water also had an impact on the water quality.

Nandan *et al.* (2001) studied seasonal fluctuation at Hertala Lake in Jalgaon and reported abundance of blue green algae was due to higher concentration of dissolved carbon dioxide, carbonates, total alkalinity, phosphates and chlorides. Nagarathna and Hosmani (2002) studied the factors influencing the bloom of *Nitzschia obtuse* in a polluted lake in Mysore. Correlation matrix and cluster analysis indicated that most of the physico-chemical parameters were inversely proportional to the growth of diatoms. Nandan and Aher (2005) assessed water quality of Haranbaree Dam in Maharastra using algal communities and recorded pollution tolerant genera like *Navicula, Oscillatoria* and *Euglena*. Mukhopadhyay and Dewanji (2005) investigated relationship between species of hydrophytes and Secchi disc visibility, pH, dissolved oxygen, electrical conductivity, total N, total P and chlorophyll-a concentration in two tropical ponds near Kolkata. They reported that *Alternanthera philoxeroides, Nymphoides hydrophylla, Lemna aequinoctialis,* and *Vallisneria spiralis* were dominant species that were found to subsist over wide amplitude of nutrient levels thereby showing their adaptability to highly eutrophic ecosystems.

Ranjani *et al.* (2007) studied physico-chemical characteristics of Ghariyarwara Pond in Nepal and observed dominance of Chlorophyceae throughout the year and seasonal variations in the other phytoplankton populations. Shiddamallayya and Pratima (2008) studied water quality of tank in Bhalki town of Bidar by analyzing pH, DO, hardness, Mg, chlorine, nitrite, sulphates and chemical oxygen demand. They observed positive co-relation between pH and Mg, DO and hardness. The study revealed that pH, hardness, silicon, total solids and sulphates were key factors that changed the chemistry of the water body.

Boyera *et al.* (2009) studied conditions like circulation, salinity, water quality patterns, sediments and disturbance in nutrients that frequently caused dense phytoplankton blooms of Florida Bay and in turn altered the structure and function of the estuary. Phytoplankton diversity in four lakes of Satara District in Maharashtra was investigated by Bhosale *et al.* (2010). They recorded 68 species of phytoplanktons and 13 species of filamentous algae belonging to Cyanophyceae, Chlorophyceae, Euglenophyceae, Dinophyceae, and Bacillariophyceae.

Suresh *et al.* (2011) studied two fresh water tanks from Davangere district in Karnataka to know the phytoplankton diversity and reported that, Bathi tank had low while Kundavada tank had high diversity of phytoplankton. Verma *et al.* (2011) studied physico-chemical parameters along with phytoplanktons of Kankaria Lake in Gujrat and reported that maximum number of physical and chemical parameters were within the desirable limit of WHO. Ladipo *et al.* (2011) studied the seasonal and spatial distributions of physico-chemical parameters to determine water quality in Lagos Lagoon. The study revealed that strong seasonal variation was the major controlling factor in the lagoon.

Studies of nutrient load and other limnological parameters of Sabke reservoir, Katsina state was analysed by Bala and Bolorunduro (2011). Except transparency, DO, pH, TDS and Nitrate values indicated significant variation between rainy and dry season. Vasanthkumar and Vijaykumar (2011) recorded diurnal variations in physico-chemical parameters of Bheema River and concluded that it is oligotrophic in nature.

Seasonal changes in water quality parameters of a rain fed Lake in Aurangabad were investigated by Smarat *et al.* (2012). They reported that total alkalinity and phosphates were beyond the permissible limits. Water quality and phytoplankton diversity from Gopeswar Temple Pond in Assam, was investigated by Baruah and Kakati (2012). They recorded 45 species of phytoplanktons representing Chlorophyceae, Cyanophyceae, Bacillariophyceae, Euglenophyceae, Chrysophyceae and Dinophyceae members and recorded phytoplankton population peaks in summer and monsoon periods. They also reported the presence of *Microcystis aeruginosa* and *Navicula cryptocephala* throughout the year indicating cultural eutrophication.

Algal flora in Kodaikanal Lake was studied by Singh and Balasingh (2012) and recorded 59 genera and 115 species of phytoplanktons, belonging to Chlorophyceae, Bacillariophyceae, Cyanophyceae, Dinophyceae, Euglenophyceae and Chrysophyceae. Rani and Sivakumar (2012) studied seasonal variations in phytoplankton population in three perennial ponds in Tamil Nadu and revealed that physico-chemical parameters influenced growth of phytoplanktons. Patel and Patel (2012) made a comparative study of the physico-chemical parameters of Lake Lodra and Lake Nardipur in Gujarat. Their study revealed that the both lakes were polluted due to anthropogenic activities.

Chandra *et al.* (2012) assessed drinking water quality of Porur Lake in Chennai, Hussain Sagar Lake in Hyderabad and Vihar Lake in Mumbai for various physico-chemical parameters. They reported that the parameters studied were manifold higher than the prescribed limit by the WHO & BIS standard. Saxena (2012) studied water quality and trophic status of Raipur Reservoir and placed it in meso-eutrophic category. Namdeo *et al.* (2013) made ecological evaluation of the physico-chemical characteristics in Barna Reservoir in Central India. Their study revealed that the ecology of Barna reservoir in different seasons showed dynamism in physico-chemical parameters which is attributed to factors like fertilizers, weathering of rocks and meteorological phenomenon in the catchment area.

Rashmi and Somashekar (2013) recorded phytoplankton diversity of Lakkinakoppa Pond Shivamogga. They reported 54 species of phytoplanktons belonging to the four major classes *viz.*, Bacillariophyceae, Chlorophyceae, Cyanophyceae and

Euglenophyceae that occurred throughout the study period. Ayyanna and Narayudu (2013) carried out hydrological study of fresh water Pond at Kakinada village, of Venkatapuram. The study revealed that the parameters were within permissible limits and the water was found suitable for domestic, irrigational and Pisciculture purpose. Patil *et al.* (2013) analyzed physico-chemical parameters of fresh water reservoir near Khanapur, Maharastra and reported that all the parameters were within permissible limits indicating that the water from reservoir was suitable for drinking and fishing purpose.

Kaparapu and Rao (2013) studied seasonal variations, correlation coefficient and biodiversity indices of phytoplankton of Riwada reservoir, in Andhra Pradesh. They reported 57 genera belonging to Chlorophyceae, Bacillariophyceae, Cyanophyceae and Euglenophyceae. Their study revealed that the reservoir had balanced phytoplankton community. Verma *et al.* (2013) studied physico-chemical parameters of Kankaria Lake in Gujarat and indicated that maximum number of physical and chemical parameters were within the desirable limit. Devi *et al.* (2013) studied limnological status of two temple ponds in Assam and revealed that rainfall, conductivity, water temperature and free carbon dioxide were responsible for variability in the plankton community.

Mahadik and Jadhav (2014) studied algal diversity of Ujani reservoir. They reported 75 species of phytoplanktons belonging to Chlorophyceae, Charophyceae, Bacillariophyceae and Cyanophyceae. Singh (2014) studied seasonal variations in the physico-chemical parameters of Gomti River in Lucknow and reported deteriorating water quality and unsuitability of water for domestic use. According to Hosmani (2014) climatic changes and variations in the physico-chemical constituents of the water are responsible for algal blooms. Mahesh *et al.* (2014) assessed trophic state of Dantaramakki Lake in Mysore using GIS technique and reported that the lake revealed mesotrophic state in February and March, and eutrophic state in April.

2.3: Biomonitoring and Nestedness analysis

Bere and Tundisi, (2010) studied the role of diatoms in the biological monitoring and stated promising future for using diatoms in characterization and monitoring of ecological conditions. Kalyoncu and Serbetci (2013) used OMNIDIA program for estimation of stream quality in Turkey and found that only a few diatom taxa indicated alfa-mesosaprobity and polysaprobity. Hosmani (2013) studied 20 Lakes of southern Karnataka using Palmer's index and reported that all the lakes were organically polluted. Bere *et al.* (2014) tested the applicability of diatom-based water quality assessment indices to urban streams in Zimbabwe and found that diatom indices exhibited consistent classifications and strong correlations with water quality variables.

Kavya and Savitha (2014) used OMNIDIA GB 5.3 software to study the degradation of two Lakes in Mysore. They reported that the diversity of Bacillariophyceae was considerably high in Karanji Lake when compared to Kukkarahalli Lake as a result of anthropogenic pollution. Nautiyal *et al.* (2015) examined the ecological status of epilithic diatom assemblages of Mandakini, a glacier-fed Himalayan river using OMNIDIA GB 5.3 software. The ecological values revealed that the assemblages were in β-mesosaprobic and mésotraphentic states.

Dalu *et al.* (2016) assessed the water quality of a river in Africa using diatom indices calculated by OMNIDIA software and reported non significant correlations between the diatom index values and nutrient concentrations. Venkatachalapathy and Karthikeyan (2016) used diatoms as bio-indicators to assess the water quality of surface waters and concluded that diatom indices can be a reliable tool for environmental impact assessment.

The concept of nestedness was proposed by Hulten (1937) to describe patterns of species composition within arctic and boreal biota. Atmar and Patterson (1993) studied species distribution patterns within habitat and method of identifying idiosyncratic species in a nested community in an archipelago. Matthews (2004) investigated the floras of 56 sedge meadow wetlands in northern Illinois (USA) to find the degree of nestedness in these communities and concluded that the nested pattern was closely related to site. Derek *et al*. (2004) studied whether habitat could produce a subset pattern of community structure and observed that nested subset pattern is a result of an ontogenetic habitat.

Joppa *et al.* (2010) stated that ecological networks are unusually nested when compared with loosely constrained random networks. Soininen *et al.* (2011) analyzed nestedness of diatom communities in freshwaters within a drainage basin in Helsinki and concluded that degree of nestedness was related mainly to water temperature, conductivity, and trophic status of the water, results suggested that habitat quality may be an important predictor of nestedness.

Karthick *et al.* (2011) studied nestedness pattern of stream diatoms in Central Western Ghats and found that the nested pattern by diatom community was highly significant, with high proportion of idiosyncratic and cosmopolitan species.

2.4: Trace metal contamination and accumulation of metals by aquatic macrophytes

Sobczynski and Siepak (2001) reported results of speciation analysis of selected heavy metals in bottom sediment samples from lakes in Wielkopolski National Park in Poland. Results revealed that Zn, Pb, Cd and Mn were found in higher amounts while Fe and Cu did not occur in any of the lakes. Agnieszka (2004) analyzed heavy metals and macronutrients from water, bottom sediments and leaves of *Nymphaea alba* and *Nuphar lutea* sampled from 14 eutrophic lakes in West Poland. The study revealed that the concentrations of macro- and micro-elements in the examined plants differed significantly and were dependent on chemical properties of the water and bottom sediments. The study also revealed that both the plants had the potential to monitor for these metals. Odjegba and Fasidi (2004) reported that *Pistia stratiotes* accumulates Hg and Zn. It was observed the concentration of accumulated metals was higher in root tissue rather than in shoot and concluded that the plant as effective phytoremediator species for the above metals.

Kumar *et al.* (2006) carried out biomonitoring study using 7 species *viz., Bergia odorata, Hydrilla verticillata, Ipomoea aquatica, Najas graminea, Nelumbo nucifera, Phragmites karka* and *Typha angustata* of Nal Sarovar Bird Sanctuary in Gujarat to ascertain the degree of trace element contamination. More accumulation in root was recorded than in the stem or leaves. Positive correlation between combinations of different metal-pairs was observed and the metal concentration varied as Zn> Cu > Ni > Co > Pb > Cd.

Vardanyan and Ingole (2006) analysed 45 macrophytes belonging to 8 families collected from two different physiographic locations *viz.*, Sevan Lake Armenia and

Carambolim Lake, Goa, India. Study revealed that the aquatic macrophytes play a very significant role in removing the different metals from the ambient environments thereby reducing the effect of high concentration of heavy metals from the Lake ecosystem. Sabine *et al.* (2006) reported that the most serious problems caused by eutrophication of shallow lakes in Germany are the disappearance of submerged macrophytes and the switch to a turbid, phytoplankton-dominated state. According to them if the concentration of total P is reduced it would result in increase water clarity. Vestena *et al.* (2007) studied Cd accumulation in *Eichhornia crassipes* and *Salvinia auriculata* and reported that both species were Cd accumulators.

Mishra *et al.* (2008) employed three aquatic plants *viz., Eichhornia crassipes, Lemna minor* and *Spirodela polyrhhiza* for the removal of heavy metals from coal mining effluents. Results revealed that combination of *E. crassipes* and *L. minor* was the most efficient for the removal of heavy metals while *E. crassipes* was the most efficient in monoculture. Translocation factor for metal concentration revealed that metals were largely retained in the roots of aquatic macrophytes. Analytical results showed that plant roots accumulated heavy metals approximately 10 times of its initial concentration present in the effluent. It was also reported that, these plants did not show metal toxicity symptoms when subjected to toxicity assessment therefore found to be suitable in phytoremediation of coal effluents.

Hillermannova *et al.* (2008) compared differences in the accumulation of trace metals by the individual groups of aquatic plants (submerged and emergent) and assessed a possible use of the individual plant species in phytoremediation techniques. Representative samples of water, sediments and aquatic macrophytes were taken from three anthropogenically loaded streams in six monitoring cycles. *Phalaroides* *arundinacea*, *Scirpus silvaticus* and *Rumex aquaticus* were analyzed for metal contents. The results of the research indicated that the accumulation of trace metals in plants was influenced by their ecological group (emergent – submerged). Submerged plants accumulated more amounts of metals as compared to emergent ones.

Dhir (2009) studied the capacity of *Salvinia natans* to accumulate heavy metals, inorganic nutrients, explosives from wastewaters and reported that *Salvinia natans* has properties such as high productivity, high sorption capacity and high metal removal potential and hence can be used in phytoremediation strategies. Abida *et al.* (2009) analyzed heavy metal concentration in water, sediments and fish from Madivala Lake. Heavy metal concentration, in water was in the order Pb > Cr > Cd > Ni, while in sediments it was Pb > Cr > Cd > Ni. The maximum concentration of heavy metals was found in kidney and liver, the order of heavy metal level in various organs is muscle >gills >liver >kidney. The presence of elevated levels of Pb and Cd was a concern as the fish from the Lake was consumed by local residents around the area.

Millaleo *et al.* (2010) stated that Mn is an essential element for plants, intervening in metabolic processes, like photosynthesis and as an enzyme antioxidant-cofactor. Its phytotoxicity is manifested in a reduction of biomass and photosynthesis, and biochemical disorders such as oxidative stress, under low pH and redox potential conditions in the soil. It is also reported that though Mn is an essential micronutrient it is toxic plants when present in higher concentrations. Xi *et al.* (2010) successfully demonstrated the use *Eichhornia crassipes* in treatment of swine waste water for N and P reduction.

Hariprasad and Dayananda (2011) reviewed the research articles pertaining to the uptake of heavy metal by plants through contaminated soil, their accumulation and potential threat to animal and human health. It was reported that the heavy metals in water bodies damage the aquatic organisms. Wei and Guihua (2011) reviewed articles pertaining to Fe as an essential element, its environmental impacts on physiology and ecology of aquatic organisms, sources, speciation, cycle and uptake mechanisms as well as its impact of on physiology and ecology of phytoplankton and aquatic plants in freshwater lakes. Othman *et al.* (2011) found that all six aquatic plant species *viz., Eichhornia crassipes, Hydrilla verticillata, Cabomba fuscata, Salvinia natans, Nelumbo nucifera* and *Pistia stratiotes* showed potential as ecological indicator for unhealthy aquatic ecosystems or as phytoindicator for heavy metal contaminants by accumulating Ar, Cu, Pb and Zn.

Christophe *et al.* (2011) carried out toxic metals assessment of Nokoue Lake by analyzing water and sediments samples and reported that Pb and Ar concentrations were higher. Roy and Kalita (2011) carried out analysis of heavy metals having estrogenic properties from three different sites around Guwahati city and concluded that the estrogenic heavy metal concentration in water was in the order Pb>Cr>Ni>Hg>Cd.

Thilakar *et al.* (2012) used aquatic macrophytes such as *Pistia stratiotes* L. and *Salvinia natans* (L.) in trace metal accumulation and phytoremediation of Cr and Cu contaminated aquatic environment. Their study revealed that both these species are ‘hyperaccumulators’ and can be effectively used in phytoremediation. Nirmal Kumar *et al.* (2012) studied heavy metal accumulation by *Nelumbo nucifera* Gaerth, *Typha angustata* Bory Chaub, *Ipomoea aquatica* Forsk and *Hydrilla verticillata* (L.f.) Royle, and also their concentration in water and sediment in a freshwater wetland (Varasda) in Central Gujarat. Their study revealed that trace metals in water increased after religious activities like idol immersion during post-monsoon.

Vahdati and Khara (2012) evaluated the concentration of heavy metals released by the urban, industrial and agricultural activities in Anzali lagoon. Also analyzed lead and cadmium accumulation in *Hydrocotyl eranocloides*, and *Ceratophyllum demersum*. The results revealed that amount of the absorption were significant in the stem of *Hydrocotyle*. Malik and Biswas (2012) stated that due to rapid industrialization, modern agriculture and other anthropogenic activities, heavy metal pollution in soil and water has become a serious threat to the human and animal health.

Siriwan *et al.* (2006) and Wolff *et al*. (2012) studied the toxicity and accumulation of heavy metals, Cd and Pb in two aquatic ferns, *viz., Salvinia cucullata* and *S. auriculata*. The roots of *S. cucullata* showed higher Cd and Pb contents than leaves suggesting that the metals were bound to the root cells and were partially transported to the leaves. *Salvinia auriculata* showed accumulation of Cd from polluted aquatic ecosystems. The results suggested that *S. auriculata* showed good potential for use as a bioindicator and it can be used in the biomonitoring of aquatic ecosystems contaminated by Cd.

Nsikak *et al.* (2013) reviewed speciation analysis of metals in sediments of aquatic ecosystems and agro systems. They suggested that speciation analysis should be adopted while conducting the assessment of trace metals in order to obtain useful information on species differing in accumulation potential of metals. Ekpo *et al*. (2013) investigated heavy metal concentrations in water, sediments and fish from Akampa area in Nigeria and reported that water and sediment samples showed higher concentrations of the studied metals that were above the WHO standards in water. They also reported bioaccumulation of metals in *Heterotis niloticus, Oreochromis niloticus* and *Clarias gariepicus*.

Loveson *et al.* (2013) successfully demonstrated the efficiency of duckweed, *Spirodela polyrrhiza* in improving the quality of two polluted wetlands of Eloor industrial area, in Kerala. Chiodi *et al.* (2015) studied heavy metal accumulation in different macrophytes by calculating the bioaccumulation factor and reported the trend of metal accumulation in shoots was in the order as *Lemna gibba>Potamogeton pectinatus>Ceratophyllum demersum>Eichhornia crassipes >Najas armata>Pragmites australis*. Ugya *et al*. (2015) used *Pistia stratiotes* for removal of heavy metals *viz.*, Hg, Cd, Mn, Ag, Pb, Zn from a stream polluted by waste water. The Bioconcentration (BCF) and Biotranslocation (BTF) Factors of each metals analyzed were determined. Study showed that *Pistia stratiotes* is a suitable candidate for effective removal of these heavy metals.

Das *et al.* (2016) studied the potential of *Eichhornia crassipes* for Cd remediation in a hydroponic system and observed high tolerance and accumulation capabilities. Rai and Singh (2016) discussed the benefits of using *Eichhornia crassipes* as cost-effective and eco-friendly in accumulation and absorption of the heavy metals from aquatic bodies, biofuel and biogas production through fermentation and decomposition and fertilizer production through composting/vermicomposting. George and Gabriel (2017) investigated the heavy metal decontaminating activity of *Salvinia molesta* from municipal waste water. Their study revealed that *S. molesta* was efficient in reducing the heavy metal concentration in the waste water.

CHAPTER - 3

To survey the sources of eutrophication of water bodies in Goa.

3.1: INTRODUCTION

Good quality water is an essential requisite of all living organisms to carry out daily activities. Severe alterations in water quality may prove harmful, leading to the death of aquatic organisms. Because of human negligence the quality of water is gradually deteriorating (Virendra *et al.*, 2013). Industries have grown enormously throughout the world in the past few decades. As a result resources have been overexploited to fulfill the increasing demand of human civilization, resulting in pollution of water, land, and air.

About 70% of water pollution in India is due to the release of domestic waste into water bodies (Gaikwad *et al.*, 2004). Improper management of water systems has caused serious problems in the availability of drinking water (Subba, 1995). When waste from industry is discharged without proper treatment into water, the physical, chemical and biological characteristics are altered to make it unsuitable for human use (Sachidanandamurthy and Yajurvedi, 2006). Physical and chemical parameters like light, temperature, DO, nitrates and phosphates influence the levels of primary productivity, affecting trophic structure and total biomass of the aquatic food web (Wetzel, 1975). There are enormous challenges in the water resources protection and water safety management fields. Lake eutrophication has become a global environmental issue (Smith, 2003). Washing of nutrient rich soil into water bodies leads to eutrophication over a period of time (Smith, 2003). Cultural eutrophication is caused by human land use, including agriculture and industrial developments. Sewage, agriculture, and small scale industries increase nutrient input in watersheds and the amount of input varies according to the types of human activity in each watershed (Smith and Schindler, 2009). The combination of these effects causes a rapid growth of phytoplanktons and aquatic macrophytes. Regular application of chemical fertilizers and P-laden manure has resulted in the gradual accumulation of P in soil, which enters into lakes resulting freshwater eutrophication (Bumb and Baanante, 1996).

According to literature reports, water bodies throughout the world are polluted due to urban runoff, septic tank leachete, and agricultural runoff and dumping of waste, *etc.* Many fresh water bodies in Goa are used as a source of irrigation, recreation and for drinking water. It is imperative to investigate and point out how best the water bodies from different places could be utilized for the benefit of local residents. Such studies are of great importance as they are concerned with basic sanitary and health problems of people residing in the vicinity of the water bodies. Present survey aimed in finding out if similar conditions existed in the state of Goa leading to water pollution. In this chapter, detailed observations are recorded from a survey study and an attempt to identify the sources of eutrophication of water bodies in Goa.

3.2: MATERIALS AND METHODS

Different fresh water bodies situated in the state of Goa *viz.*, Benaulim, Carmbolim, Khandola, Marcela, Keri, Madkai, Ponda, Sulabhat, Curtorim, Macasana, Shiroda, Mayem and Canacona were surveyed to assess their present status. Photographs of different sources responsible for water pollution were taken during the visits. Based on this survey study, two water bodies each from north and south Goa were chosen to evaluate their usefulness based on physico-chemical and biological properties.

3.3: OBSERVATIONS AND DISCUSSION

It was observed that in Goa there are many small scale industries in the vicinity of water bodies releasing waste water into the water bodies thereby causing pollution. Activities like boating, immersion of idols during festivals, dumping of solid waste, leachete from septic tank, washing of vehicles, bathing of domestic animals and washing of clothes, were commonly observed during the survey. These activities resulted in declining the water quality and affecting aesthetic beauty of several water bodies. Besides this industrial, agricultural, livestock, residential, urban and mining runoff from surrounding areas was also responsible for water pollution **(Plate 1)**.

The degradation of urban lakes due to septic tank leachete is a common phenomenon in the state. The factors regulating the composition of aquatic microbial community is useful in predicting the persistence and behaviour of human, animal and plant pathogens in natural water (Yigal *et al.,* 1989). Water contaminated with fecal matter poses serious health risks for fish consumers and swimmers. Microbial pathogens are introduced into waters bodies in various ways, like leakage of septic tanks, sewer malfunction, contaminated storm drains, runoff from animal feedlots, human fecal discharge and other sources (Aslan- Yilmaz *et al.,* 2004). Enumeration of fecal coliforms, *Escherichia coli* and */or Enterococcus sp.* is used to assess microbial water quality. These micro-organisms can inhabit the intestines of warm-blooded animals, (Chou *et al.,* 2004) and are responsible for intestinal infections, such as dysentery, typhoid and cholera. Thus the water becomes unfit for domestic or agricultural purposes.

Plate 1

Plate 1

Sources of Water pollution in the state

A. Growth of macrophytes at Syngenta Lake.

B. Dumping of food waste in Curtorim Lake.

C. and **D**. A film of greasy layer due to dumping of pollutants at Maitolem (Macasana) Lake.

E and **F**. Dumping of waste at Carambolim Lake.

G and **H**. Runoff from industries and agricultural sites to lakes in Kundai and Mardol area.

Agricultural activities in Goa are involving excess use of fertilizers and pesticides to enhance productivity (Alvares, 1993). This has threatened the ground and surface water on a large scale. The waters and soils continue to be polluted, when necessary precautions are not taken during usage of chemicals (Tulay, 2010). Increased use of fertilizers has also resulted in nitrate pollution in many places (Alvares, 1993). The use of water with high nitrate level for drinking purposes reduces the oxygen carrying capacity of the blood and can lead to ***methemoglobinaemia*** in babies (Smith *et al.*, 1971). Many agricultural activities involve use of organic materials, such as farm manures or composts that contain higher concentration of trace elements. The use of bio-solids and composts increases the total amount of Cu, Zn, Pb, Cd, Fe and Mn in soils (He *et al.,* 2005).

Human-induced pollution through excessive fertilizer use, untreated wastewater effluents, deforestation results in stripping of top soil. Besides mining activities and use of detergents has significantly increased nutrient load into lakes in Goa, accelerating eutrophication beyond natural levels (Alvares, 1993). These loads are responsible for deleterious changes in the natural ecosystem. Excessive biological productivity in water bodies has inflicted significant environmental and societal damage to fresh water systems in the state. Hypoxic conditions are known to result when plants and algae die and decompose stripping water of dissolved oxygen, leading to fish kills and degrading the aesthetic and recreational value of the lake thereby disrupting the normal food webs in lakes (Ecological Society of America, 2008).

Heavy monsoon runoff from the open cast mining carries washings of reject material into water bodies. Besides, there is widespread pollution of water systems due to percolation, pollution and disruption of water table.

CHAPTER - 4

To determine physical, chemical and biological characteristics of water bodies and to study seasonal variations in water quality of selected water bodies as affected by pollutants.

4.1: INTRODUCTION

Limnological investigations are aimed to assess the water quality and its interaction with biotic and abiotic factors. The role of water in nature is unique, as animals and plants have large percentages of water in their make-up required for their sustenance. Physico-chemical properties of freshwater bodies are characterized by the climatic, geochemical, geo-morphological and pollution conditions. Besides, physico-chemical properties also influence biological productivity of the water body. Physical parameters of water quality such as turbidity, conductivity and water mass influence the chemical nature of water and greatly affect its biota (Gupte and Nisar, 2013). Large scale urban growth and migration of people from rural to urban areas, besides industrial development and other activities have resulted in generation of industrial effluents (Verma and Saksena, 2010). Due to contamination of water bodies the trophic status changes and renders them unsuitable for human use. Hence, regular monitoring of these factors is essential to determine the status of water body. These factors in turn are greatly influenced and modified by climate and vegetation of a particular place (Garg *et al.,* 2006). Control of pollutant-oriented problems for providing good quality water to serve various purposes such as drinking, irrigation, recreational and, industrial and to protect the valuable freshwater resources to safeguard public health can be done by monitoring water quality (Bartram *et al.,* 2002). It is very important to test the water quality before it is used. Selection of parameters for testing of water solely depends on the purpose for which it will be used (Mushini *et al.,* 2012). Water contains variety of floating, dissolved, suspended, microbiological as well as bacteriological impurities. Physical and chemical parameters are to be analyzed for the physical appearance of water and to know the degree of contamination by various pollutants respectively (Singh and Singh, 2008). The concept of Water Quality Index (WQI) is based on the comparison of the water quality parameters with respective to regulatory standards and assesses appropriateness of the quality of the water for a variety of uses such as habitat for aquatic life, irrigation, recreation, drinking water *etc.* (Cude, 2001; Abbasi, 2002). Canadian Water Quality Index which is also known as Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) is being used by many countries all over the world and has also been endorsed by United Nations Environmental Program (UNEP) in 2007 as a model for Global Drinking Water Quality Index (GDWQI).

Goa is the smallest state situated in the coastal region of India **(Fig. 1)**. It encompasses an area of 3,702 km^2. It lies between the Latitudes 14°53′54″ N and 15°40′00″ N and Longitudes 73°40′33″ E and 74°20′13″ E **(Fig. 2)**. Goa features a tropical monsoon climate and being near Arabian Sea, it is hot and humid throughout the year. The month of May is usually the hottest, seeing daytime temperatures of over 35 °C. There are three seasons *viz.*, monsoon (June - September), post-monsoon (October - January) and pre-monsoon (February - May). Over 90% of the average annual rainfall (120 inches) is received during the monsoon season. The state is divided into two districts *viz.* north Goa and south Goa. The different types of aquatic ecosystems in the state include wetlands, estuarine, marine, lakes, ponds, rivers and springs. Water pollution is one of the environmental issues in Goa and largest source of water pollution is untreated sewage, along with agricultural runoff and unregulated small scale industry. Studies on the ecological status and pollution levels of fresh water bodies in the state are scanty. Hence in the present study pH, temperature, total dissolved solids, turbidity, DO, BOD, nitrates (NO_3), phosphates (PO_4^-) and total chlorophyll were analyzed to understand their seasonal variations and to know the trophic status of selected water bodies.

Fig.1: Map of India showing location of Goa.

Fig.2: Map of Goa showing location of study sites.

4.2: MATERIALS AND METHODS

4.2.1: Study sites and description

Two water bodies each from North Goa (Syngenta Lake and Khandola Pond) and South Goa (Lotus Lake and Curtorim Lake) were selected for the study. Analysis of water samples was carried out on monthly basis from January 2014 to December 2015.

i. **Syngenta Lake** is in the premises of M/s Syngenta Agro Chemicals at Corlim in Tiswadi taluka located on the banks of Cumbarjua canal situated between 15.5^{o} N Latitude 73.94^{o}E Longitudes **(Fig. 3)**.

ii. **Khandola Pond** is situated between 15.5^{o}N Latitude and 73.9^{o}E Longitude at Marcela in Ponda taluka. It is a source of irrigation to areca nut plantation existing in the surrounding areas **(Fig. 4)**.

iii. **Lotus lake** is situated between 15.2^{o}N Latitude and 73.9^{o}E Longitude at Benaulim in Salcete taluka. The lake is polluted and has abundant growth of aquatic weeds **(Fig. 5)**.

iv. **Curtorim Lake** is situated between 15.2^{o}N Latitude and 74.0^{o}E Longitude at Curtorim in Salcete taluka. Lake is a source of irrigation for paddy crop **(Fig. 6)**.

Samples collected on monthly basis were used for analysis of following parameters:

4.2.2: pH

pH of water samples was measured using digital pH meter.

4.2.3: Temperature

Temperature was recorded using a thermometer.

Fig.3: Location of Syngenta Lake, Corlim Goa.

Fig.4: Location of Khandola Pond, Marcela Goa.

Fig.5: Location of Lotus Lake, Benaulim Goa.

Fig.6: Location of Curtorim Lake, Curtorim Goa.

4.2.4: Total Dissolved Solids

Total dissolved solids were analyzed by gravimetric method (APHA, 2012).

Method:

For analyzing the total dissolved solids, a dried, pre-weighed evaporating dish was taken in which 100 ml filtered sample was poured. The clear filtrate was evaporated at 180^0C for 1h. The dish was cooled in a desiccator and final weight was recorded.

Calculation:

TDS mg/L = $(W_2 – W_1)$ x 1000 / Sample volume (ml)

Where; W_1 - initial weight of dish; W_2 - final weight of dish.

4.2.5: Turbidity

Turidity of the water samples was measured using Turbidity meter.

4.2.6: Dissolved oxygen (DO)

DO was analyzed by using Winkler's Method **(**APHA, 2012).

Method:

The sample was filled in glass stopper BOD bottle avoiding any kind of bubbling. To this 2ml of $MnSO_4$ and 2ml of alkaline KI was added. Brown precipitate formed was allowed to settle. To this, 2ml of conc. H_2SO_4 was added to dissolve the precipitate. The contents (50ml) were titrated against 0.025N sodium thiosulphate till straw yellow colour appeared. To this, 1 ml of starch was added as an indicator. Titration was continued till the blue colour disappeared.

Calculation:

DO mg/L = (ml x N) of sodium thiosulphate x 8 x 1000 / $V_2 (V_1 – v) / V_1$

Where: V_1 - Volume of sample bottle = 300 ml; V_2 - Volume of contents titrated = 50 ml; v - Volume of $MnSO_4$ and KI added (2 + 2) = 4 ml

4.2.7: Biological Oxygen Demand (BOD)

BOD test (5 day) - Titration method using sodium thiosulphate **(**APHA, 2012).

Method:

One liter dilution water was prepared in a glass container by bubbling distilled water for 24 h. To this 1 ml each of phosphate buffer, magnesium sulphate, calcium chloride, and ferric chloride solutions were added. pH was neutralized to 7 by using 1N NaOH or H_2SO_4. Two sets were prepared. One of the set was kept in BOD incubator for 5 days at 20^{o}C while DO of other set was determined immediately. After 5 days incubation period the DO of the other set was analyzed. Similarly a blank set was prepared by taking two BOD bottles for dilution water. Of one bottle DO was determined immediately and where as the other was subjected to incubator for 5 days along with the sample.

Calculation:

BOD mg/L = (D_0 – D_5) x dilution factor

Where: D_0 - initial DO; D_5 - final DO

4.2.8: Nitrates

Nitrates were determined by Spectrophotometer using stock nitrate solution (PDA method) (Rao, 1988).

Method:

Standard curve was prepared using concentrations from 0 to 1mg/L of stock nitrate solution (KNO_3) at an interval of 0.1 mg/L. Absorbance of standards was read at 410 nm. For sample analysis, 50 ml of filtered sample was evaporated in porcelain basin to dryness. It was cooled and the residue was dissolved in phenol disulphonic acid. The contents were diluted to 50 ml by adding distilled water and 6 ml of liquid ammonia was added to develop yellow color. OD was taken at 410 nm.

4.2.9: Phosphates

Phosphates were determined by using stannous chloride method **(**APHA, 2012).

Method:

Standard curve was prepared by using concentrations from 0 to 5 mg L^{-1} of standard phosphate solution (K_2HPO_4), 50 ml of each solution was taken to which 2 ml of ammonium molybdate and 5 drops of $SnCl_2$ were added. Blue colour appeared after adding these chemicals. OD was recorded at 690 nm. Same procedure was repeated for 50 ml of filtered sample. A blank set was also prepared in above manner.

4.2.10: Total chlorophyll

Total chlorophyll was estimated by using Arnon's method (Arnon, 1949).

Method:

500 ml of sample was concentrated in a centrifuge at 500 rpm for 1 minute and the palate was transferred to mortar and pestle. Pinch of $MgCO_3$ and 2 - 3 ml of acetone (90%) were added. The contents were ground thoroughly and kept for 4 - 6 h for the pigment to elute. The extract was decanted and final volume was made upto10 ml by adding acetone (90%). Absorbance was recorded at 664, 647 and 630 nm.

Calculations:

C_a = 11.85 (absorbance 664) -1.54 (absorbance 647) - 0.08 (absorbance 630).

C_b = 21.03 (absorbance 647) - 5.43 (absorbance 664) - 2.66 (absorbance 630).

C_c = 24.52 (absorbance 630) - 7.60 (absorbance 647) - 1.67 (absorbance 664).

4.3: The Canadian Council of Ministries of the Environment (CCME, WQI 2001)

Calculation of the Index was done by using CCME Water Quality Index 1.0 user's manual. CCME WQI (Water Quality Index) allows one to evaluate surface water quality for the purpose of protection of aquatic life with the help of certain guidelines. The index method was initially proposed by Horton (1965). Since then, the formulation and use of indices has been strongly advocated by agencies responsible for water supply and control of water pollution. The CCME WQI is calculated based on the formula developed by the British Columbia Ministry of Environment, Lands and Parks (CCME, 2001). The Index incorporates three elements:

a) **Scope:** Expresses the percentage of parameters for which at least one measurement did not comply with the corresponding guideline during the period of study.

   F_1 (Scope) = Number of failed parameters/ Total number of parameters x100

b) **Frequency:** Represents the number of times these objectives are not met.

   F_2= Number of failed results/ total number of results x100

c) **Amplitude:** Represents the difference between non compliant analytical results and the guidelines to which they refer.

   F_3 = nse / 0.01 X nse +0.01

Where nse is normalized sum excursions.

The index produces a number between – 0 (worst water quality) and 100 (best water quality). These numbers are divided into 5 descriptive categories to simplify presentation. The CCME WQI of the selected water bodies was determined, using CCME WQI calculator. Data pertaining to physico-chemical parameters like temperature, turbidity, TDS, DO, BOD, nitrates, and phosphates were used to determine the water quality of the selected study sites.

4.4 Statistical analysis:

4.4.1: One way ANNOVA and Tukey's (HSD) Post Hoc Test

Analysis of Variance (ANOVA): Data generated during the study period was subjected to VASSAR STATS for testing one way ANOVA.

4.4.2: Principal Component Analysis (PCA): PCA was carried out using PAST software.

4.4.3: Pearson's correlation matrix:

Data pertaining to physico-chemical parameters and phytoplankton count was analyzed for Pearson's Correlation matrix, using SPPSS - 19 software.

4.5: RESULTS AND DISCUSSION

Results of physico-chemical analysis of water samples are tabulated in **Tables 1 to 9,** while the monthly variations recorded are graphically represented in **Figures 7 to 15**.

4.5.1: pH

The pH of water in the selected water bodies undertaken for the study ranged from 5.9 to 7.8. Variations in pH were recorded in all the water bodies studied. The pH in Syngenta Lake varied from 5.9 to 6.8, Khandola Pond varied from 6.0 to 7.1, Lotus Lake ranged from 5.9 to 7.8 while at Curtorim Lake it ranged from 5.5 to 7.2 **(Table 1; Fig. 7)**. The variations recorded in phytoplankton diversity may be attributed to the changing pH levels. Physico-chemical and biological characteristics of water bodies are known to influence each other (Verma and Mohanty, 1995). The pH range of 5.0 to 8.5 is reported to be ideal for phytoplankton growth (Robert *et al.*, 1974). As pH levels

Table 1: Variations in pH of selected water bodies.

pH				
Months	**Syngenta Lake**	**Khandola Pond**	**Lotus Lake**	**Curtorim Lake**
Jan’14	6.1	7.1	7.8	6.8
Feb’14	5.9	6.1	6.6	6.9
Mar’14	6.2	6.0	6.4	6.7
Apr’14	6.2	6.1	6.0	6.9
May’14	6.3	6.0	5.9	6.7
June’14	6.4	6.8	6.0	7.6
July’14	6.8	6.4	6.7	7.6
Aug’14	6.4	6.2	6.0	7.6
Sept’14	6.2	6.4	6.5	7.5
Oct’14	6.0	6.4	6.0	7.6
Nov’14	6.5	6.4	6.6	6.4
Dec’14	6.7	6.4	6.0	6.9
Jan’15	6.1	7.1	6.8	6.6
Feb’15	6.0	6.1	6.6	6.7
Mar’15	6.2	6.1	6.4	7.1
Apr’15	6.2	6.1	6.0	6.7
May’15	5.9	6.0	5.8	6.8
June’15	6.2	6.1	6.0	6.7
July’15	6.2	6.3	6.7	6.6
Aug’15	6.4	6.2	6.7	6.6
Sept’15	6.4	6.4	6.0	6.5
Oct’15	6.3	6.3	5.4	6.1
Nov’15	6.1	6.4	6.2	5.4
Dec’15	6.3	6.4	6.5	6.3

Legend: Values are average of three readings.

move away from this range it causes stress in the systems of aquatic organisms and reduces survival rates. Apart from organisms, extreme pH levels increases the solubility of nutrients such as P, N, C and certain heavy metals like Pb, Cu, Cd, become more mobile thereby increase the risk of absorption by aquatic life. Metals tend to be more toxic at lower pH because they are more soluble in acidic waters (Ramachandra and Solanki, 2007). In fresh waters, low pH affects the phytoplanktons due to the dissolution of salts, while high pH causes discolouration of their cells. High pH levels impart bitter taste to water. Most natural changes occur due to interactions with surrounding rock and other materials. pH can also fluctuate with precipitation and wastewater or mining discharges. In addition, CO_2 concentrations can influence pH levels. (http://water.epa.gov/type/rsl/monitoring/vms54.cfm).

4.5.2: Temperature

The water temperature at the study sites varied from 25^oC to 31^oC **(Table 2; Fig. 8)**. Maximum temperature was recorded in May (late summer and early rainy season) and minimum in January (winter season). Water temperature plays an important role in controlling the occurrence and abundance of phytoplanktons (Nanzeen, 1980). The seasonal change of productivity is related to variation in temperature and photic conditions (Sondergaard and Sand, 1979). Water temperature has been called as ‘abiotic master’ factor due to its effect on aquatic organisms (Brett, 1971). It influences many other parameters and can alter the physical and chemical properties of water as it affects the metabolic rates and biological activity of aquatic organisms (Wetzel, 2001). Fluctuations in temperature can affect the behaviour of aquatic organisms, such as moving to warmer or cooler water after feeding, predator-prey responses and resting or migrating routines. Algal photosynthesis increases with temperature, although different

Table 2: Variations in Temperature of selected water bodies.

Temperature (^{0}C)				
Months	**Syngenta Lake**	**Khandola Pond**	**Lotus Lake**	**Curtorim Lake**
Jan’14	25.0	25.0	25.5	25.5
Feb’14	28.0	28.0	29.0	29.0
Mar’14	28.0	28.0	29.0	29.0
Apr’14	30.0	30.0	30.0	30.0
May’14	31.0	31.0	31.0	31.0
June’14	30.8	30.8	30.0	30.0
July’14	28.4	30.8	30.0	30.0
Aug’14	27.4	28.4	26.2	26.2
Sept’14	28.4	27.4	28.4	28.4
Oct’14	29.0	28.4	29.0	29.0
Nov’14	29.0	29.0	29.0	29.0
Dec’14	28.0	28.0	28.0	28.0
Jan’15	23.0	23.0	25.0	25.0
Feb’15	25.0	25.0	29.0	29.0
Mar’15	29.0	29.0	29.0	29.0
Apr’15	30.0	30.0	30.0	30.0
May’15	32.0	32.0	32.0	32.0
June’15	31.0	31.0	31.0	31.0
July’15	28.0	28.2	30.0	30.0
Aug’15	27.5	27.5	26.0	26.0
Sept’15	28.0	28.1	28.4	28.4
Oct’15	29.0	29.0	29.1	29.0
Nov’15	29.0	29.0	29.0	29.1
Dec’15	28.0	28.0	28.4	31.0

Legend: Values are average of three readings.

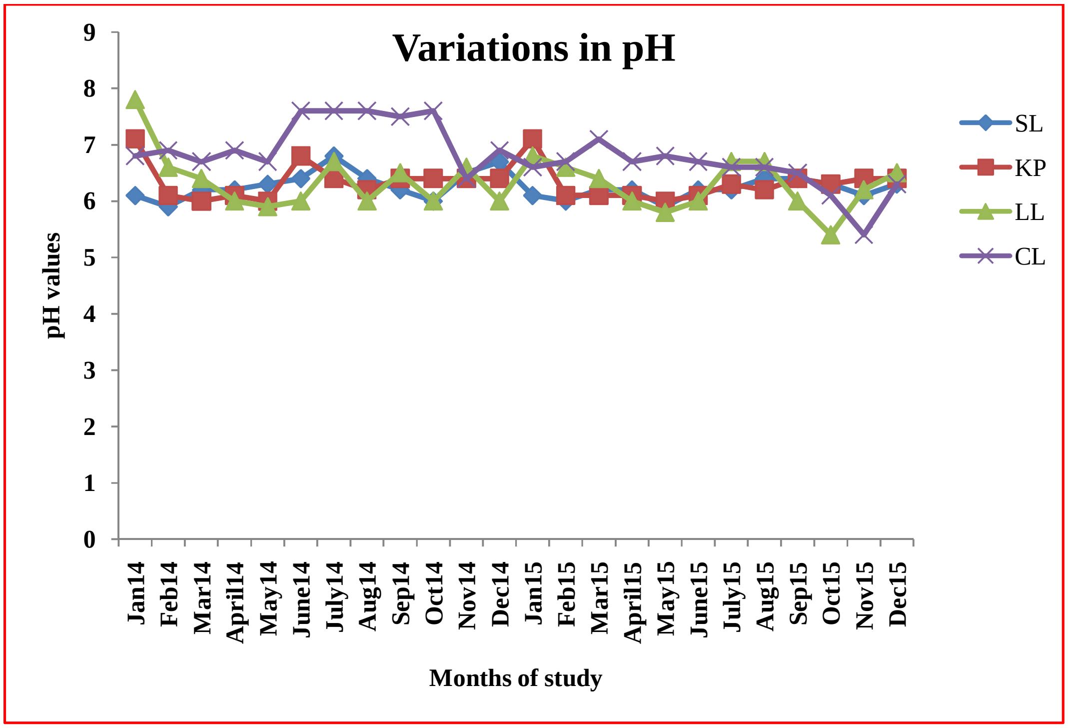

Fig. 7: Variations in pH of selected water bodies.

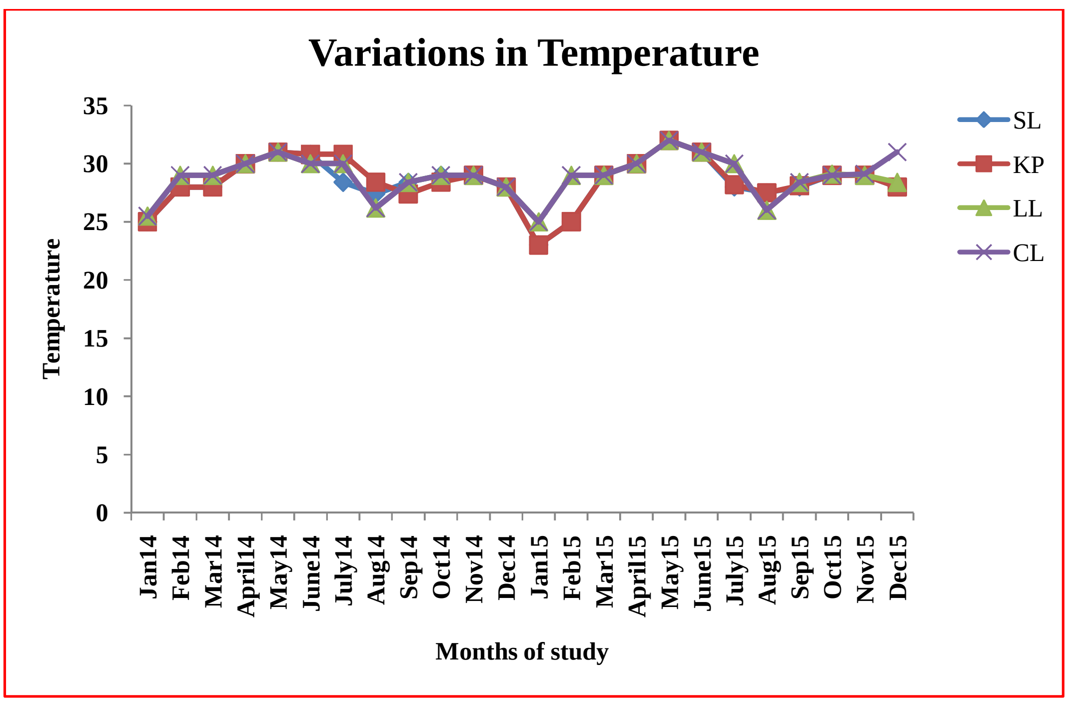

Fig. 8: Variations in Temperature of selected water bodies.

Legend: SL = Syngenta Lake; KP = Khandola Pond; LL = Lotus Lake; CL = Curtorim Lake.

species have different peak temperatures for optimum photosynthetic activity. Algal blooms are resulted due to increase in water temperature (Spencer and King, 1989). The solubility of oxygen and other gases decreases as temperature increases hence colder lakes can hold more dissolved oxygen than warmer waters (http://ga.water.usgs.gov/edu/temperature.html). Water temperature can be affected by conditions like sunlight, heat transfer from the atmosphere and turbidity.

Shallow and surface waters are more easily influenced by these factors than deep water (http://www.ess.uci.edu/~cpasquer/classes/ess130/notes/lec18.pdf). In polluted water, temperature can have profound effects on DO and BOD. All metabolic and physiological activities, process like reproduction, movement, distribution of aquatic organisms are greatly influenced by water temperature (Gupta and Sharma, 1993).

4.5.3: Total Dissolved Solids (TDS)

The TDS were least at Khandola Pond (32.60 to 51.45 mg L^{-1}), followed by Syngenta Lake (604 to745 mg L^{-1}), Lotus Lake (616 to 1078 mg L^{-1}) and were maximum at Curtorim Lake (922 to 1389 mg L^{-1}) **(Table 3; Fig. 9)**. Beeton (1965), attributed an increase in TDS in St. Lawrence Great Lakes to cultural eutrophication and suggested the separation of Oligotrophic (TDS<100 ppm) and Eutrophic (TDS>100 ppm) lakes based on TDS values. Increase in TDS above 100 ppm in Syngenta, Lotus and Curtorim Lakes indicate cultural eutrophication. Higher values of TDS are due to contamination of domestic waste water, garbage, fertilizers, *etc.* (Verma *et al.*, 2013). During the present study maximum amounts of TDS were recorded in monsoon and minimum in post-monsoon and pre-monsoon. Depending on the ionic properties, excessive TDS can produce toxic effects on fish. They can also affect water taste and

Table 3: Variations in Total Dissolved Solids of selected water bodies.

TDS(mg/L)				
Months	**Syngenta Lake**	**Khandola Pond**	**Lotus Lake**	**Curtorim Lake**
Jan'14	620.0	41.2	616.5	1124.0
Feb'14	745.0	49.6	673.2	1207.0
Mar'14	685.0	40.2	782.0	1308.0
Apr'14	634.0	43.7	968.0	1240.0
May'14	645.0	51.5	997.0	1285.0
June'14	621.0	38.7	962.0	1389.0
July'14	687.0	32.6	1078.0	1317.0
Aug'14	606.0	47.6	910.0	1210.0
Sept'14	616.0	50.2	825.0	1118.0
Oct'14	604.0	49.3	845.0	922.0
Nov'14	560.0	41.0	785.0	971.0
Dec'14	538.0	40.4	726.0	1104.0
Jan'15	614.0	43.2	735.0	1135.0
Feb'15	645.0	41.0	682.2	1076.0
Mar'15	668.0	40.2	698.0	1108.0
Apr'15	698.0	46.7	784.0	1140.0
May'15	665.0	54.4	708.0	1295.0
June'15	681.0	39.7	662.0	1395.0
July'15	692.0	36.2	1209.0	1457.0
Aug'15	742.0	49.8	1410.0	1465.0
Sept'15	767.0	52.7	1120.0	1308.0
Oct'15	694.0	47.3	975.0	1220.0
Nov'15	660.0	42.1	878.0	1107.0
Dec'15	638.0	39.4	786.0	1285.0

Legend: Values are average of three readings.

often indicates high alkalinity or hardness (Thompson, 2006). With high amounts of suspended solids water becomes aesthetically unsatisfactory for bathing and its palatability becomes inferior (Ramchandra and Solanki, 2007).

4.5.4: Turbidity

Turbidity measurements are used as an indicator of water quality based on clarity and estimated total suspended solids in water. Higher turbidity levels were recorded during monsoon while low values were recorded during post-monsoon. The values ranged from 22 to 53 NTU in Syngenta Lake, 15.4 to 31 NTU in Khandola Pond, 29 to 54.78 NTU in Lotus Lake and 26 to 56.7 NTU in Curtorim Lake **(Table 4; Fig. 10)**. Increased turbidity levels in monsoon may be due to rainfall and surface runoff of water bringing sediments from the surrounding area. Similar observations have been recorded in earlier (Saxena *et al.,* 1966). High turbidity levels can diminish visibility and often feeding behaviours, in addition to physically harming aquatic life. The suspended solids may disrupt the natural movements and migrations of aquatic populations. Heavy rainfall affects water flow, which in turn affects turbidity. In mine areas where construction activities are on, wind can blow dust, sediment and other particles into the water (Ansari and Prakash, 2000).

4.5.5: Dissolved Oxygen (DO)

DO is an important parameter in assessing water quality because of its influence on the organisms living within a waterbody. In limnology, DO is an essential factor as high or low level can harm aquatic life and affect water quality (Wetzel, 2001). DO levels ranged between 6.01 to 12.06 mg L^{-1} at Syngenta Lake, 7.20 to 11.97 mg L^{-1} at

Table 4: Variations in Turbidity of selected water bodies.

Turbidity (NTU)				
Months	**Syngenta Lake**	**Khandola Pond**	**Lotus Lake**	**Curtorim Lake**
Jan'14	22.0	17.2	29.0	26.0
Feb'14	28.0	19.0	33.0	32.0
Mar'14	34.0	18.0	33.0	33.0
Apr'14	42.0	18.4	38.0	33.0
May'14	49.0	18.7	42.0	34.0
June'14	46.0	16.4	37.4	35.0
July'14	48.0	24.3	43.0	42.0
Aug'14	51.0	30.4	52.7	45.0
Sept'14	46.0	27.2	42.1	41.0
Oct'14	41.0	21.3	37.2	37.0
Nov'14	37.0	17.7	31.2	32.0
Dec'14	33.0	14.4	29.8	29.0
Jan'15	29.0	17.2	31.0	27.5
Feb'15	26.0	18.0	37.0	34.0
Mar'15	34.0	18.0	43.0	36.0
Apr'15	42.0	18.4	48.0	37.3
May'15	49.0	18.7	52.0	41.0
June'15	48.0	16.4	53.4	45.0
July'15	51.0	28.3	48.0	54.0
Aug'15	53.0	31.0	54.7	56.7
Sept'15	47.0	28.2	52.1	41.3
Oct'15	43.0	23.3	48.7	39.0
Nov'15	41.0	18.7	41.2	35.6
Dec'15	39.0	15.4	39.5	34.0

Legend: Values are average of three readings.

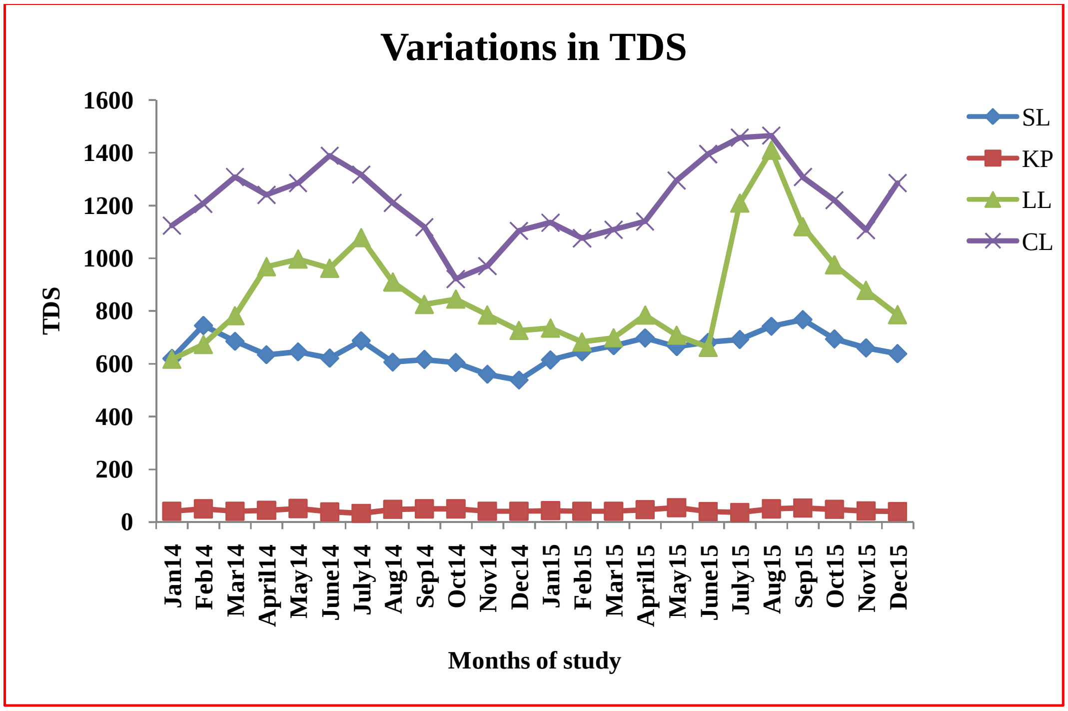

Fig. 9: Variations in TDS of selected water bodies.

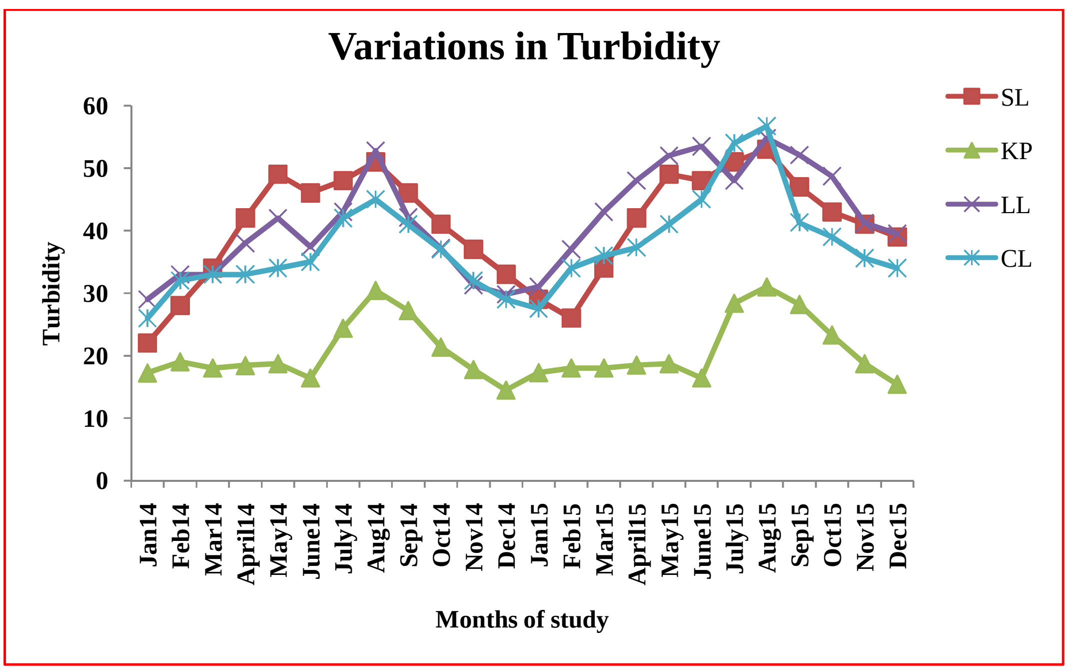

Fig. 10: Variations in Turbidity of selected water bodies.

Legend: SL = Syngenta Lake; KP = Khandola Pond; LL = Lotus Lake; CL = Curtorim Lake; TDS = Total dissolved solids.

Khandola Pond, 5.68 to 10.30 mg L^{-1} at Lotus Lake and 8.14 to 12.77 mg L^{-1} at Curtorim Lake **(Table 5; Fig. 11)**. DO values were maximum during rainy season and minimum during summer season. These variations may be due to natural turbulence in the rainy season and higher bacterial decomposition of organic matter due to good aeration caused by rain water as observed in an earlier study (Prasad, 1991). Jitendra *et al.,* (2008) observed low DO during summer and attributed to higher temperatures and low solubility of oxygen in water consequently affecting the BOD.

4.5.6: Biological Oxygen Demand (BOD)

The results of BOD showed significant monthly variations during the study period. The BOD values were maximum in summer followed by monsoon and winter seasons. Levels of BOD varied from 6.07 to 18.34 mg L^{-1} at Syngenta Lake, 18.79 to 47.83 mg L^{-1} at Lotus Lake, and 21.89 to 59.9 mg L^{-1} at Curtorim Lake. BOD was below detectable level at Khandola Pond **(Table 6; Fig. 12)**. Increase in BOD levels caused rapid depletion of DO. According to Sankar *et al.,* (2002) and Ahipathi and Puttaiah, (2006) high BOD in summer may be due to the increased oxygen demand for the degradation of the organic wastes dumped into the water body. The decrease in BOD levels in late monsoon and post- monsoon may be due to low temperature that is known to slow down the microbial activity (Bhatt *et al.,* 1999). Run off from residential areas carry excess organic waste contributing to increase in oxygen demand.

4.5.7: Nitrates

The nitrate levels in the water bodies varied from 0.20 to 0.54 mg L^{-1}in Syngenta Lake, 0.23 to 0.58 mg L^{-1}in Khandola Pond, 1.43 to 4.55 mg L^{-1}in Lotus Lake and 0.80 to 2.76 mg L^{-1}in Curtorim Lake **(Table 7; Fig. 13)**. High nitrate levels were recorded

Table 5: Variations in Dissolved Oxygen of selected water bodies.

DO (mg/L)				
Months	**Syngenta Lake**	**Khandola Pond**	**Lotus Lake**	**Curtorim Lake**
Jan'14	8.1	7.2	6.0	8.9
Feb'14	6.8	7.4	6.6	8.1
Mar'14	6.8	8.6	6.7	8.5
Apr'14	6.08	7.9	8.1	8.9
May'14	6.0	8.0	5.6	7.9
June'14	6.8	7.2	9.2	8.5
July'14	9.6	9.3	10.3	9.1
Aug'14	10.5	10.9	9.4	11.7
Sept'14	12.0	11.9	9.3	11.0
Oct'14	10.2	11.4	8.1	12.7
Nov'14	9.2	10.2	7.4	10.1
Dec'14	9.1	9.2	7.3	8.1
Jan'15	8.0	7.3	6.0	7.9
Feb'15	7.8	7.4	6.1	7.1
Mar'15	6.3	7.6	6.7	6.5
Apr'15	6.0	7.7	6.1	6.9
May'15	5.9	7.0	5.1	6.3
June'15	6.0	7.8	5.2	5.6
July'15	6.6	7.3	6.2	6.1
Aug'15	7.5	7.9	6.4	7.7
Sept'15	6.95	7.9	6.3	6.0
Oct'15	6.0	8.4	5.1	5.7
Nov'15	6.2	8.2	6.4	6.2
Dec'15	7.1	9.2	6.3	7.9

Legend: Values are average of three readings.

Table 6: Variations in Biological Oxygen Demand of selected water bodies.

BOD (mg/L)				
Months	**Syngenta Lake**	**Khandola Pond**	**Lotus Lake**	**Curtorim Lake**
Jan’14	10.5	BDL	36.8	36.8
Feb’14	10.1	BDL	32.3	32.4
Mar’14	12.5	BDL	32.4	32.7
Apr’14	14.0	BDL	36.8	36.9
May’14	13.2	BDL	37.7	38.2
June’14	11.3	BDL	21.8	37.7
July’14	8.5	BDL	18.7	32.4
Aug’14	6.0	BDL	25.9	26.3
Sept’14	8.1	BDL	27.9	21.8
Oct’14	12.8	BDL	27.5	29.9
Nov’14	11.3	BDL	33.7	25.9
Dec’14	10.5	BDL	37.7	29.6
Jan’15	11.5	BDL	39.8	37.8
Feb’15	11.7	BDL	42.3	42.4
Mar’15	12.5	BDL	37.4	42.7
Apr’15	15.0	BDL	46.8	46.9
May’15	15.6	BDL	48.9	50.2
June’15	18.3	BDL	47.8	57.4
July’15	13.5	BDL	41.8	42.0
Aug’15	10.6	BDL	39.7	40.3
Sept’15	12.4	BDL	37.9	41.8
Oct’15	17.9	BDL	44.5	59.9
Nov’15	14.3	BDL	39.7	51.0
Dec’15	10.5	BDL	35.0	38.2

Legend: Values are average of three readings; BDL- Below detectable level.

Table 7: Variation in Nitrate levels of selected water bodies.

Nitrates (mg/L)				
Months	**Syngenta Lake**	**Khandola Pond**	**Lotus Lake**	**Curtorim Lake**
Jan’14	0.20	0.27	1.43	0.80
Feb’14	0.72	0.23	1.58	1.27
Mar’14	0.82	0.56	1.66	1.50
Apr’14	0.31	0.47	1.76	1.78
May’14	0.54	0.36	1.81	2.57
June’14	0.33	0.50	2.16	1.32
July’14	0.41	0.58	4.55	2.27
Aug’14	0.50	0.34	3.16	2.76
Sept’14	0.53	0.38	3.38	1.43
Oct’14	0.48	0.31	4.45	1.27
Nov’14	0.31	0.30	3.06	1.19
Dec’14	0.29	0.29	2.38	1.27
Jan’15	0.21	0.21	1.76	0.93
Feb’15	0.34	0.23	1.65	1.43
Mar’15	0.73	0.50	1.75	1.67
Apr’15	0.24	0.49	1.70	1.51
May’15	0.32	0.32	1.81	1.55
June’15	0.37	0.35	2.24	2.30
July’15	0.43	0.28	2.95	2.45
Aug’15	0.59	0.33	3.19	2.64
Sept’15	0.57	0.38	3.38	2.40
Oct’15	0.53	0.32	2.55	1.73
Nov’15	0.45	0.29	2.17	1.65
Dec’15	0.37	0.27	2.02	2.57

Legend: Values are average of three readings.

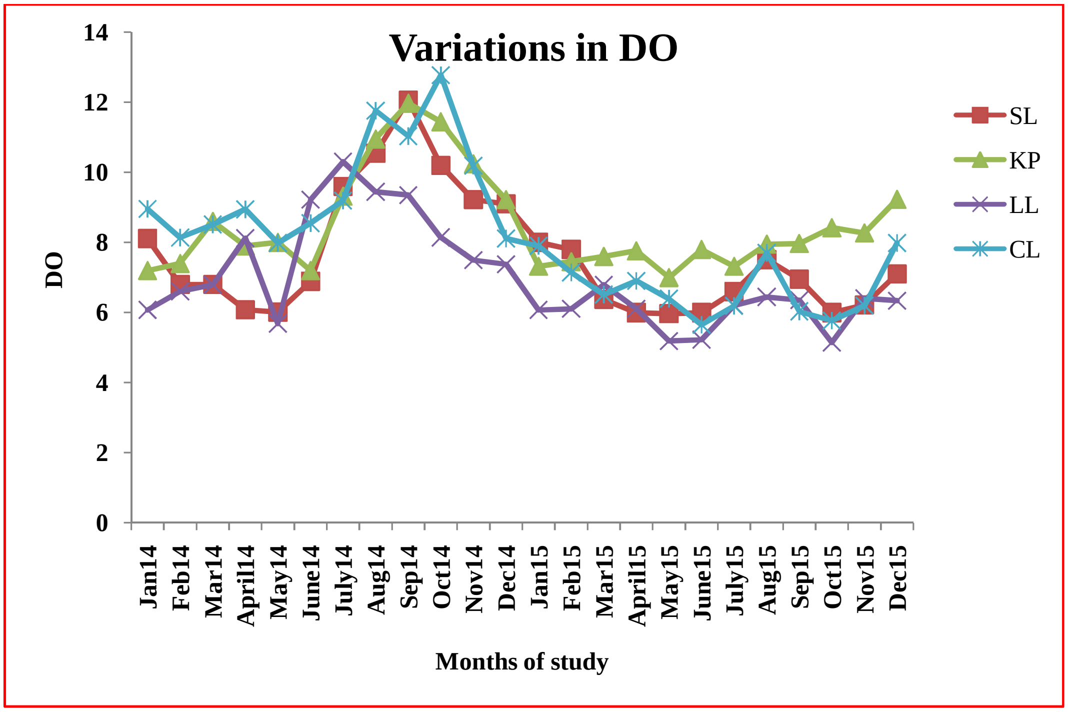

Fig. 11: Variations in DO of selected water bodies.

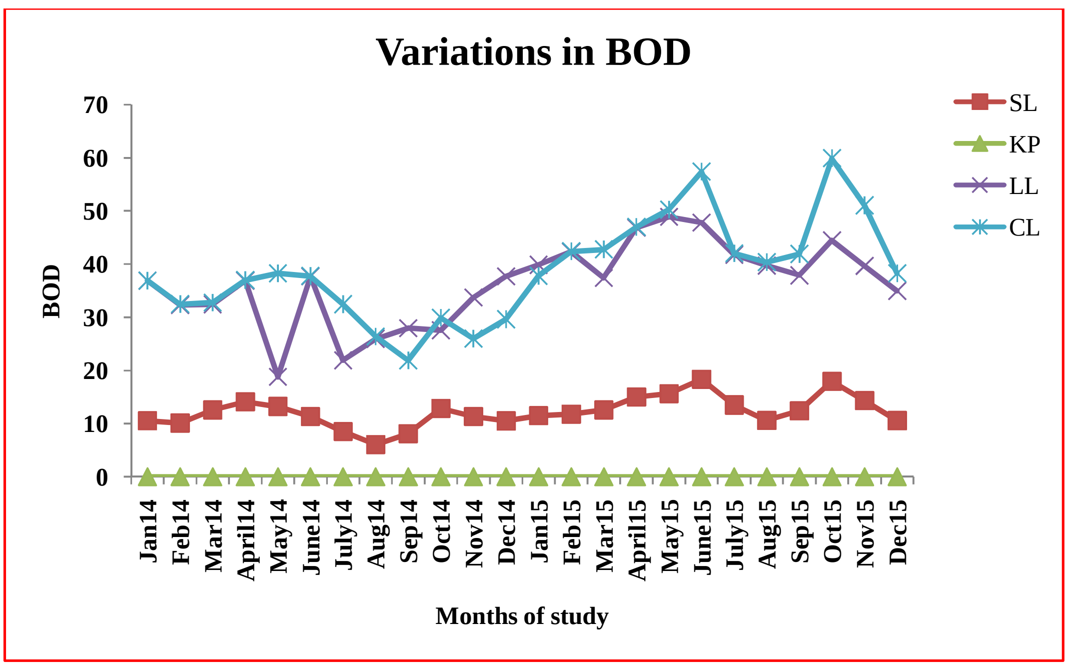

Fig. 12: Variations in BOD of selected water bodies.

Legend: SL = Syngenta Lake; KP = Khandola Pond; LL = Lotus Lake; CL = Curtorim Lake; DO = Dissolved oxygen, BOD = Biological oxygen demand.

during monsoon and low levels were recorded during post-monsoon season. Similar observations have been recorded earlier (Garg *et al.*, 2006; Sinha and Biswas, 2011; Prabhakar *et al.*, 2012). Nitrates are useful as nutrients but their entry into water resources increases the growth of nuisance algae, macrophytes and triggers eutrophication (Trivedy and Goel, 1986).

4.5.8: Phosphates

Even though P is essential for growth of organisms, the discharge of raw wastewater, agricultural drainage, or industrial waste to water body stimulates the growth of photosynthetic aquatic micro- and macro-organisms in large quantities (USEPA, 1973). In the present study variations in P concentrations in different water bodies were recorded and ranged from 0.07 to 0.31 mg L^{-1} in Syngenta Lake, 0.01 to 0.30 mg L^{-1} in Khandola Pond, 0.01 to 2.41 mg L^{-1} in Lotus Lake and 0.01 to 1.72 mg L^{-1} in Curtorim Lake **(Table 8; Fig. 14)**. During monsoon season, levels of nitrates and phosphates elevate as they enter the water bodies from the surrounding area, especially farmlands and sewage (Sawaiker and Rodrigues, 2016). Higher of concentration of P may also be due to inflow of domestic waste, washing activities and bathing of cattle (Joseph *et al.*, 1993). Levels of phosphates and nitrates are known to deplete DO resulting in the formation of algal blooms (Ansar and Khad, 2005). According to Yanamadala (2005), high levels of phosphates and nitrates have an impact on the overall health of the water and its organisms.

Table 8: Variation in Phosphate levels of selected water bodies.

Phosphates (mg/L)				
Months	**Syngenta Lake**	**Khandola Pond**	**Lotus Lake**	**Curtorim Lake**
Jan'14	0.10	0.01	0.01	0.01
Feb'14	0.12	0.02	0.03	0.02
Mar'14	0.23	0.01	0.10	0.01
Apr'14	0.10	0.04	0.25	0.04
May'14	0.24	0.02	0.25	0.12
June'14	0.27	0.02	0.30	0.15
July'14	0.25	0.30	2.41	1.72
Aug'14	0.19	0.25	1.92	0.49
Sept'14	0.20	0.15	0.78	0.55
Oct'14	0.15	0.15	0.60	0.30
Nov'14	0.19	0.10	0.19	0.19
Dec'14	0.10	0.02	0.10	0.10
Jan'15	0.11	0.01	0.27	0.19
Feb'15	0.07	0.02	0.20	0.30
Mar'15	0.09	0.01	0.21	0.48
Apr'15	0.10	0.04	0.18	0.40
May'15	0.20	0.02	0.25	0.47
June'15	0.25	0.02	0.39	1.15
July'15	0.29	0.01	1.01	1.22
Aug'15	0.31	0.02	1.62	1.54
Sept'15	0.28	0.04	1.70	0.95
Oct'15	0.22	0.03	1.03	0.40
Nov'15	0.17	0.02	0.17	0.20
Dec'15	0.12	0.01	0.11	0.12

Legend: Values are average of three readings.

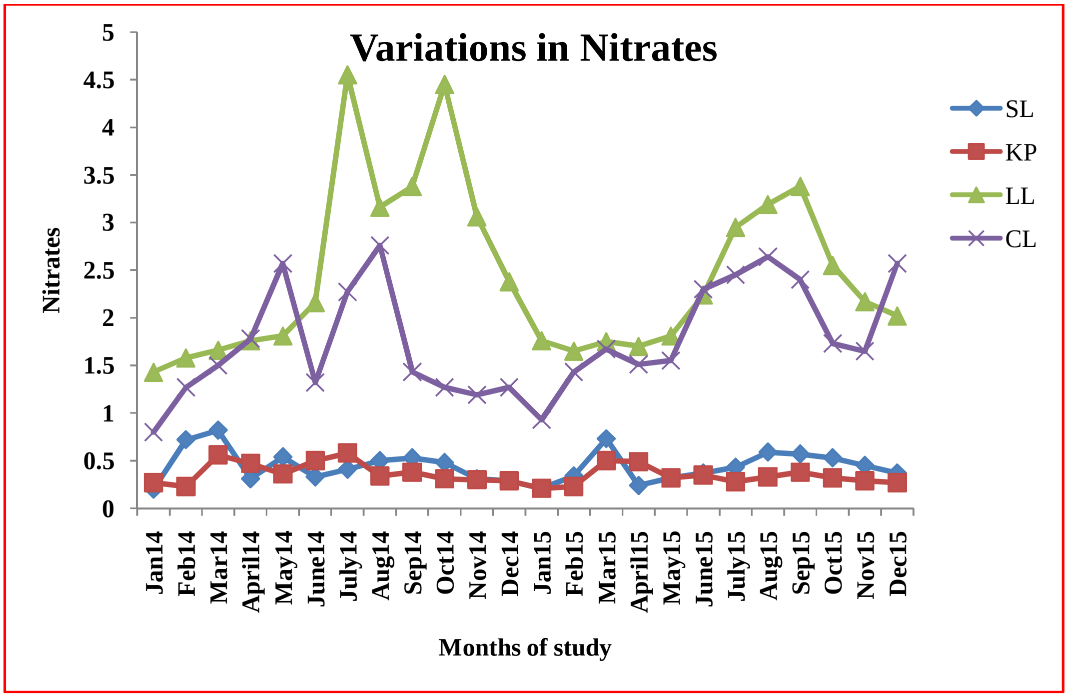

Fig. 13: Variations in Nitrates of selected water bodies.

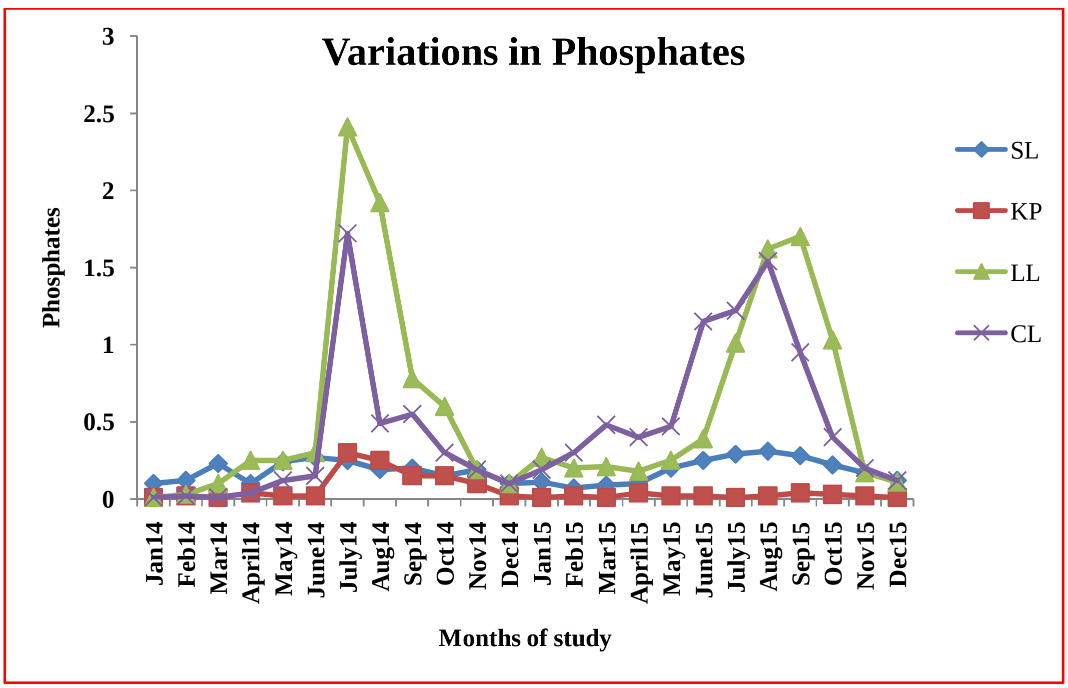

Fig. 14: Variations in Phosphates of selected water bodies.

Legend: SL = Syngenta Lake; KP = Khandola Pond; LL = Lotus Lake; CL = Curtorim Lake.

4.5.9: Total Chlorophyll

Surface waters that have high amount of chlorophyll are typically high in nutrients like P and N. In the present study, the chlorophyll concentration varied from 10.76 to 23.43 mg m^{-3} at Syngenta Lake, 2.7 to 5.25 mg m^{-3} at Khandola Pond, 16.52 to 39.23 mg m^{-3} at Lotus Lake and 19.04 to 54.4 mg m^{-3} at Curtorim Lake **(Table 9; Fig. 15)**. High amount of chlorophyll was observed during late summer and during October. This is due to increase in water temperature resulting in accelerating primary production (Mandal *et al.,* 2005). Chlorophyll being the main photosynthetic pigment in all oxygen-evolving photosynthetic algae, other algal pigments have limited distribution and considered as accessory or secondary pigments (Akpan, 1994).

Photosynthetic pigment concentrations are used extensively to estimate phytoplankton biomass (Marker *et al.,* 1980). Assessment of Chlorophyll is relatively easy, cheap and rapid (Santos *et al.,* 2010). All green plants contain chlorophyll *a*, which constitute about 1 to 2% of the dry weight of planktonic algae. Microscopic phytoplanktons play some of the biggest roles in climate control, oxygen supply and food production. These single-celled organisms are responsible for more than 40% of Earth's photosynthetic production. (http://earthobservatory.nasa.gov/Features/Polynyas)

4.6: Water Quality Index

Standard values of CCME WQI to categorize water quality are depicted in **Table 10**. The results of the water quality indicate that all the four water bodies are of poor quality with the index values less than 40 (**Tables 11** to **14)**. The scope (F_1) values for all the water bodies are 100 or nearing 100. This is primarily because of the failure of most of the parameters to reach the objectives. The condition observed in Khandola Pond is

Table 9: Variation in Total Chlorophyll content of selected water bodies.

Total Chlorophyll (mg/m^3)				
Months	**Syngenta Lake**	**Khandola Pond**	**Lotus Lake**	**Curtorim Lake**
Jan'14	14.2	2.8	27.0	28.6
Feb'14	12.3	2.7	25.0	27.4
Mar'14	10.7	3.0	25.6	29.2
Apr'14	14.7	3.3	27.6	30.1
May'14	21.7	3.9	30.4	34.4
June'14	20.7	3.2	33.2	27.2
July'14	16.4	3.0	23.2	23.2
Aug'14	18.5	2.7	22.4	21.7
Sept'14	20.9	3.31	16.5	19.0
Oct'14	21.3	3.6	25.2	28.3
Nov'14	19.3	3.4	24.7	23.3
Dec'14	17.2	3.1	26.5	27.3
Jan'15	15.2	3.0	29.1	31.0
Feb'15	12.3	2.9	26.1	37.2
Mar'15	11.7	3.0	27.6	39.2
Apr'15	19.7	3.8	29.8	44.5
May'15	26.7	4.9	37.4	47.7
June'15	22.7	5.2	39.2	52.2
July'15	17.4	3.1	30.0	45.2
Aug'15	12.5	3.0	27.4	40.0
Sept'15	14.9	3.0	27.7	43.0
Oct'15	23.4	4.6	35.2	54.4
Nov'15	18.3	3.4	29.1	47.0
Dec'15	14.2	3.2	26.4	34.4

Legend: Values are average of three readings.

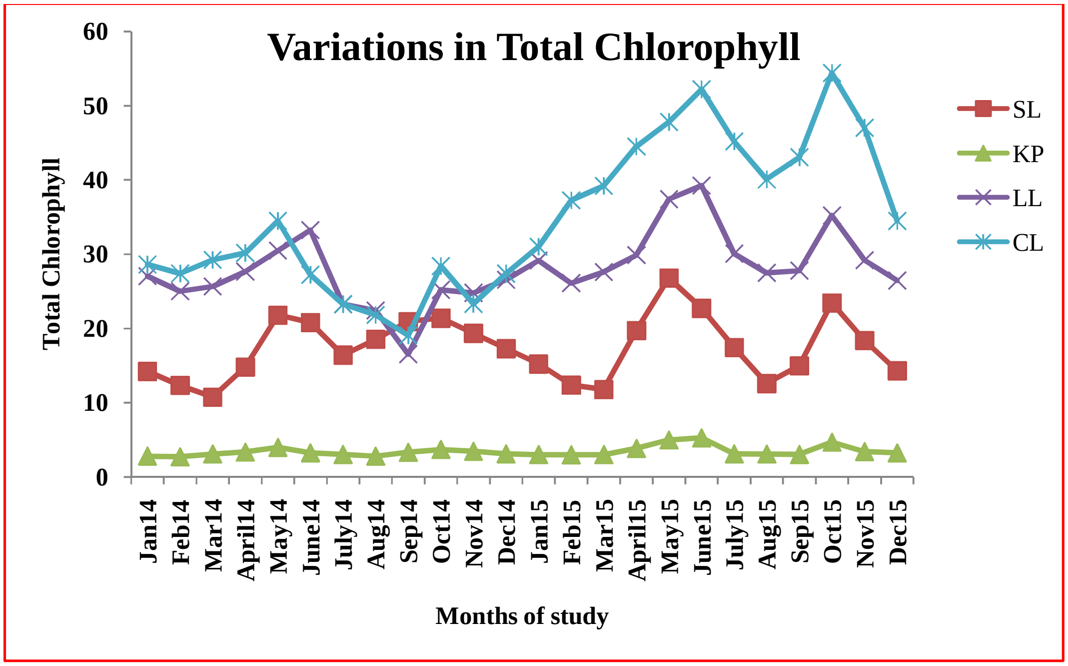

Fig. 15: Variations in Total Chlorophyll of selected water bodies.

Legend: SL = Syngenta Lake; KP = Khandola Pond; LL = Lotus Lake; CL = Curtorim Lake.

Table 10: CCME WQI- and categorization of water quality.

Sr. No	Rating	WQI	Categorization
1.	Excellent	95 - 100	Water quality is protected with virtual absence of threat or impairment conditions very close to natural levels.
2.	Good	80 - 94	Water quality is protected with only a minor degree of threat, condition rarely deviate from natural condition.
3.	Fair	65 - 79	Water quality usually protected, but occasionally threatened, conditions sometimes deviate from normal levels.
4.	Marginal	45 - 64	Water quality is frequently threatened; conditions often deviate from normal levels.
5.	Poor	0 - 44	Water quality almost always threatened; conditions regularly deviate from natural levels.

Table 11: CCME WQI for Syngenta Lake 2014-15.

Data Summary	Overall	Drinking	Aquatic	Recreation	Irrigation	Livestock
CWQI	15	11	5	10	8	22
Categorization	Poor	Poor	Poor	Poor	Poor	Poor
F1 (Scope)	93	100	100	100	100	75
F2 (Frequency)	54	60	84	78	73	50
F3 (Amplitude)	100	100	100	92	100	100

Table 12: CCME WQI for Khandola Pond 2014-15.

Data Summary	Overall	Drinking	Aquatic	Recreation	Irrigation	Livestock
CWQI	26	24	6	8	19	29
Categorization	Poor	Poor	Poor	Poor	Poor	Poor
F1 (Scope)	64	70	100	100	80	62
F2 (Frequency)	47	49	80	78	58	39
F3 (Amplitude)	100	100	100	97	100	99

Table 13: CCME WQI for Lotus Lake 2014-15.

Data Summary	Overall	Drinking	Aquatic	Recreation	Irrigation	Livestock
CWQI	11	10	4	9	7	17
Categorization	Poor	Poor	Poor	Poor	Poor	Poor
F1 (Scope)	100	100	100	100	100	88
F2 (Frequency)	60	67	87	78	76	56
F3 (Amplitude)	100	100	100	94	100	100

Table 14: CCME WQI for Curtorim Lake 2014-15.

Data Summary	Overall	Drinking	Aquatic	Recreation	Irrigation	Livestock
CWQI	12	11	6	8	8	17
Categorization	Poor	Poor	Poor	Poor	Poor	Poor
F1 (Scope)	100	100	100	100	100	88
F2 (Frequency)	56	62	80	78	73	54
F3 (Amplitude)	100	100	100	96	100	100

slightly different with the scope values ranging from 62 to 100 with the parameters DO, phosphates and nitrates passing the objectives. Frequency (F_2) ranged from 50 to 84 at Syngenta Lake, 39 to 80 at Khandola Pond, 60 to 87 at Lotus Lake and 54 to 80 at Curtorim Lake indicating that the percentage of analytical results do not comply with the guidelines and water is unsuitable for drinking, aquatic, recreation and irrigation purpose. Amplitude (F_2) values are 100 or nearing 100 indicating the difference between overall degree of non-compliance of analytical results and guidelines.

4.7: One way ANNOVA and Tukey's (HSD) Post Hoc Test

(L1-Syngenta Lake, L2-Khandola Pond, L3-Lotus Lake, L4-Curtorim Lake)

a) Variations in **pH -** HSD [.05] = 0.31; HSD [.01] = 0.38

L1 vs L2 non-significant

L1 vs L3 non-significant

L1 vs L4 P<.01

L2 vs L3 non-significant

L2 vs L4 P<.01

L3 vs L4 P<.01

Variations in pH were non-significant in L1 and L2, L1 and L3, L2 and L3.

b) Variations in **temperature** were non-significant in all the water bodies.

c) Variations in **TDS -** HSD [.05] = 93.31; HSD [.01] =114.05

L1 vs L2 P<.01

L1 vs L3 P<.01

L1 vs L4 P<.01

L2 vs L3 P<.01

L2 vs L4 P<.01

L3 vs L4 P<.01

Variations in TDS were significant for all the water bodies.

d) Variations in **Turbidity** - HSD [.05] = 5.64; HSD [.01] = 6.9

L1 vs L2 P<.01

L1 vs L3 non-significant

L1 vs L4 non-significant

L2 vs L3 P<.01

L2 vs L4 P<.01

L3 vs L4 non-significant

Variations in turbidity were non-significant in L1 and L3, L1 and L4, L3 and L4.

e) Variations in **DO** - HSD [.05] =1.23; HSD [.01] =1.5

L1 vs L2 non-significant

L1 vs L3 non-significant

L1 vs L4 non-significant

L2 vs L3 P<.01

L2 vs L4 non-significant

L3 vs L4 non-significant

Variations in DO were non-significant in L1 and L2, L1 and L3, L2 and L4, L3 and L4.

f) Variations in **BOD -** HSD [.05] = 4.78; HSD [.01] = 5.84

L1 vs L3 P<.01

L1 vs L4 P<.01

L3 vs L4 non-significant

Variations in BOD were non-significant in L3 and L4.

g) Variations in **Nitrates** - HSD [.05] = 0.41; HSD [.01] = 0.5

L1 vs L2 non-significant

L1 vs L3 $P<.01$

L1 vs L4 $P<.01$

L2 vs L3 $P<.01$

L2 vs L4 $P<.01$

L3 vs L4 $P<.01$

Variations in nitrates were non-significant in L1 and L2.

h) Variations in **Phosphates** - HSD [.05] = 0.32; HSD [.01] = 0.39

L1 vs L2 nonsignificant

L1 vs L3 $P<.01$

L1 vs L4 nonsignificant

L2 vs L3 $P<.01$

L2 vs L4 $P<.01$

L3 vs L4 nonsignificant

Variations in phosphates were non - significant in L1 and L2, L1 and L4, L3 and L4.

i) Variations in **Total Chlorophyll** - HSD [.05] = 4.53; HSD [.01] = 5.53

L1 vs L2 $P<.01$

L1 vs L3 $P<.01$

L1 vs L4 $P<.01$

L2 vs L3 $P<.01$

L2 vs L4 $P<.01$

L3 vs L4 $P<.01$

Total Chlorophyll there were significant variations in all water bodies.

4.8: Principal component analysis

4.8.1: Syngenta Lake - The principal component in this lake was turbidity and total chlorophyll while temperature played a supporting role **(Fig. 16)**.

4.8.2: Khandola Pond - Turbidity was the principal component found correlated to TDS **(Fig. 17)**.

4.8.3: Lotus Lake - BOD played important role as principal component followed by turbidity and total chlorophyll **(Fig. 18)**.

4.8.4: Curtorim Lake - Total chlorophyll played major role as principal component followed by BOD **(Fig. 19)**.

4.9: Pearson's Correlation Matrix

4.9.1: Syngenta Lake - showed positive correlation between turbidity and phosphates, turbidity and total chlorophyll, temperature and total chlorophyll, temperature and turbidity while negative correlation was recorded between BOD and DO **(Table 15)**.

4.9.2: Khandola Pond - There was positive correlation between temperature and nitrates, DO and phosphates, temperature and total chlorophyll while pH and temperature showed negative correlation **(Table 16)**.

4.9.3: Lotus Lake - positive correlation was observed between TDS and phosphates, TDS and nitrates, Turbidity and phosphates, DO and nitrates, BOD and total chlorophyll, phosphates and nitrates where as negative correlation was observed between pH and temperature, BOD and DO, DO and total chlorophyll **(Table 17)**.

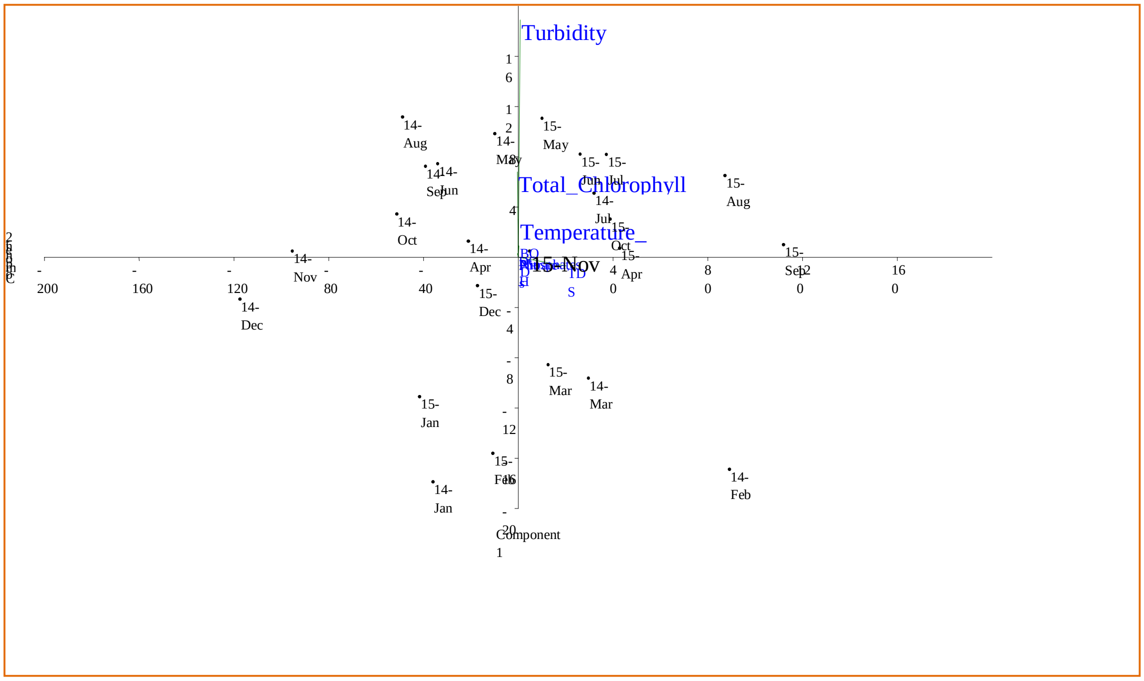

Fig. 16: Principle Component Analysis of physico-chemical parameters of Syngenta Lake 2014-15.

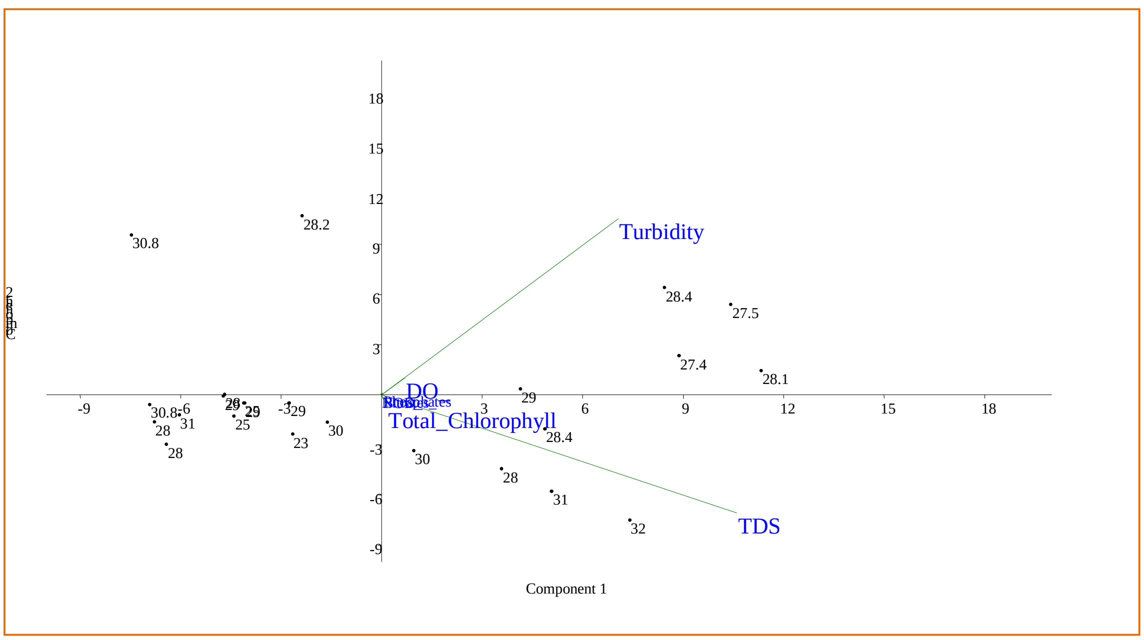

Fig. 17: Principle Component Analysis of physico-chemical parameters of Khandola Pond 2014-15.

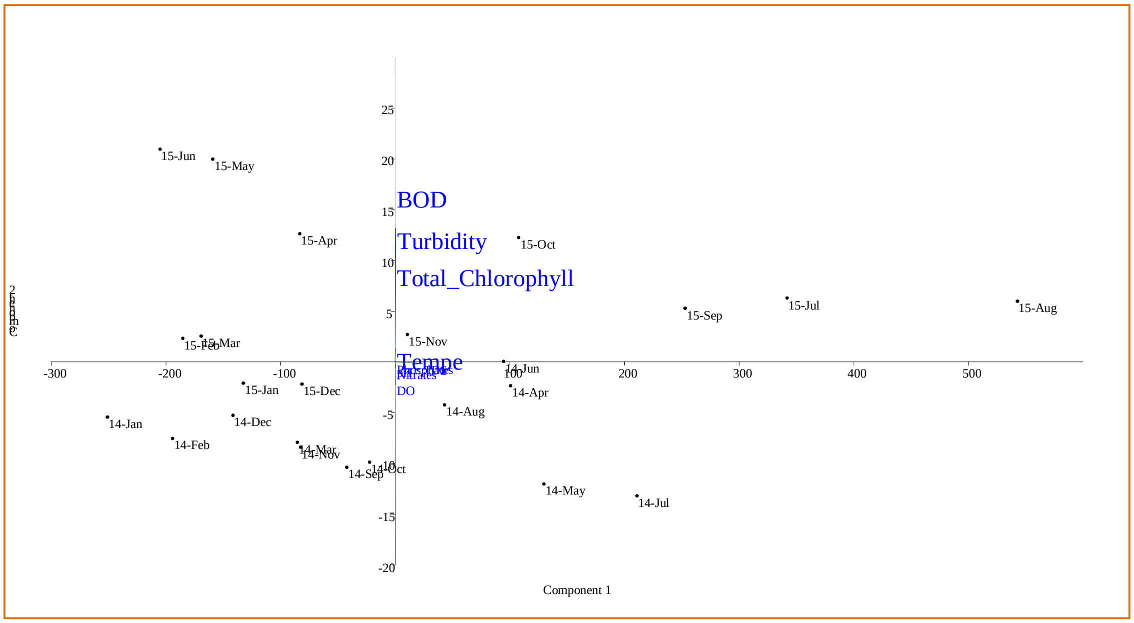

Fig. 18: Principle Component Analysis of physico-chemical parameters of Lotus Lake 2014-15.

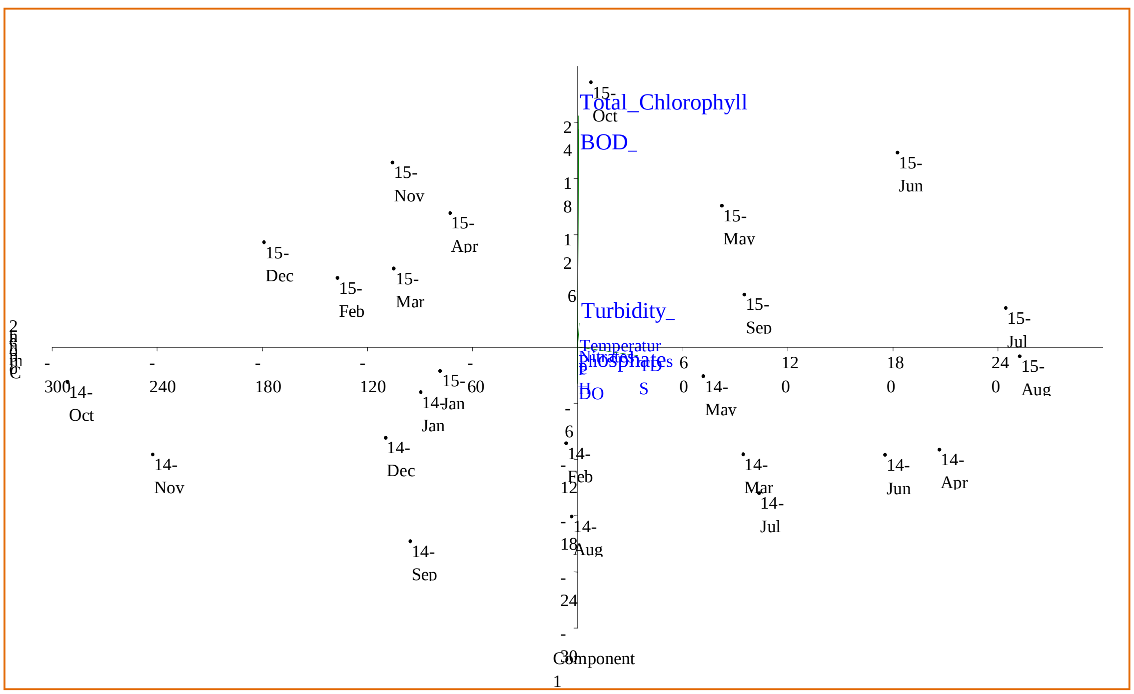

Fig. 19: Principle Component Analysis of physico-chemical parameters of Curtorim Lake 2014-15.

Table 15: Pearson's correlation matrix for Syngenta Lake.

	pH	Temp.	TDS	Turb.	DO	BOD	Nitrates	Phos.	TC
pH	1								
Temp.	.053	1							
TDS	-.169	.105	1						
Turb.	.357	.600**	.265	1					
DO	.429*	-.457*	-.398	-.122	1				
BOD	-.344	.459*	.274	.116	-.685**	1			
Nitrates	-.068	.131	.501*	.130	.037	-.091	1		
Phos.	.373	.349	.410*	.764**	-.069	.085	.308	1	.
TC	-.031	.614**	-.232	.519**	-.239	.416*	-.328	.289	1

Legend: Temp.- Temperature; TDS -Total dissolved solids; Turb.- Turbidity; Phos.- Phosphates; TC - Total chlorophyll.

Table 16: Pearson's correlation matrix for Khandola Pond.

	pH	Temp.	TDS	Turb.	DO	Nitrates	Phos.	TC
pH	1							
Temp.	-.552**	1						
TDS	-.289	.074	1					
Turb.	-.158	-.037	.314	1				
DO	-.028	.002	.111	.317	1			
Nitrates	-.293	.532**	-.239	.043	.042	1		
Phos.	-.022	.170	-.071	.470*	.701**	.296	1	
TC	-.289	.572**	.260	-.195	-.096	.004	-.163	1

Legend: *. Significant at the 0.05 level (2-tailed) **. Significant at the 0.01 level (2-tailed).
Temp.-Temperature; TDS-Total dissolved solids; Turb.- Turbidity; Phos.-Phosphates; TC- Total chlorophyll.

4.9.4: Curtorim Lake - TDS and turbidity, TDS and nitrates, turbidity and nitrates, turbidity and phosphates, BOD and total chlorophyll, phosphates and nitrates were positively correlated where as pH and BOD, pH and total chlorophyll, DO and BOD, DO and total chlorophyll were negatively correlated in this water body **(Table 18)**.

Table 17: Pearson's correlation matrix for Lotus Lake.

	pH	Temp.	TDS	Turb.	DO	BOD	Nitrates	Phos.	TC
pH	1								
Temp.	-.538**	1							
TDS	-.122	-.030	1						
Turb.	-.432*	.261	.508*	1					
DO	.052	-.110	.190	-.153	1				
BOD	-.120	.117	-.170	.261	-.622**	1			
Nitrates	-.095	-.041	.524**	.289	.574**	-.426*	1		
Phos.	-.066	-.163	.695**	.585**	.438*	-.303	.761**	1	
TC	-.409*	.449*	-.038	.356	-.645**	.661**	-.372	-.230	1

Legend: Temp.- Temperature; TDS-Total dissolved solids; Turb.- Turbidity; Phos.- Phosphates; TC-Total chlorophyll.

Table 18: Pearson's correlation matrix for Curtorim Lake

	pH	Temp.	TDS	Turb.	DO	BOD	Nitrates	Phos.	TC
pH	1								
Temp.	.018	1							
TDS	.049	.260	1						
Turb.	-.006	.149	.585**	1					
DO	.505*	-.276	-.333	-.108	1				
BOD	-.608**	.334	.266	.179	-.839**	1			
Nitrates	-.012	.193	.622**	.778**	-.142	.155	1		
Phos.	.072	.082	.506*	.828**	-.171	.162	.675**	1	
TC	-.696**	.340	.264	.330	-.839**	.951**	.259	.243	1

Legend: *. Significant at the 0.05 level (2-tailed) **. Significant at the 0.01 level (2-tailed).

Temp.-Temperature; TDS-Total dissolved solids; Turb.-Turbidity; Phos.-Phosphates; TC-Total chlorophyll.

CHAPTER - 5

To survey the macrophytes and phytoplanktons from polluted and non-polluted water bodies.

5.1: INTRODUCTION

5.1.1: Macrophytes

Macrophytes are aquatic plants growing in or near waters which can be emergent, submerged or free floating. They are found to colonize in different types of aquatic ecosystems, such as lakes, reservoirs, wetlands and streams and become important components, influencing ecological processes like nutrient cycling and attributes of other aquatic attached assemblages such as species diversity (Wetzel, 2001; Kalff, 2002). Macrophytes influence nutrient cycling in two other ways *viz.*, retention of solids and nutrients by their submerged roots and leaves, and reduction of nutrients released from sediments through protection against wind and wave action (Meerhoff *et al.*, 2003). Nutrients like P and N that are limiting are released by macrophytes and rapidly used by micro-algae and bacteria which may be free-living or attached to macrophyte surfaces and their detritus (Stets and Cotner, 2008). In addition, macrophytes influence several other physico-chemical properties of the water column like changes in oxygen, inorganic carbon, pH and alkalinity that results from their metabolism (Caraco and Cole, 2002). Owing to their high rate of biomass production, they have primarily been characterized as important food resource for aquatic organisms, providing both living (grazing food webs) and dead organic matter e.g. detritivorous food webs (Poi and Casco, 2003). Macrophytes are also known to provide shelter for small fish (Meerhoff *et al.*, 2003). Nutritionally, an ecosystem with simple floristics does not have a wide variety of food materials, and deficiencies of specific nutrients may occur. Therefore, when present in moderate quantities, macrophytes increase the stability of reservoir ecosystems (Davies, 1970). Besides, they play an important role in cleaning up of aquatic environment.

Macrophytes play an important role in phytoremediation of contaminated Lakes as they assist in heavy metal cycling. They are also important in bio-monitoring of aquatic ecosystems, as changes in the composition of the aquatic vegetation are considered as biological indicator of water quality (Schneider and Melzer, 2003).

5.1. 2: Phytoplanktons

Phytoplanktons play an important role in the biosynthesis of organic matter in aquatic ecosystems, which directly or indirectly serve as food (Telesh, 2004; Ozedon, 2013). They float in water and often multiply rapidly resulting in increased turbidity. Groups like blue-green algae, green algae, diatoms, desmids, euglenoids, *etc*. being important among aquatic flora, form the basic link in the food chain of all aquatic life. Nutritional status of a lake affects energy flow in planktonic food webs. The ratio of primary production to total biomass, reflecting energy turnover, is low in eutrophic conditions (Lampert and Sommer, 1997). The ratio of total heterotrophic to autotrophic biomass (H/A ratio), indicating the balance between consumption and primary production, declines with eutrophication. The changes in phytoplankton biomass are related to eutrophication and the distribution of phytoplankton apparently is related to nutritional status and selective grazing by zooplanktons (Burkepile and Hay, 2006; Ingole *et al.*, 2010).

The four groups of organisms *viz.*, phytoplankton, zooplankton, fish and macrophytes, that appear in European Water Frame-work Directives (EWFD) represent ecological structure of water over a range of temporal and spatial scales and functional roles. Seasonal changes in temperature, radiations, hydrology and nutrient availability are the most important variables which determine plankton abundance (Payne, 1986).

5.1.3: Biomonitoring

Freshwater communities are sensitive to environmental variations (Darchambeau *et al.*, 2014). Phytoplankton dynamics influence trophic levels and potability of water for human uses (Fisher *et al.*, 2009; Sharma *et al.*, 2013). Among phytoplanktons, diatoms respond to environmental changes quickly and this can be early warning towards freshwater ecological problems (Suphan *et al*., 2012). Several studies on diatoms as bioindicators of pollution have been carried out earlier (Van Dam *et al.,* 1994, Bere *et al.,* 2014, Mangadze *et al*., 2015, Dalu *et al*., 2016). Biological monitoring is a low cost approach for assessing the effects of environmental stressors (Bere and Tundisi, 2010). Various indices have been developed for monitoring pollution in water bodies. One of the simplest and effective water quality indexes, utilizing diatom population is IDSE/5 - the index of Saprobity-Eutrophication. 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. The design of OMNIDA Software for computation of diatom indices has facilitated the use of diatom based biomonitoring (Leconite *et al.,* 1993). The software is a comprehensive data base having an inbuilt ecological data for 13,000 diatom species.

5.1.4: Nestedness of diatoms

Diversity of community and population abundance of a particular group of species are controlled by environment, inter- and intra-species interactions, landscape conditions, historical events and evolutionary processes (Karthick *et al.,* 2010). The concept of nestedness was proposed by Hulten (1937) to describe patterns of species composition within arctic and boreal biota. It has been recognized as a characteristic pattern of community organization (Rodrigues *et al.,* 2006). It is a measure of structure in an ecological system, usually applied to species-sites systems (describing the distribution of species across locations), or species-species interaction networks (describing the interactions between species). Nestedness is particularly common in mutualistic networks, such as those involving plants species and their pollinators or seed dispersers (Bascompte *et al.,* 2003; Ollerton *et al.,* 2007). In the study of biogeographic patterns of species occurrence, nestedness analysis has become increasingly popular. The more a system is 'nested', the more it is organized.

In general, the species assemblages are associated with species-area relationship, known as the 'nested subsets' pattern (Wright *et al.,* 1998). The nested subset pattern arises because species differ in their distribution across space. Some species use a wider range of resources and tolerate a variety of abiotic conditions. These species can establish their populations in wider areas than with relatively narrow niches (Cook and Quin, 1995). Nested pattern develops in an ecosystem due to different colonization abilities of species. Like many other microorganisms diatoms are least studied, particularly from the tropical regions of the world (Soininen, 2008). Diatoms are one of the largest groups of eukaryotic microorganisms that are autotrophic in nature. They occur in all wet/damp places with a diverse range of habitats across the continents. Diatoms grow as single cells, or form simple filaments/colonies and are sensitive to physico-chemical parameters of water (Soininen *et al.,* 2009). In the present study, the role of diatoms as indicators of water quality of selected water bodies using Louis-Leclercq Diatomic Index of Saprobity- Eutrophication (IDSE/5) and the quality of water in terms of organic pollution as well as anthropogenic eutrophication has been attempted. This was to ascertain the level of degradation in the selected water bodies due to organic and anthropogenic pollution, to identify the diatom species indicating organic and anthropogenic pollution, to derive Louis Leclercq index of Saprobity-

Eutrophication (IDSE/5) using OMNIDIA GB 5.3 software and know the trophic state of the selected water bodies. The objectives of the nestedness study was to find out nestedness index of diatoms, to know whether the indicator diatoms were *autocathonous* or *allocathonous* to each of the water body, and to identify the possible drivers for nested patterns in the selected water bodies.

5.2: MATERIALS AND METHODS

During the study, macrophytes were found growing in three water bodies *viz.*, Syngenta, Lotus and Curtorim Lakes, while the Khandola Pond did not show presence of macrophytes. At the time of sampling two plants per species were handpicked from the selected water bodies, washed carefully and used for herbaria preparation to confirm its taxonomic identification using the available bibliographies (Almeida, 1990; Biswas, 1936; Cook, 1968). Three dominant macrophytes *viz.*, *Salvinia molesta*, *Eichhornia crassipes* and *Pistia stratiotes* were used for the study of trace metal accumulation during pre-monsoon, monsoon and post-monsoon seasons.

For phytoplankton study, one litre of water sample was collected in sterile plastic bottles and Lugol solution (0.7ml/100 ml 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, remaining sample was concentrated by centrifugation at 1500 rpm and the total volume was made to 20 or 10 ml depending on density of phytoplanktons. Later, the phytoplanktons were examined immediately upon fixation using student research microscope. Dimensions were measured using micrometry and photomicrographs were obtained using Nikon DS Fi 2 camera. Counting was done by

Laky drop method (Suxena, 1987). Identification was carried out using standard bibliographies and monographs (Iyengar, 1940; Desikachary, 1959; Edmondson, 1966; Prescott, 1969; Sarode and Kamath, 1984; Prasad and Misra, 1992; Gandhi, 1998; Krishnamurthy, 2000; Kramer and Lange - Bertalot, 2003; Karthick *et al.*, 2010; APHA, 2012). The identification work was carried out after collecting the water samples on monthly basis from the selected water bodies for a period of two years *i.e.* Jan. 2014 to Dec. 2015. The data on diatom counts was used for biomonitoring studies and for calculation of nestedness.

For biomonitoring study, each taxon was coded with acronyms as per the rules of OMNIDA GB 5.3 software. Diatom species counts were entered into diatom database - index calculation tool, OMNIDIA version GB 5.3 (Lecointe *et al.*, 1993). The output of the software provides various metrics of water quality through the indices and ecological characteristics. The Louis Leclercq IDSE/5 index was calculated using this software (Leclerq and Maquet, 1987). Seven ecological indicator values given by Van Dam *et al.* (1994) were derived for selected water bodies using the OMNIDIA GB 5.3 software and were used for interpreting theresults. These values indicate the conditions required for growth and survival of diatoms and include pH, salinity (S), nitrogen uptake (NU), oxygen requirements (OR), saprobity (SP), trophic state (TS) and moisture (M), and also to determine the water quality. Each parameter was measured on a scale of 1-7. OMNIDIA is also used to compute degradation (D) using IDSE/5 Louis Leclercq index for organic pollution (OP) and anthropogenic eutrophication (AE). For nestedness calculation, the data was analysed using Nestedness temperature calculator.

5.3: RESULTS AND DISCUSSION

In all, 15 macrophytes have been identified from the three water bodies **(Plates 2, 3** and **4; Table 19)**, while no macrophytes were recovered from Khandola Pond. *Salvinia molesta*, *Eichhornia crassipes* and *Pistia stratiotes* were dominant at Syngenta, Lotus and Curtorim Lakes, respectively. These plants were used to study trace metal accuumulation and the potential role in phytoremediation.

A total of 125 phytoplanktons were indentified from all the study sites. Seventy four species of chlorophyceae belonging to 26 genera were recorded during the study period **(Plates 5** to **10)**. Chlorophyceae members dominated all the water bodies. Four genera of Euglenophyceae were identified with 16 species out of which only two members *i.e. Euglena minuta* and *E. oxyuries* were recorded from Khandola Pond **(Plates 11** and **12)**. Fourteen species of Cyanophyceae belonging to seven genera were recovered from all the study sites of which *Chroococcus varius* and *Merismopedia sp.* were found growing in Khandola Pond **(Plate 13)**. Twenty one species of Bacillariophyceae belonging to 12 genera were recorded from the study sites **(Plates 14** and **15)**. *Cocconeis placentula, Navicula halophila, N. radiosa, N. rhynococephala, N. mutica* and *Pinnularia dolosa* were recovered from Khandola Pond. Among the study sites, Khandola Pond showed least diversity of phytoplanktons. This could be attributed to lesser degree of pollution in this water body. List of phytoplanktons emcountered during the study are tabulated in **Tables 20** to **23**.

5.4: Perason's correlation matrix

The water samples were collected for phytoplankton estimation at an interval of 30 days. Precaution was taken to avoid filamentous forms (even if they were present in the

Plate 2

Plate 2

Macrophyte species

A. *Eichhornia crassipes* (Mart.) Solms

B. *Heterophyllum ceratophyllum* L.

C. *Hydrilla verticillata* (L. f.) Royle

D. *Limnophylla* sp.(unidentified)

E. *Ludwigia adsendens* (L.) H.Hara

F. *Marsilea minuta* L.

Plate 3

Plate 3

Macrophyte species

A. *Nymphaea alba* L.

B. *Nymphea rubra* Roxb. Ex Saliab

C. *Panicum repens* L.

D. *Persicaria glabra* (Willdenow) M. Gómez de la Mazay

E. *Pistia stratiotes* L.

F. *Salvinia molesta* Mitchel

Plate 4

Plate 4

Macrophyte species

A. *Schaenoplecitiella articulate* L.

B. *Utricularia vulgaris* L.

C. *Vallisnaria* sp. (unidentified)

Table 19: Macrophytes identified during study period.

Sr. No.	Name	SL	LL	CL
1	*Eichhornia crassipes* (Mart.) Solms	-	+	+
2	*Heterophyllum ceratophyllum* L.	+	+	+
3	*Hydrilla verticillata* (L. f.) Royle	+	+	+
4	*Limnophylla* sp.(unidentified)	+	+	+
5	*Ludwigia adsendens* (L.) H.Hara	-	+	+
6	*Marsilea minuta* L.	-	+	+
7	*Nymphaea alba* L.	+	+	+
8	*Nymphea rubra* Roxb. Ex Saliab	+	+	+
9	*Panicum repens* L.	-	+	+
10	*Persicaria glabra* (Willdenow) M. Gómez de la Mazay	-	+	+
11	*Pistia stratiotes* L.	-	+	+
12	*Salvinia molesta* Mitchel	+	+	+
13	*Schaenoplecitiella articulata* L.	-	+	-
14	*Utricularia vulgaris* L.	+	+	+
15	*Vallisnaria* sp.(unidentified)	-	-	+

Legend: SL = Syngenta Lake; KP = Khandola Pond; LL = Lotus Lake; CL = Curtorim Lake.

Plate 5

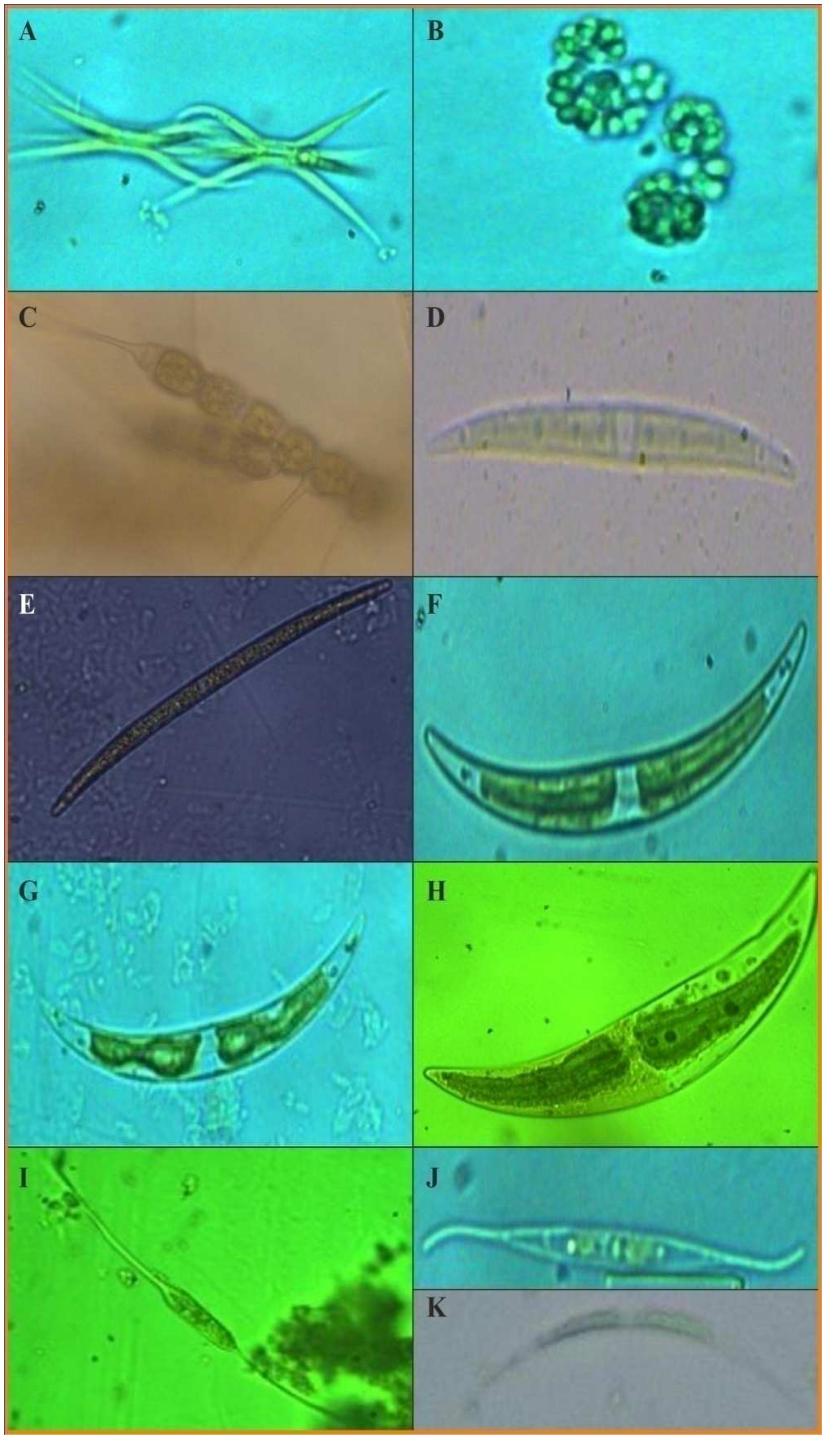

Plate 5

Phytoplanktons - (Chlorophyceae members)

A. *Ankistrodesmus falcatus var. tumidus*

B. *Botryococcus braunii* Kutzing

C. *Bulbochaete setigera* C. *Agardh* ex Hirn.

D. *Closterium bailyanum* Brebisson

E. *Closterium liniatum* Ehrenberg ex Ralfs

F. *Closterium nematodes* var. *microteres* Skuja

G. *Closterium porrectum* Nordst

H. *Closterium ehrenbergii* Menagh

I. *Closterium kuetzingii* Brebisson

J. *Closterium setacum* Ehrenberg ex Ralfs

K. *Clostredium diane* Ehrenberg

Plate 6

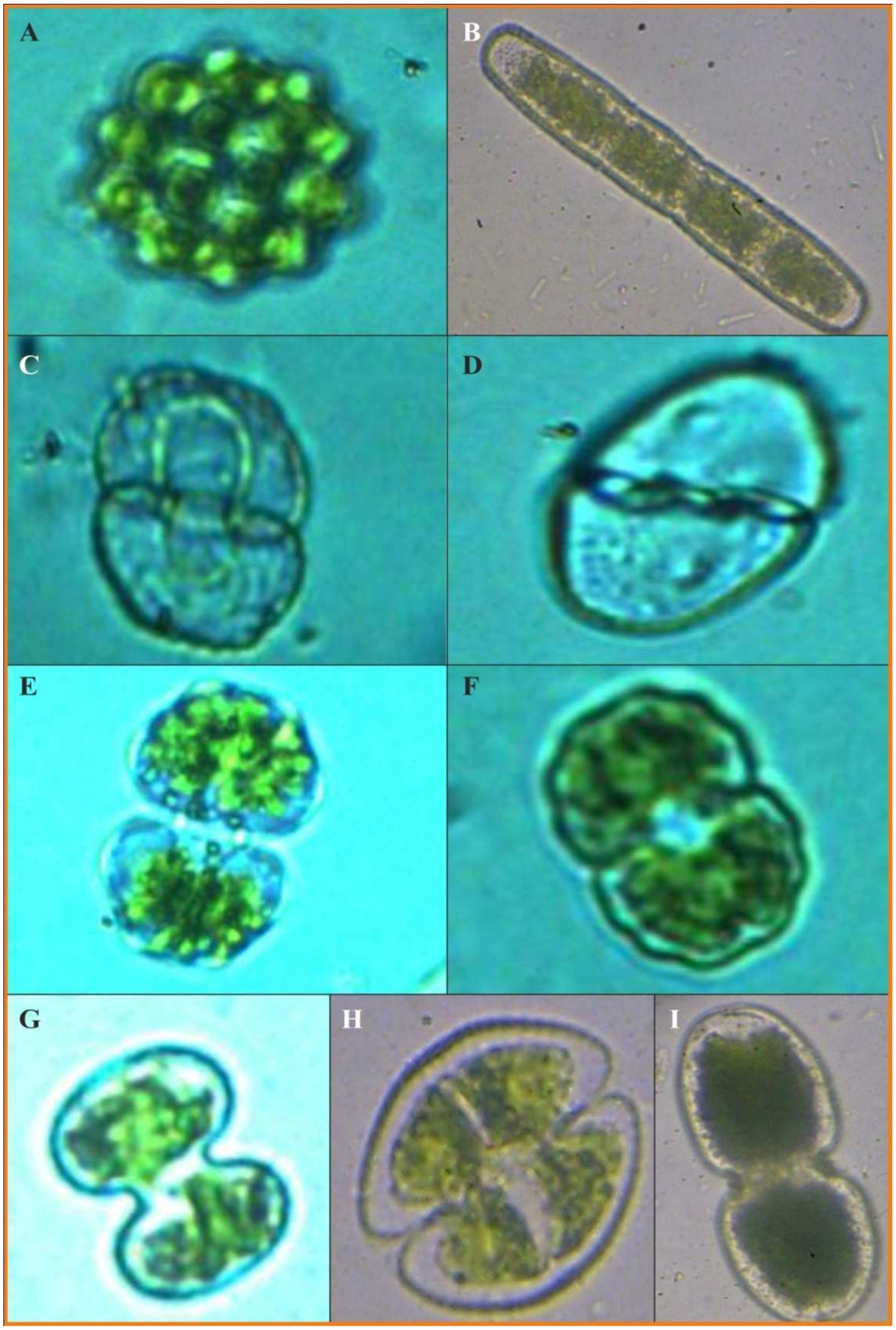

Plate 6

Phytoplanktons - (Chlorophyceae members)

A. *Coelastrum microporum* Nageli

B. *Cosmarium cucurbitinum* var. *longum* A. M. Scott and Gronblad

C. *Cosmarium reniformae* (Ralfs) W. Archer

D. *Cosmarium granatum* Brebisson ex Ralfs

E. *Cosmarium contractum* Kirchner

F. *Cosmarium dubium* Borgeo

G. *Cosmarium subretusiforme* West and West

H. *Cosmariuml undelii* Belf

I. *Cosmarium maculatum* Turner

Plate 7

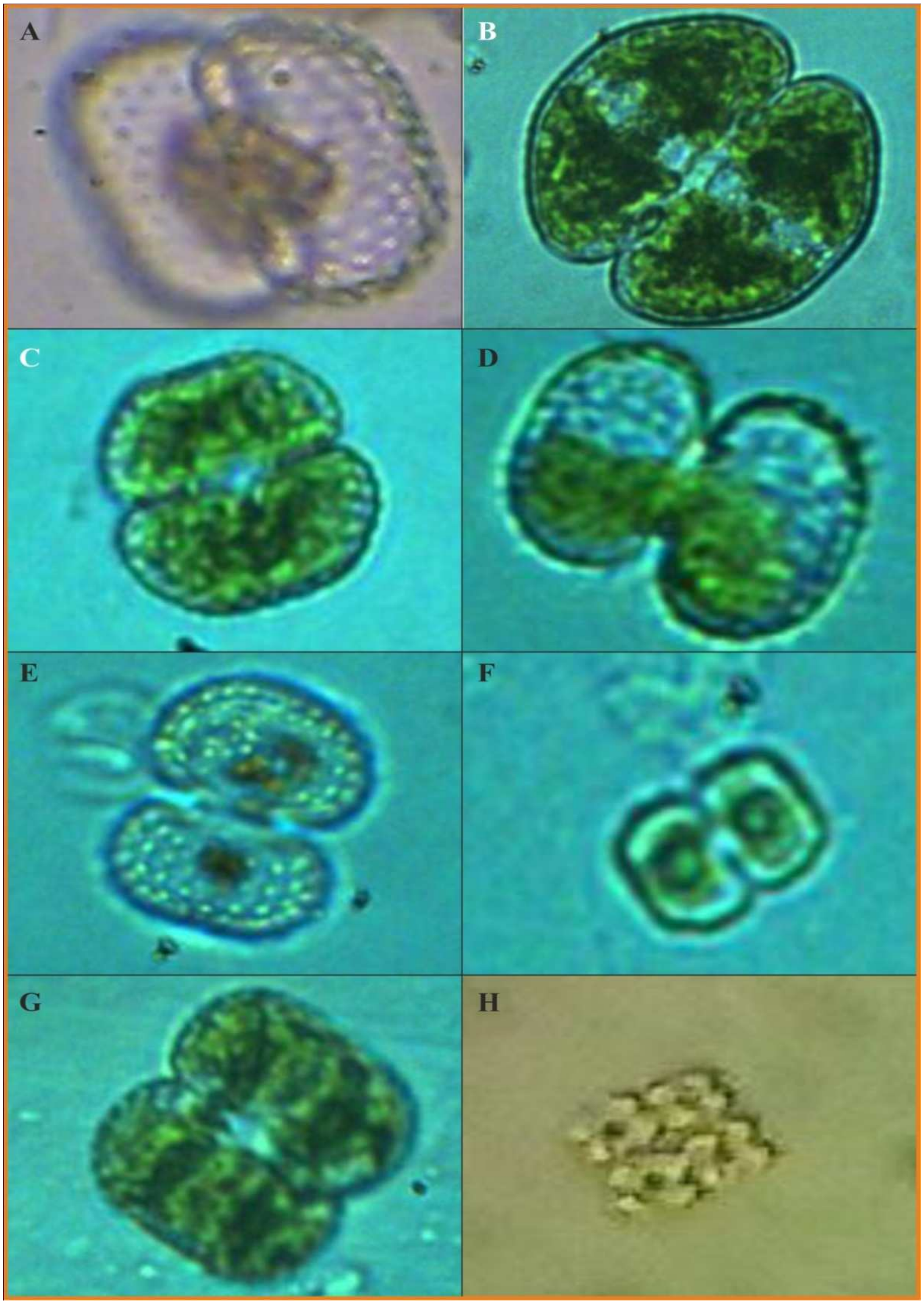

Plate 7

Phytoplanktons - (Chlorophyceae members)

A. *Cosmarium margaritatum* (Lundell) J. Roy et Bisset

B. *Cosmarium obsoletum* (Hantzsch) Reins

C. *Cosmarium ordinatum* (Borges) West

D. *Cosmarium portianum* Archer

E. *Cosmarium punctulatum* Brebisson

F. *Cosmarium regnelli* Wille

G. *Cosmarium margaritaceaum* (Lund) Roy and Bisset

H. *Cruciginia quadrata* Morren

Plate 8

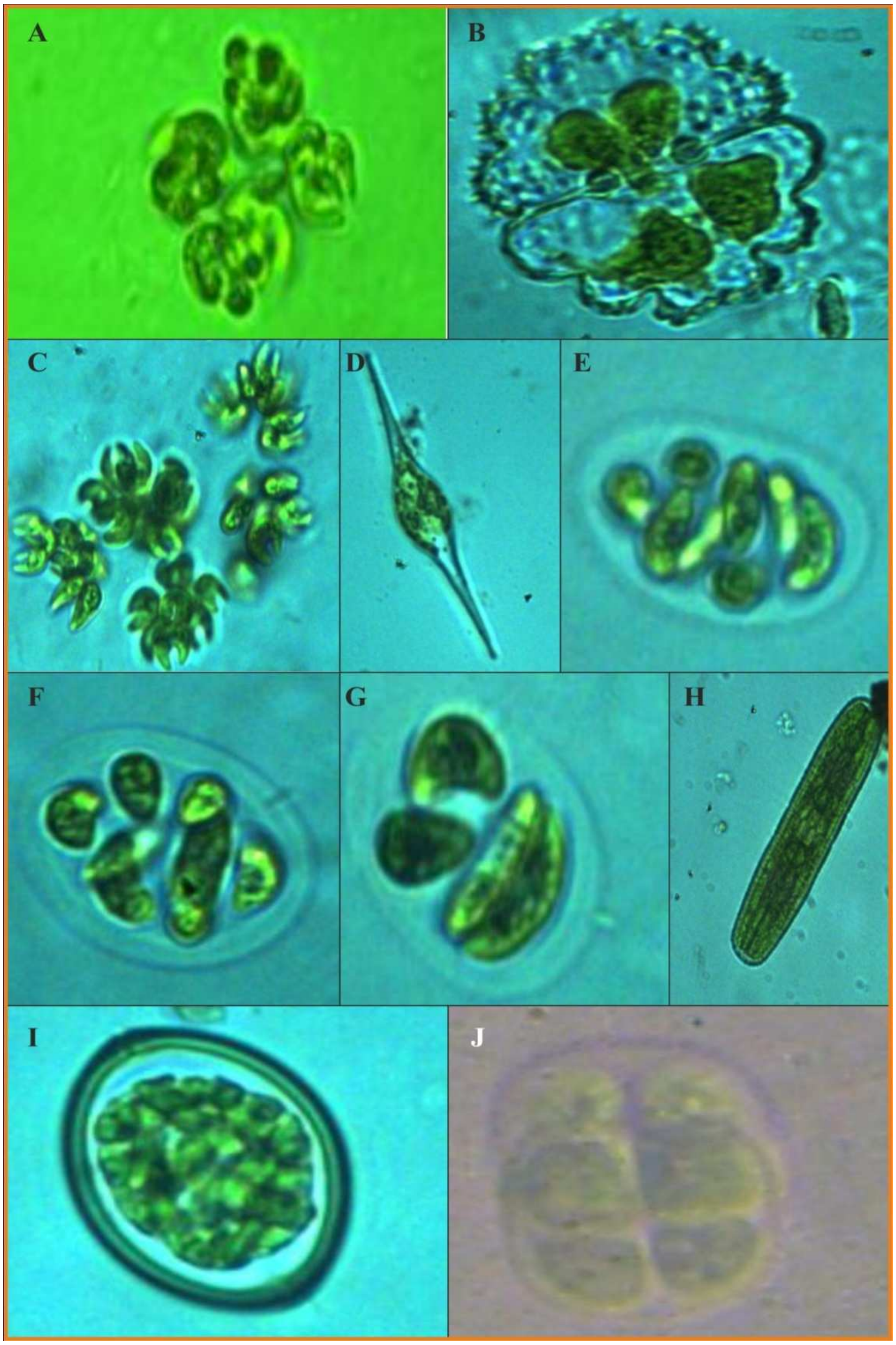

Plate 8

Phytoplanktons - (Chlorophyceae members)

A. *Dictyosphaerium pulchellum* H. C. Wood

B. *Euastrum spinulosum* Delponte

C. *Kirchneriella lunaris* (Kirchner)

D. *Korshikoviella limnetica* (Lemmermann) P. C. Silva

E. *Nephrocytiicum agardrianum* Nageli

F. *Nephrocetium limneticum* (G. M. Smith) G. M. Smith

G. *Nephrocyticum obesum* West & G. S. West

H. *Netrium digitus* (Brebisson ex Ralfs) Itzigsohn & Rothe

I. *Oocystis solitaria* Wittrock in Wittrock and Nordstedt

J. *Pandorina morum* Bory

Plate 9

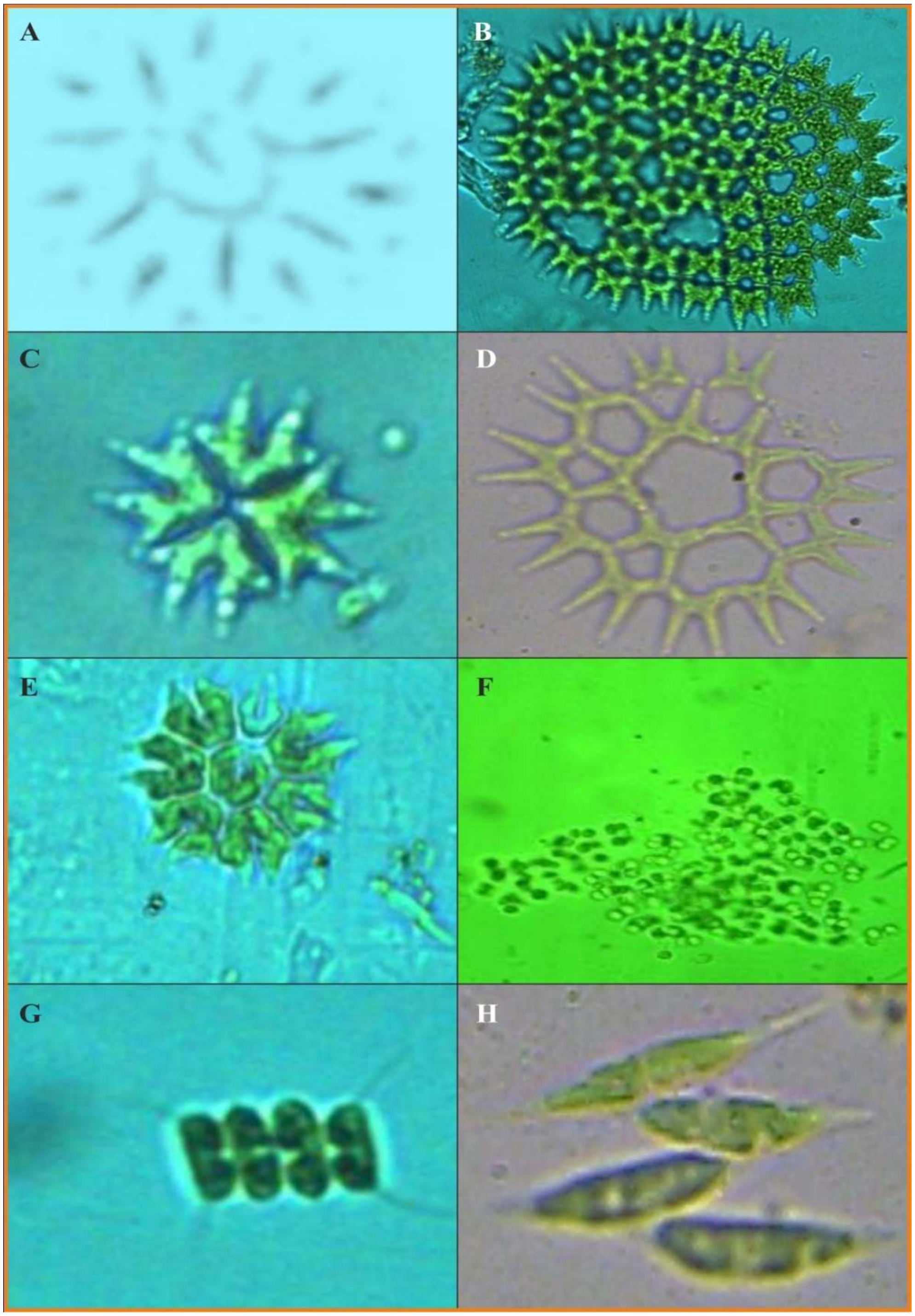

Plate 9

Phytoplanktons - (Chlorophyceae members)

A. *Pediastrum biradiatum* Meyen

B. *Pediastrum duplex* (cohaerans) Bohlin

C. *Pediastrum obtusum* Lucks

D. *Pediastrum duplex var. raticulatum* Lagerheim

E. *Pediastrum tetras* (Ehrenberg) Ralfs

F. *Protococcus viridis* C. Agardh

G. *Scenedesmus armatus* (Chodat)

H. *Scenedesmu sbernadii* G. M. Smith

Plate 10

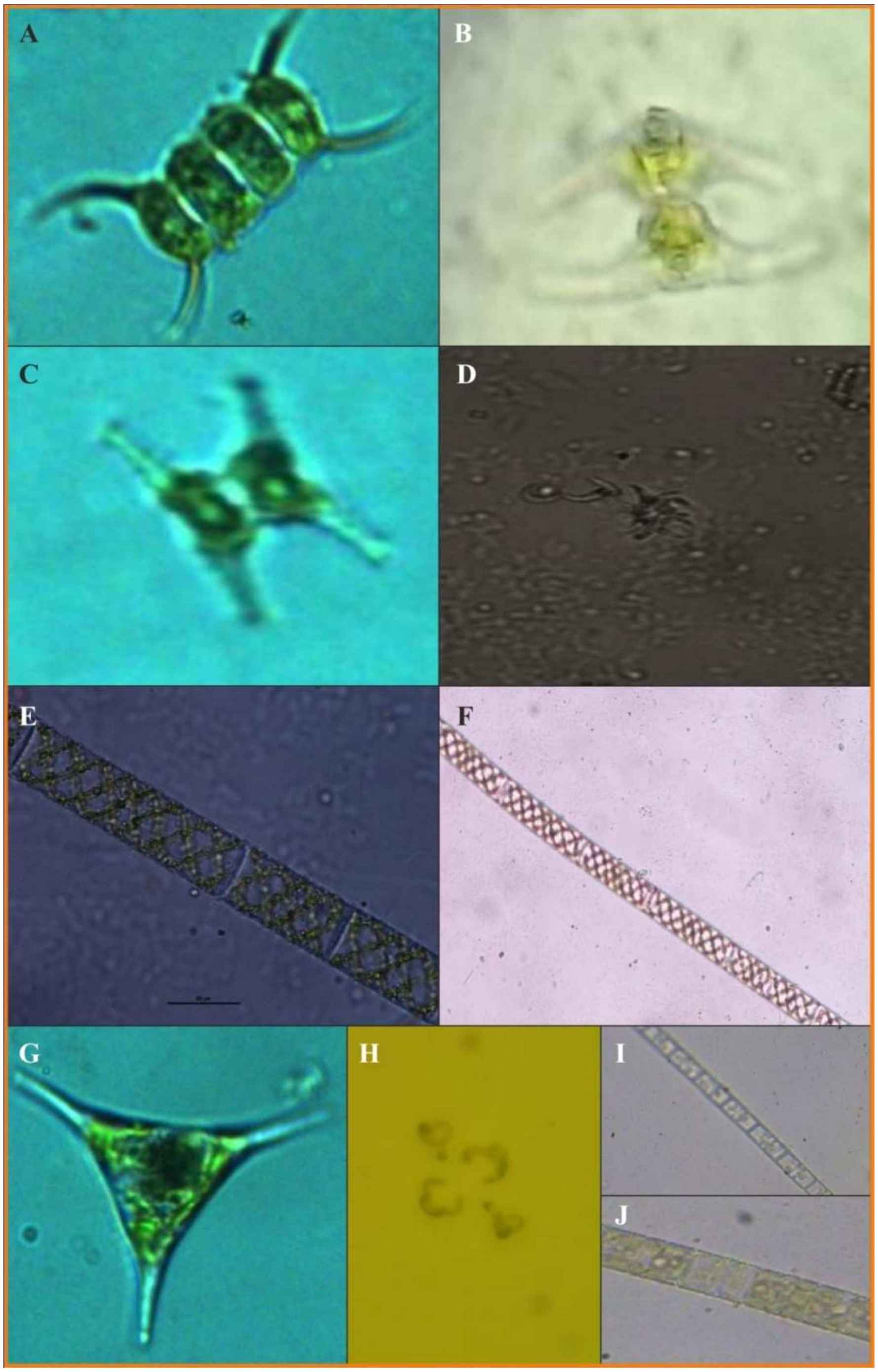

Plate 10

Phytoplanktons - (Chlorophyceae members)

A. *Scenesdesmus quadricauda* (Trupin)

B. *Strauastrum inflaxum* Brebisson

C. *Strauastrum thinimannii* Willi Krieger

D. *Selenastrum gracile* Reinsch

E. *Spirogyra crassa* Kutzing

F. *Spirogyra gratiana* Transeau

G. *Tetraederon trigonum* (Nageli) Hansgirg

H. *Tetralantus lagerheimii* (Tiling)

I. *Ulothrix cylindricum* Kuetzing

J. *Ulothrix zonata* (Weber et Mohr) Kutzing

Plate 11

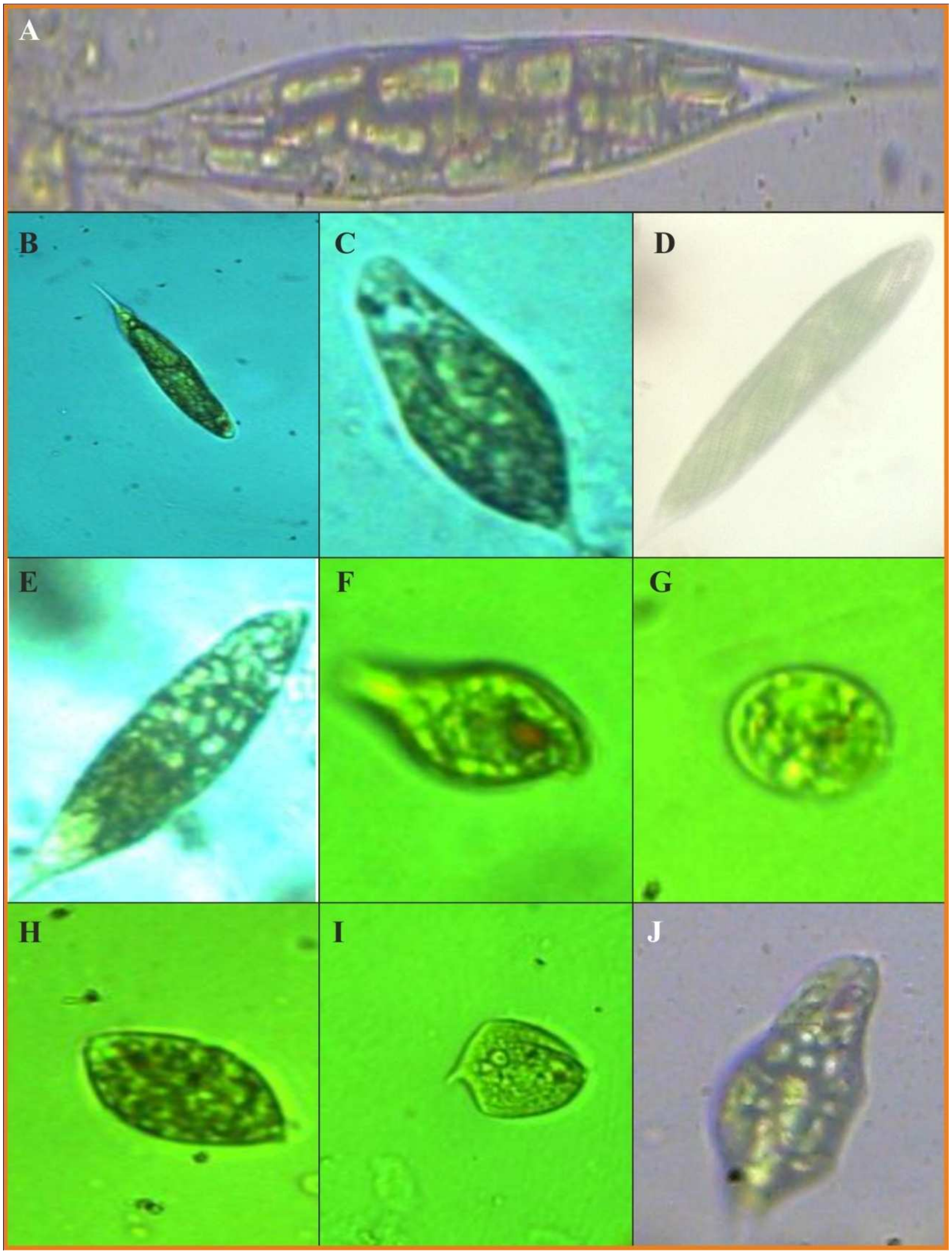

Plate 11

Phytoplanktons - (Euglenophyceae members)

A. *Euglena acus* (O. Muller) Ehrenberg

B. *Eugnena elongate* Schewiakoff

C. *Euglena gracilis* Klebs

D. *Euglena oxyuriss* Schmarda

E. *Euglena polymorpha* P. A. Dangeard

F. *Euglena proxima* Dangeard

G. *Lepocinclis ovum* Ehrenberg

H. *Liponcinclisf usiformis var. major*

I. *Phacus curvicauda* Swirenko

J. *Phacus asymmetrica* Prescott

Plate 12

Plate 12

Phytoplanktons - (Euglenophyceae members)

A. *Phacus chloroplastus*

B. *Trachlomonas charkoweinsis* Swirenko

C. *Trachalomona volvocina* Ehrenberg

Plate 13

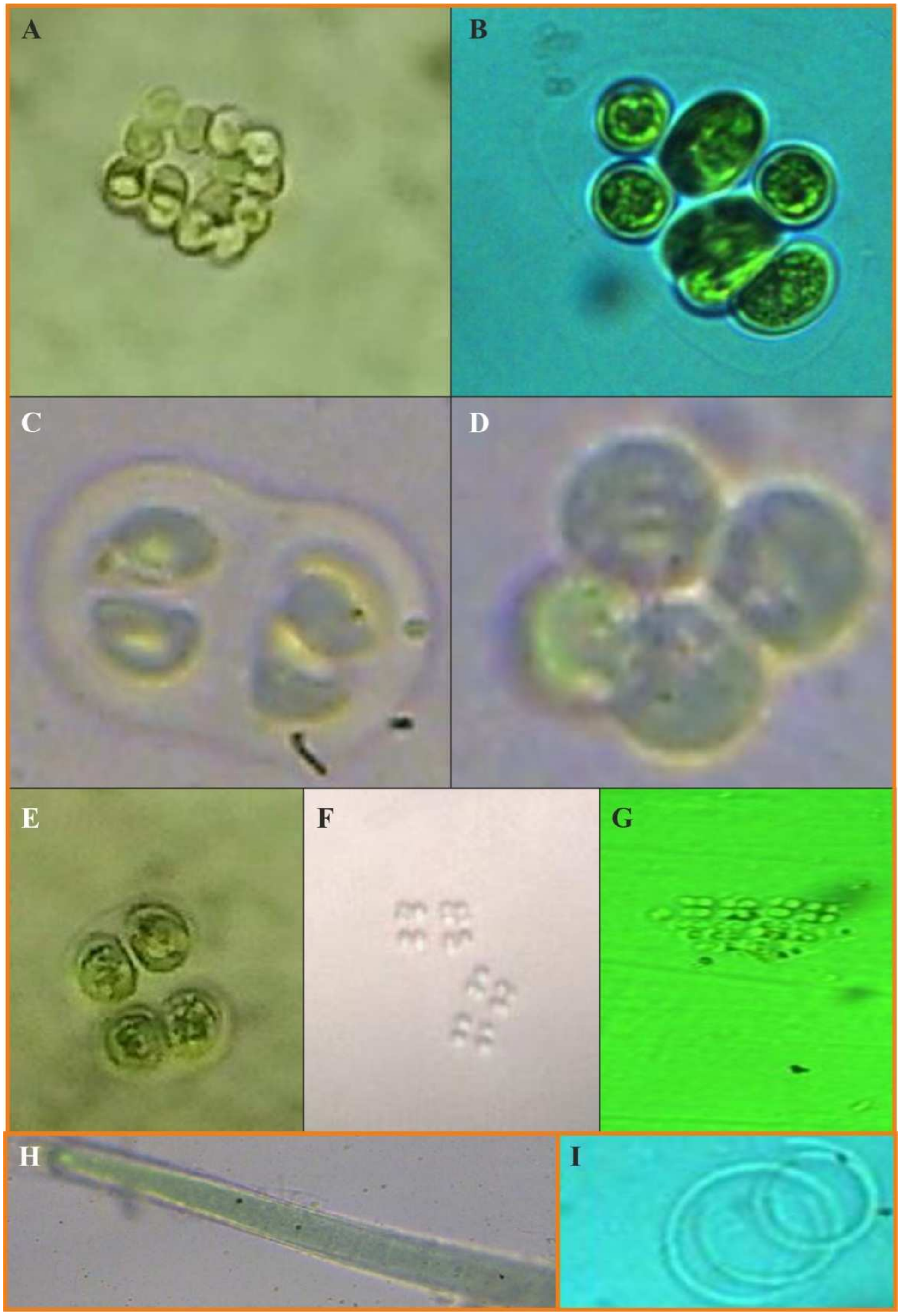

Plate 13

Phytoplanktons - (Cyanophyceae members)

A. *Chroococcus dispersus* (Keissler) Lemmermann

B. *Chroococcus limnaticus* Lemmermann

C. *Chroococcus minor* Kutzing

D. *Chroococcus prescotti* Drouet and Dialr

E. *Chroococcus varius* A. Braun in Rabenhorst

F. *Merismopedia punctata* Meyen

G. *Merismpedia tennussima* Lemmerman

H. *Oscilatoria princeps* Vaucher *ex* Gomont

I. *Spirulina nordestedii* Gommont

Plate 14

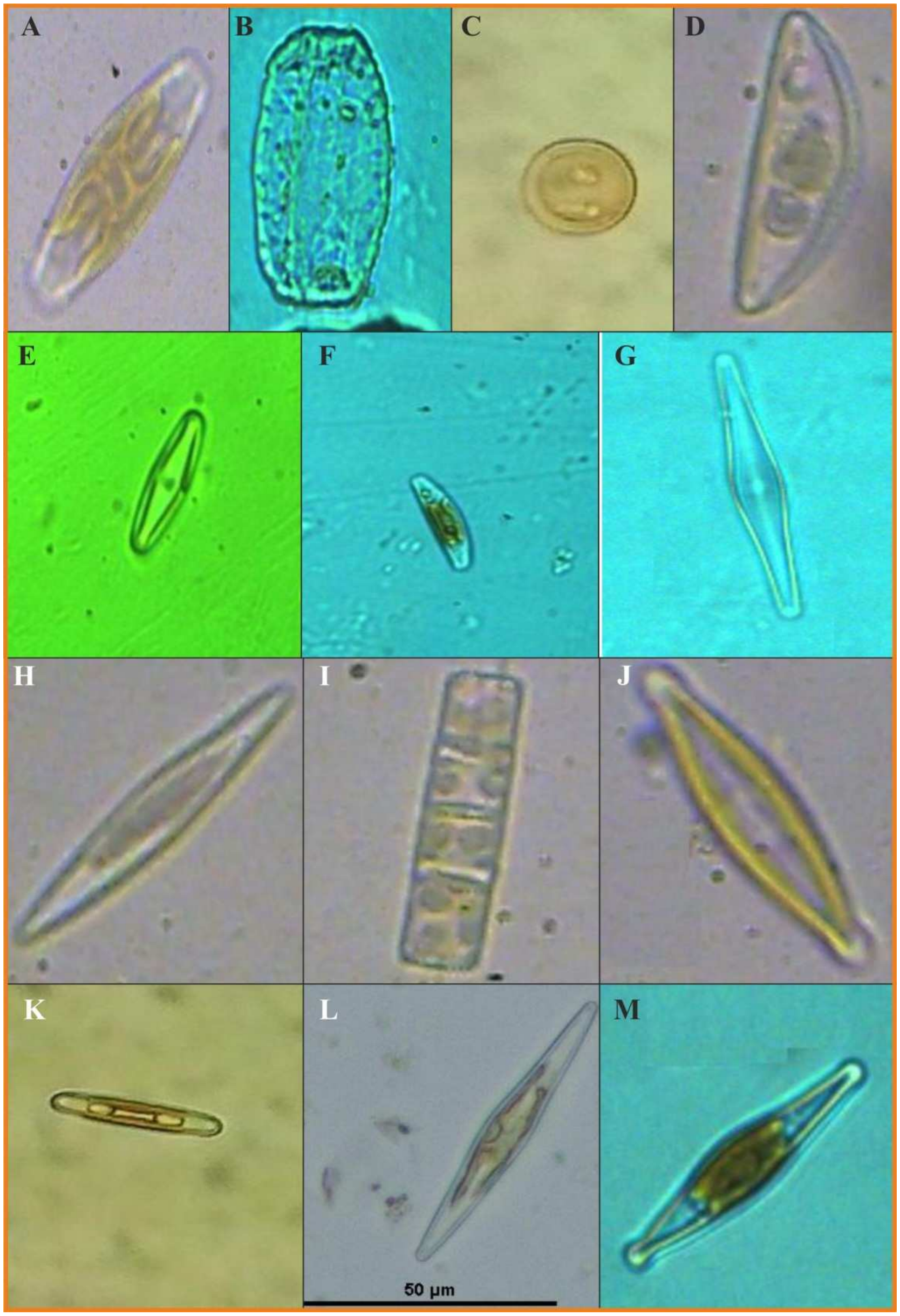

Plate 14

Phytoplanktons - (Bacillariophyceae members)

A. *Ahninthes exigua* Gurnow

B. *Amphora ovalis* (Kutzing) Kutzing

C. *Cocconeis placentula* Ehrenberg

D. *Cymbella chandolensis* Gandhi

E. *Diploneis elliptica* (Kutzing) Cleve

F. *Eunotia tumida* Gandhi

G. *Gomphonema subtiles* Ehrenbe

H. *Gomphonema parabolum* Kuetzing

I. *Melosira islandica* O. Muller

J. *Navicula halophila* (Gurnow) Cleve

K. *Navicula mutica* Kutzing

L. *Navicula radiosa* Kutzing

M. *Navicula rhynococephala*

Plate 15

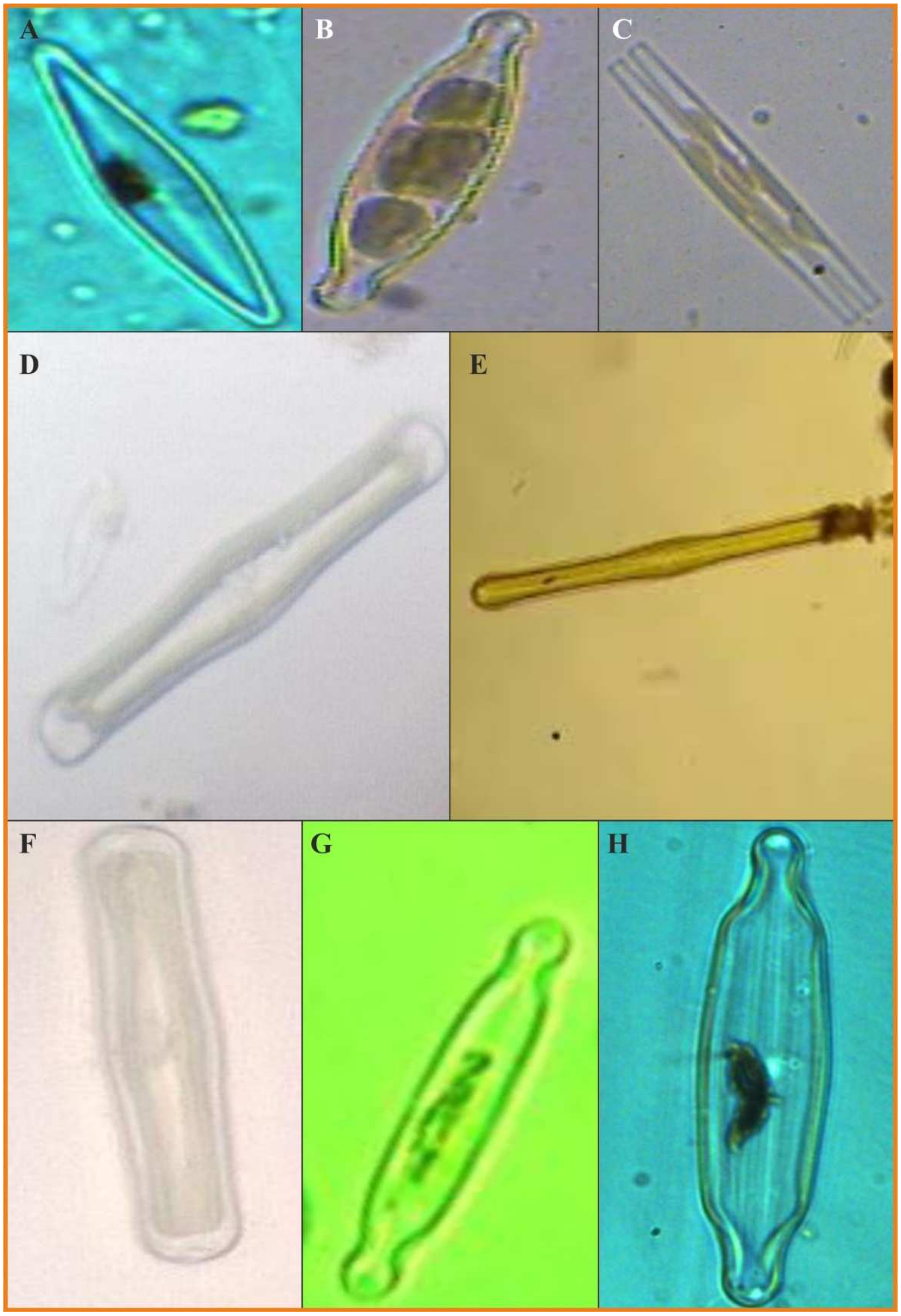

Plate 15

Phytoplanktons - (Bacillariophyceae members)

A. *Navicula microcephala* Grunow

B. *Navicula sphaerophora* Kutzing

C. *Synedra ulna* (Nitzsch) Ehrenberg

D. *Pinnularia dolosa* H. P. Gandhi

E. *Pinnularia gibba* Ehrenberg

F. *Pinnularia graciloids* Huste

G. *Stauroneis anceps* Ehrenberg

H. *Stauroneis phoenicenteron* (Nitzsch) Ehrenberg

Table 20: Phytoplanktons (Chlorophyceae members) isolated from the study sites.

Sr. No.	Species	SL	KP	LL	CL
1	*Actinastrum hantzschii* var. elongatum	+	-	+	+
2	*Ankistrodesmus falcatus* (Corda) Ralfs	+	-	+	+
3	*Ankistrodesmus falcatus var. tumidus*	+	-	+	+
4	*Botryococcus braunii* Kutzing	+	-	+	+
5	*Bulbochaete setigera* C. *Agardh* ex Hirn.	+	-	-	+
6	*Closterium baillyanum* Brebisson	+	-	+	+
7	*Closterium ehrenbergii* Menagh	+	-	+	+
8	*Closterium lineatum* Ehrenberg ex Ralfs	+	-	+	+
9	*Closterium navicula* (Brebisson) Lutkemuller	+	-	+	+
10	*Closterium nematodes* var. *microteres* Skuja	+	-	+	+
11	*Closterium porrectum* Nordst	+	-	+	+
12	*Closterium setaceum* Ehrenberg ex Ralfs	+	-	+	+
13	*Closterium kuetzingii* Brebisson	+	-	+	+
14	*Closterium turgidum* Ehrenberg ex Ralfs	+	-	+	+
15	*Clostredium diane* Ehrenberg	+	-	+	+
16	*Coelastrum microporum* Nageli	+	-	+	+
17	*Cosmarium subretusiforme* West and West	+	-	+	+
18	*Cosmarium bioculatum* (Breb) ex Ralfs	+	-	+	+
19	*Cosmarium contractum* Kirchner	+	-	+	+
20	*Cosmarium dubium* Borgeo	+	+	+	+
21	*Cosmarium granatum* Brebisson	+	-	+	+
22	*Cosmarium granatum* Brebisson ex Ralfs	+	-	+	+
23	*Cosmarium lundellii* Belf	+	-	+	+
24	*Cosmarium maculatum* Turner	+	-	+	+
25	*Cosmarium obsoletum* (Hantzsch) Reins	+	-	+	+
26	*Cosmarium ordinatum* (Borges) West	+	-	+	+
27	*Cosmarium porrectum* Nordst	+	-	+	+
28	*Cosmarium portianum* Archer	+	-	+	+
29	*Cosmarium punctulatum* Brebisson	+	+	+	+
30	*Cosmarium regnellii* Wille	+	+	+	+
31	*Cosmarium ceylanicum* West & G.S.West	+	+	+	+
32	*Cosmarium cucurbitinum* var. *longum* A.M. Scott & Gronblad	+	-	+	+
33	*Cosmarium margaritatum* (P. Lundell) J.Roy & Bisset	+	-	+	+
34	*Cosmarium margaritaceaum* (Lund) Roy and Bisset	+	-	+	-
35	*Cosmerium reniformae* (Ralfs) W. Archer	+	-	+	+
36	*Crucigenia quadrata* Morren	+	-	+	+
37	*Dictyosphaerium pulchellum* H.C.Wood	-	-	+	-
38	*Euastrum ansatum* Ehrenberg	+	+	+	+
39	*Euastrum spinulosum* Delponte	+	+	+	+

(Contd.)

40	*Kirchneriella lunaris* (Kirchner)	+	-	+	+
41	*Kirchneriella obsa* (Teil)	+	-	+	+
42	*Korshikoviella limnetica* (Lemmermann) P.C.Silva	-	-	+	-
43	*Nephrocytium agardrianum* Nageli	+	-	+	+
44	*Nephrocytium obesum* West & G.S.West	+	-	+	+
45	*Nephrocytium limneticum* G.M.Smith	+	-	+	-
46	*Nephrocytium lunatum* W. West	+	-	-	+
47	*Netrium digitus* (Brebisson ex Ralfs) Itzigsohn & Rothe	+	+	+	+
48	*Oocystis solitaria* Wittrock in Wittrock & Nordstedt	+	-	+	+
49	*Oocystis gigas* W. Archer	+	-	+	+
50	*Pandorina morum* Bory	-	-	+	+
51	*Pediastrum biradiatum* Meyen	+	-	+	+
52	*Pediastrum duplex* cohaerans (Bohlin)	+	-	+	+
53	*Pediastrum duplex* var. *reticulatum* Lagerheim	+	-	+	+
54	*Pediastrum duplex* var. *gracillimum* West and West	+	+	+	+
55	*Pediastrum obtusum* Lucks	+	+	+	+
56	*Pediastrum tetras* (Ehrenberg) Ralfs	+	+	+	+
57	*Protococcus viridis* C. Agardh	+	-	+	+
58	*Scenedesmus aculeolatus* (Kirchin.) Chodat	+	-	+	+
59	*Scenedesmus armatus* (Chodat)	+	-	+	+
60	*Scenedesmus bernardii* G.M. Smith	+	-	+	+
61	*Scenedesmus dimorphus* (Turpin) Kützing	+	-	+	+
62	*Scenedesmus oahulesis* (Lemmerman)	+	-	+	+
63	*Scenedesmus quadricauda* (Trupin)	+	-	+	+
64	*Sehroederia indica* Philipose	+	-	+	+
65	*Selanestrum gracile* Reinsch	+	-	+	+
66	*Spirogyra crassa* Kutzing	+	-	+	+
67	*Spirogyra gratina* Transeau	+	-	+	+
68	*Staurastrum contractum* Teiling	+	-	+	+
69	*Staurastrum thienemannii* Willi Krieger	+	+	+	+
70	*Staurastrum inflexum* Brebisson	+	-	+	+
71	*Tetraedron trigonum* (Nageli) Hansgirg	+	-	+	+
72	*Tetralantus lagerheimii* (Tiling)	-	-	+	-
73	*Ulothrix cylindricum* Kuetzing	+	-	+	+
74	*Ulothrix zonata* (Weber et Mohr) Kutzing	+	-	+	+

Legend: SL- Syngenta Lake, KP- Khandola Pond, LL- Lotus Lake, CL- Curtorim Lake.

Table 21: Phytoplanktons (Euglenophyceae members) isolated from the study sites.

Sr. No.	Species	SL	KP	LL	CL
1	*Euglena acus* (O. Muller) Ehrenberg	+	-	+	+
2	*Euglena elongata* Schewiakoff	+	-	+	+
3	*Euglena gracilis* Klebs	+	-	+	+
4	*Euglena minuta* Prescott	+	+	+	+
5	*Euglena oxyuris*s Schmarda	+	+	+	+
6	*Euglena polymorpha* P.A. Dangeard	+	-	+	+
7	*Euglena proxima* Dangeard	+	-	+	+
8	*Leponcinclis fusiformis var. major*	+	-	+	+
9	*Leponcinclis ovum* Ehrenberg	+	-	+	+
10	*Leponcinclisfusiformis* (H. J. Carter) Lemmerman	+	-	+	+
11	*Phacus asymmetrica* Prescott	+	-	+	+
12	*Phacus chloroplastus*	+	-	+	+
13	*Phacus curvicauda* Swirenko	+	-	+	+
14	*Trachalomonas charcoviences* Swirenko	+	-	+	+
15	*Trachalomonas rotunda* Swirenko	+	-	+	+
16	*Trachalomonas volvocina* Ehrenberg	+	-	+	+

Legend: SL = Syngenta Lake; KP = Khandola Pond; LL = Lotus Lake; CL = Curtorim Lake.

Table 22: Phytoplanktons (Cyanophyceae members) isolated from the study sites.

Sr. No.	Species	SL	KP	LL	CL
1	*Anabaena circinalis*	+	-	+	+
2	*Chroococcus limnaticus* Lemmermann	+	-	+	+
3	*Chroococcus minor* Kutzing	+	-	+	+
4	*Chroococcus pallidus* (Nageli) Nageli	+	-	+	+
5	*Chroococcus prescottii* Drouet and Dialr	+	-	+	+
6	*Chroococcus varius* A. Braun in Rabenhorst	+	+	+	+
7	*Chroococcus dispersus* (Keissler) Lemmermann	+	-	+	+
8	*Gomphosphaeria lacustris* Chodat	+	-	+	+
9	*Merismopedia* sp. (unidentified)	+	+	+	+
10	*Merismopedia punctata* Meyen	+	-	+	+
11	*Merismopedia tenuissima* Lemmerman	+	-	+	+
12	*Nostoc* sp. (unidentified)	+	-	+	+
13	*Oscillatoria princeps* Vaucher *ex* Gomont	+	-	+	+
14	*Spirulina nordestedii* Gommont	+	-	+	+

Legend: SL = Syngenta Lake; KP = Khandola Pond; LL = Lotus Lake; CL = Curtorim Lake.

Table 23: Phytoplanktons (Baillariophyceae members) isolated from the study sites.

Sr. No.	Species	SL	KP	LL	CL
1	*Ahninthes exigua* Gurnow	+	-	+	+
2	*Amphora ovalis* (Kutzing) Kutzing	+	-	+	+
3	*Cocconeis placentula* Ehrenberg	+	+	+	+
4	*Cymbella chandolensis* Gandhi	+	-	+	+
5	*Diploneis elliptica* (Kutzing) Cleve	+	-	+	+
6	*Eunotia tumida* Gandhi	+	-	+	+
7	*Gomphonema parabolum* Kuetzing	+	-	+	+
8	*Gomphonema subtiles* Ehrenberg	+	-	+	+
9	*Melosira islandica* O. Muller	+	-	+	+
10	*Navicula halophila* (Gurnow) Cleve	+	+	+	+
11	*Navicula microcephala* Grunow	+	-	+	+
12	*Navicula radiosa* Kutzing	+	+	+	+
13	*Navicula rhynococephala*	+	+	+	+
14	*Navicula mutica* Kutzing	+	+	+	+
15	*Navicula sphaerophora* Kutzing	+	-	+	+
16	*Pinnularia dolosa* H.P.Gandhi	+	+	+	+
17	*Pinnularia gibba* Ehrenberg	+	-	+	+
18	*Pinnularia graciloids* Huste	+	-	+	+
19	*Stauroneis phoenicenteron* (Nitzsch) Ehrenberg	+	-	+	+
20	*Stauroneis anceps* Ehrenberg	+	-	+	+
21	*Synedra ulna* (Nitzsch) Ehrenberg	+	-	+	+

Legend: SL = Syngenta Lake; KP = Khandola Pond; LL = Lotus Lake; CL = Curtorim Lake.

centrifuged samples they were not counted for organisms per drop) and floating debris. One litre of sample was centrifuged to make the final volume to 10 ml. (the sample was adjusted to 20 or 10 ml depending on the phytoplankton density). The phytoplanktons identified were recorded as organisms per drop **(Tables 24** to **31)**.

Correlations were drawn between physico-chemical parameters and frequently occurring phytoplanktons. Positive and negative correlations between physico-chemical parameters and phytoplanktons were observed. The study revealed that variations in the concentration levels of the parameters like temperature, turbidity, DO, BOD, nitrates and phosphates were responsible for fluctuation in phytoplankton density.

5.4.1: Correlations observed in Syngenta Lake

Cosmarium subretusiforme, Scenedesmus armatus, Chroococcus disparus, Pinnularia dolosa, Navicula halophila and pH were negatively correlated while positive correlation was seen between *Cosmarium ordinatum, Euglena minuta, Trachalomonas volvocina, Ch. disparus* and temperature. *T. volvocina* and *P. dolosa* were positively correlated with turbidity. Negative correlation was seen between *E. minuta, T. volvocina, Spirulina nordesttedii, P. dolosa* and DO where as *C. ordinatum, T. volvocina, S. nordesttedii* and *N. halophila* showed positive correlation with BOD. *Cosmarium subretusiformae, E. minuta, T. volvocina, P. dolosa, N. halophila* and nitrates showed positive correlation while *C. ordinatum, S. armatus, E. minuta,* and *Ch. disparus* showed positive correlation with phosphates. *Cosmarium subretusiforme, E.minuta, T. volvocina, Ch. disparus, S. nordesttedii* and *N. halophila* were positively correlated with total chlorophyll. *Cosmarium ordinatum* was inversely proportional to

Table 24: Distribution of phytoplanktons in Syngenta Lake during Jan 2014 - Dec. 2014 (Organisms/drop).

Species	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sept- 14	Oct- 14	Nov- 14	Dec-14
Cosmarium subretusiforme	1	4	1	1	4	12	0	1	2	1	2	2
Cosmarium ordinatum	3	2	2	10	4	3	2	1	1	3	2	2
Scenedesmus armatus	5	2	1	8	3	2	1	3	0	5	2	2
Euglena minuta	0	2	0	3	9	6	4	0	0	4	5	2
Trachalomonas volvocina	3	5	3	4	8	7	5	0	0	4	3	2
Chroococcus dispersus	6	7	12	7	7	10	10	6	7	10	6	4
Spirulina nordestedii	6	7	19	12	15	8	6	4	3	7	4	0
Pinnularia dolosa	3	3	2	2	2	4	2	1	1	3	1	1
Navicula halophila	4	6	2	3	5	3	1	1	2	2	1	1

Table 25: Distribution of phytoplanktons in Syngenta Lake during Jan 2015 - Dec. 2015 (Organisms/drop).

Species	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sept- 14	Oct- 14	Nov- 14	Dec-14
Cosmarium subretusiforme	3	4	1	3	7	4	4	2	2	2	3	2
Cosmarium ordinatum	3	2	7	10	4	3	2	1	0	3	2	2
Scenedesmus armatus	4	2	1	8	3	2	1	3	1	5	2	2
Euglena minuta	4	5	0	4	6	6	5	3	3	4	3	4
Trachalomonas volvocina	3	2	3	9	5	6	4	3	3	7	4	3
Chroococcus dispersus	3	6	8	10	19	13	5	5	4	5	3	2
Spirulina nordestedii	3	7	10	12	15	10	6	4	3	5	3	0
Pinnularia dolosa	2	10	2	0	10	2	1	1	1	5	3	3
Navicula halophila	10	10	2	10	10	2	2	1	1	7	2	3

Table 26: Distribution of phytoplanktons in Khandola Pond during Jan 2014 - Dec. 2014 (Organisms/drop).

Species	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sept- 14	Oct- 14	Nov- 14	Dec-14
Staurastrum thienemannii	5	3	8	6	32	4	2	2	0	3	10	2
Netrium digitus	3	6	3	7	10	2	4	2	2	2	6	5
Pediastrum obtusum	3	9	2	5	6	0	0	0	2	1	2	5
Cosmarium dubium	3	9	3	3	0	0	0	0	3	0	2	10
Euastrum spinulosum	0	3	12	17	0	0	0	0	0	2	0	0
Euglena minuta	2	0	2	0	0	0	0	0	0	2	0	2
Euglena oxyuriss	0	0	0	3	3	3	1	0	0	0	0	0
Pinnularia dolosa	10	10	5	20	30	20	8	7	3	3	8	2
Navicula mutica	7	3	0	0	0	0	7	2	1	5	10	2
Navicula rhynococephala	3	8	8	18	4	9	2	2	1	10	10	7

Table 27: Distribution of phytoplanktons in Khandola Pond during Jan 2015 - Dec. 2015 (Organisms/drop).

Species	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sept. 14	Oct- 14	Nov- 14	Dec-14
Staurastrum thienemannii	6	3	8	6	34	4	2	5	1	6	10	2
Netrium digitus	4	6	3	7	10	2	4	2	2	2	6	5
Pediastrum obtusum	3	9	2	5	7	0	0	0	3	1	2	5
Cosmarium dubium	4	5	3	3	0	0	0	5	3	0	0	10
Euastrum spinulosum	0	3	10	17	0	0	0	3	5	4	0	0
Euglena minuta	2	0	2	0	0	0	0	0	0	2	0	2
Euglena oxyuriss	0	0	0	7	3	3	3	0	0	0	0	0
Pinnularia dolosa	9	10	15	32	31	14	12	5	0	3	2	2
Navicula mutica	5	10	7	0	0	0	1	1	1	7	4	2
Navicula rhynococephala	3	8	15	10	15	0	2	1	0	12	5	7

Table 28: Distribution of phytoplanktons in Lotus Lake during Jan 2014 - Dec. 2014 (Organisms/drop).

Species	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sept- 14	Oct- 14	Nov- 14	Dec-14
Scenedesmus dimorphus	3	4	2	1	3	1	3	1	0	2	5	1
Cosmarium contractum	3	2	1	1	1	3	3	1	1	2	4	4
Scenedesmus quadricauda	1	2	2	10	17	12	2	4	3	2	2	1
Ankistrodesmus falcatus	2	2	1	13	3	4	7	3	3	2	2	0
Euglena minuta	8	6	7	8	9	8	8	3	2	5	6	2
Trachalomonas volvocina	6	7	4	7	8	7	6	3	3	7	4	2
Chroococcus dispersus	4	6	7	10	12	15	15	7	4	5	3	2
Gomphosphaeria lacustris	7	12	10	0	17	0	0	3	0	8	6	3
Gomphonema parabolum	3	3	6	6	0	2	1	1	0	2	2	1

Table 29: Distribution of phytoplanktons in Lotus Lake during Jan 2015 - Dec. 2015 (Organisms/drop).

Species	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sept- 14	Oct- 14	Nov- 14	Dec-14
Scenedesmus dimorphus	3	4	2	1	6	1	3	4	3	8	5	4
Cosmarium contractum	7	2	1	1	1	3	3	0	0	2	4	4
Scenedesmus quadricauda	1	2	2	10	17	12	2	4	1	2	2	1
Ankistrodesmus falcatus	4	7	10	13	10	7	5	3	2	9	4	5
Euglena minuta	6	5	7	8	9	7	6	3	2	9	5	4
Trachalomonas volvocina	5	6	4	9	8	7	6	3	1	6	4	3
Chroococcus dispersus	6	7	15	10	18	12	8	2	5	10	8	7
Gomphosphaeria lacustris	0	16	3	8	16	6	7	3	0	10	3	3
Gomphonema parabolum	5	8	10	14	12	8	0	3	0	5	2	6

Table 30: Distribution of phytoplanktons in Curtorim Lake during Jan 2014 - Dec. 2014 (Organisms/drop).

Species	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sept- 14	Oct- 14	Nov- 14	Dec-14
Cosmarium regnellii	2	1	1	3	1	2	2	2	1	3	1	2
Cosmarium obsoletum	2	2	15	2	12	2	0	0	1	2	0	4
Scenedesmus bernardii	2	3	1	1	3	4	0	0	0	4	2	2
Actinastrum hantzschii var elongatum	2	4	2	1	1	2	3	2	2	2	1	2
Trachalomonas volvocina	8	3	6	8	8	8	8	3	2	4	4	4
Lepocinclis fusiformis	4	8	8	9	9	9	9	0	0	7	4	7
Chroococcus dispersus	8	11	10	10	10	30	12	10	3	10	6	3
Gomphosphaeria lacustris	6	9	19	0	20	0	3	5	0	7	4	3
Synedra ulna	3	3	2	3	6	2	1	1	1	6	2	1

Table 31: Distribution of phytoplanktons in Curtorim Lake during Jan 2015 - Dec. 2015 (Organisms/drop).

Species	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sept- 14	Oct- 14	Nov- 14	Dec-14
Cosmarium regnellii	4	4	6	8	9	2	2	0	0	0	3	4
Cosmarium obsoletum	4	2	15	8	12	5	0	0	2	4	0	3
Scenedesmus bernardii	2	3	4	9	12	4	0	1	0	2	2	2
Actinastrum hantzschii var elongatum	2	4	2	15	1	2	0	0	2	2	1	2
Trachalomonas volvocina	3	3	4	8	8	10	8	3	2	10	4	4
Lepocinclis fusiformis	10	8	10	7	9	7	9	0	0	5	4	7
Chroococcus dispersus	8	7	17	8	32	9	26	4	6	8	3	4
Gomphosphaeria lacustris	9	15	10	15	23	17	4	5	0	10	4	3
Synedra ulna	3	1	2	3	4	1	1	2	1	3	1	1

C. subretusiformae while there was positive correlation between *T. volvocina, E. minuta, S. nordestedii* and *Ch. disperus* and *N. halophila* and *P. dolosa* **(Table 32)**.

5.4.2: Correlations observed in Khandola Pond

Staurastrum thienemannii, Euastrum spinulosum, Navicula mutica were inversely proportional to pH whereas positive correlation was observed between *S. thienemannii, E. spinulosum, Euglena oxyuriss, E. minuta, P. dolosa* and temperature. *Euastrum spinulosum* and *E. minuta* were positively correlated with turbidity. Negative correlation was seen between *S. thienemannii, Netrium digitus, Pediastrum obtusum, E. minuta, P. dolosa, N. mutica* and DO. BOD was below detectable level. Positive correlation was observed between *E. spinulosum, E. oxyuriss, E. minuta, P. dolosa* and nitrates. There was positive correlation between *E. spinulosum, E. oxyuriss, E. minuta* and phosphates. *Staurastrum thienemannii, E. spinulosum, E. oxyuriss, E. minuta* and *N. mutica* were positively correlated with total chlorophyll. *Euastrum spinulosum* was inversely proportional to *S. thienemannii* while there was positive correlation between *E. minuta* and *E. oxyuriss* and *N. rhynococephala*, and *P. dolosa* **(Table 33)**.

5.4.3: Correlations observed in Lotus Lake

Cosmarium contractum showed positive correlation with pH, whereas *Ankistrodesmus falcatus, Chroococcus disperses* and *Gomphonema parabolum* showed negative correlation. *Scenedesmus quadricauda, Trachalomonas volvocina, Ch. disperses Gomphosphaeria lacustris* showed positive correlation with temperature. *Cosmarium contractum* showed negative correlation with turbidity whereas *A. falcatus, Ch. disperses* showed positive correlation with turbidity. *Scenedesmus dimorphus, A.*

Table 32: Correlation between Physico-chemical parameters and phytoplanktons for Syngenta Lake.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1																	
2	.053	1																
3	-.169	.105	1															
4	.357	**.600****	.265	1														
5	.429*	-.457*	-.398	-.122	1													
6	-.344	.459*	.274	.116	**-.685****	1												
7	-.068	.131	.501*	.130	.037	-.091	1											
8	.373	.349	.410*	**.764****	-.069	.085	.308	1										
9	-.031	**.614****	-.232	**.519****	-.239	.416*	-.328	.289	1									
10	**-.630****	.364	.009	.172	-.448*	.221	**.621****	.247	**.696****	1								
11	-.241	**.742****	-.026	-.075	-.370	**.713****	.244	**.756****	.060	**-.605****	1							
12	**-.638****	.062	-.077	-.096	-.498	.343	.447*	**.897****	.561*	-.107	**.717****	1						
13	.001	**.717****	.027	.351	**-.626****	.575*	**.746****	**.602****	**.522****	**.542****	.091	.105	1					
14	-.083	**.651****	.328	**.509****	**-.540****	**.738****	**.624****	.178	**.511****	.525*	.481*	.413*	**.648****	1				
15	**-.697****	**.584****	.107	.238	-.468*	.528*	.046	**.676****	**.640****	.334	.270	.051	.203	.345	1			
16	-.404	.470*	.229	.080	**-.542****	**.721****	.555*	**.681****	**.510****	.189	.504*	.222	.204	.469*	**.737****	1		
17	**-.714****	.033	.005	**.506****	**-.670****	.566*	**.652****	**.793****	.201	**.518****	-.044	-.010	.305	.070	.375	.223	1	
18	**-.602****	.148	.102	-.324	-.483*	**.743****	**.640****	**.716****	**.572****	.325	.359	.427*	.324	.379	.214	.284	**.790****	1

Legend: * Significant at the 0.05 level (2-tailed); **. Significant at the 0.01 level (2-tailed);

1.pH, 2. Temperature, 3. TDS, 4. Turbidity, 5. DO, 6. BOD, 7. Nitrates, 8. Phosphates, 9. Total Chlorophyll, 10. *Cosmarium subretusiforme* , 11. *C ordinatum*, 12. *Scenedesmus armatus*, 13. *Euglena minuta*, 14. *Trachalomonas volvocina*, 15. *Chroococcus disparus*, 16. *Spirulina nordesttedii*, 17. *Pinnularia dolosa*, 18. *Navicula halophila.*

Table 33: Correlation between Physico-chemical parameters and phytoplanktons for Khandola Pond.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1																
2	-.552**	1															
3	-.289	.074	1														
4	-.158	-.037	.314	1													
5	-.028	.002	.111	.317	1												
6	-.293	.532**	-.239	.043	.042	1											
7	-.022	.170	-.071	.470*	.701**	.296	1										
8	-.289	.572**	.260	-.195	-.096	.004	-.163	1									
9	-.534**	.741**	.513*	-.238	-.688**	-.008	-.238	.505**	1								
10	-.675**	.707**	.202	.513**	-.314	.624**	.638**	.630**	-.738**	1							
11	-.275	-.122	.318	.551*	-.718**	-.334	-.377	-.035	.346	.719**	1						
12	-.247	-.135	-.075	-.182	-.519**	.239	-.246	-.228	-.134	.103	.259	1					
13	-.609**	.635**	.115	-.032	-.184	.635**	.566*	.625**	-.091	-.008	.090	.036	1				
14	.122	.596**	-.130	.694**	-.639**	.568**	.565**	.653**	.218	.157	.013	.296	.691**	1			
15	-.085	.608**	.057	-.201	-.524**	.505**	.039	.009	.396	.406*	.152	.077	-.196	.547**	1		
16	-.614**	.227	.077	-.160	-.624**	.036	-.122	.745**	.350	.380	.194	-.211	.525**	-.275	-.225	1	
17	-.024	-.076	-.155	-.585*	.020	.079	-.106	-.208	-.095	.102	.225	.503**	-.142	.396	.328	-.366	1

Legend: * Significant at the 0.05 level (2-tailed); **.Significant at the 0.01 level (2-tailed);

BOD Values are eliminated as it was Below Detectable Level in this study site. 1. pH, 2.Temperature, 3.TDS, 4. Turbidity,5. DO, 6. Nitrates, 7. Phosphates, 8.Total Chlorophyll,

9. *Staurastrum thienemannii*, 10. *Euastrum spinulosum*, 11. *Netrium digitus*, 12. *Pediastrum obtusum*, 13. *Euglena oxyuriss*, 14. *Euglena minuta*, 15. *Pinnularia dolosa*, 16. *Navicula mutica*,

17. *N. rhynococephala*.

falcatus, T. volvocina, and *Go lacustris* showed negative correlation with DO. *Cosmarium contractum*, *E. minuta*, *Ch. disperses* and *G. parabolum* showed positive correlation with BOD. Nitrates and *S. quadricauda, T. volvocina Go. lacustris, Gomphonema parabolum* were positively correlated. *Cosmarium contractum, S. quadricauda, T. volvocina, Go. lacustris* and *G. parabolum*, showed positive correlation with phosphates. *Scenedesmus quadricauda, E. minuta, Ch. disperses* and *G. parabolum* showed positive correlation with total chlorophyll. *Cosmarium contractum, S. quadriquada, G. parabolum* and *Go. lacustris* were positively correlated while *T. volvocina* and *E. minuta* were inversely proportional to each other **(Table 34)**.

5.4.4: Correlations observed in Curtorim Lake

Trachalomonas volvocina, Gomphosphaeria lacustris and *Synedra ulna* were inversely proportional to pH. Positive correlation was seen between *Cosmarium regnellii, C. obsoletum, Scenedesmus bernardii, Trachalomonas volvocina, Synedra ulna* and temperature. *Cosmarium obsoletum, Actinastrum hantzschii* and *Chroococcus disperses* were positively correlated with turbidity. Negative correlation was seen between *C. obsoletum, Scenedesmus bernardii, T. volvocina, Lepocinclis fusiformis* and *Go lacustris* with DO while these forms showed positive correlation with BOD. Positive correlation was observed between *C. regnellii*, *S. bernardii, T. volvocina, Go. lacustris* and nitrates. *Cosmarium regnellii*, *S. bernardii, Go. lacustris* and *S. ulna* were positively correlated to phosphates. *Cosmarium regnellii*, *S. bernardii, T. volvocina* and *Go. lacustris* were positively correlated with total chlorophyll. *Scenedesmus bernadii* and *A. hantzschii* are inversely proportional with *C. obsoletum.* Positive correlations were observed between *T. volvocina*, *L. fusiformis*, *Ch. disperus*, *Go. lacustris* and *S. ulna* **(Table 35)**.

Table 34: Correlation between Physico-chemical parameters and phytoplanktons for Lotus Lake.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1																	
2	**-.538****	1																
3	-.122	-.030	1															
4	-.432*	.261	.508*	1														
5	.052	-.110	.190	-.153	1													
6	-.120	.117	-.170	.261	**-.622****	1												
7	-.095	-.041	.524**	.289	**.574****	-.426*	1											
8	-.066	-.163	**.695****	**.585****	.438*	-.303	**.761****	1										
9	-.409*	.449*	-.038	.356	**-.645****	**.661****	-.372	-.230	1									
10	-.048	.066	.093	.094	**-.518****	.269	-.074	.008	.340	1								
11	**.582****	-.266	-.329	**-.540****	-.041	**.601****	-.103	**.797****	.089	.121	1							
12	-.460*	**.633****	.003	.351	-.170	.126	**.585****	**.690****	**.578****	-.114	**.799****	1						
13	**-.506****	.457*	-.050	**.679****	**-.773****	.560*	-.257	-.054	.404	.076	-.213	.418*	1					
14	-.092	.496*	-.170	-.053	-.259	**.646****	-.384	-.277	**.565****	**.568****	.026	**.536****	.542*	1				
15	-.148	**.549****	-.195	.010	**-.607****	.158	**.685****	**.609****	.483*	.060	-.032	**.638****	**.525****	**-.813****	1			
16	**-.664****	**.678****	-.063	**.737****	-.020	**.732****	-.174	.009	**.547****	.070	-.137	**.637****	**.639****	**.704****	**.567****	1		
17	-.121	**.706****	-.279	.004	**-.563****	.101	**.674****	**.762****	.318	.431*	-.240	.360	.075	.422*	**.530****	.182	1	
18	**-.642****	.290	-.456*	.170	-.453*	**.632****	**.539****	**.611****	**.749****	.090	-.130	.339	**.734****	.436*	.435*	**.548****	.321	1

Legend: * Significant at the 0.05 level (2-tailed); **.Significant at the 0.01 level (2-tailed);

1. pH, 2. Temperature,3. TDS,, 4. Turbidity, 5. DO, 6. BOD,7. Nitrates, 8. Phosphates, 9. Total Chlorophyll, 10.*Scenedesmus dimorphus*, 11. *Cosmarium contractum*, 12. *Scenedesmus quadricauda*, 13. *Ankistrodesmus falcatus,* 14. *Euglena minuta,* 15. *Trachalomonas volvocina*, 16. *Chroococcus disperses*, 17.*Gomphosphaeria lacustris*, 18. *Gomphonema parabolum.*

Table 35: Correlation between physico-chemical parameters and phytoplanktons for Curtorim Lake.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1																	
2	.018	1																
3	.040	.234	1															
4	-.006	.149	**.641****	1														
5	.505*	-.276	-.373	-.108	1													
6	**-.608****	.334	.289	.179	**-.839****													
7	-.012	.193	**.643****	**.778****	-.142	.155	1											
8	.072	.082	**.575****	**.828****	-.171	.162	**.675****											
9	**-.696****	.340	.302	.330	**-.839****	**.951****	.259	.243	1									
10	.107	**.789****	-.241	-.156	-.222	.293	**.681****	**.660****	**.768****	1								
11	**-.779****	**.659****	.059	**.612****	**-.782****	**.633****	-.059	-.268	.538*	.439*	1							
12	-.081	**.680****	-.084	-.107	**-.552****	**.610****	**.569****	**.699****	**.788****	**.805****	**-.708****	1						
13	.134	.119	-.198	**.650****	-.081	.417	-.191	-.098	.594*	.469*	**-.659****	.452*	1					
14	**-.536****	**.542****	.425*	.082	**-.705****	**.518****	**.523****	.104	**.601****	.141	.251	.328	.116	1				
15	.043	.463*	.021	-.355	**-.650****	**.708****	-.285	-.226	.100	.460*	.463*	.384	.103	**.746****	1			
16	.205	.487*	.444*	**.627****	-.138	.168	.059	.088	.144	.390	.278	.463*	-.123	.444*	.498*	1		
17	**-.695****	.397	.107	-.043	**-.695****	**.702****	**.626****	**.529****	**.600****	.423*	**.740****	**.631****	.234	.352	.400	**.823****	1	
18	**-.552****	**.695****	-.177	-.234	.255	-.001	-.164	**.656****	-.007	.180	.375	.441*	.059	.253	.319	.185	**.633****	1

Legend: * Significant at the 0.05 level (2-tailed); **. Significant at the 0.01 level (2-tailed); 1.pH, 2. Temperature, 3. TDS, 4. Turbidity, 5. DO, 6. BOD, 7. Nitrates, 8. Phosphates, 9.Total Chlorophyll, 10. *Cosmarium regnellii*, 11. *Cosmarium obsoletum*, 12. *Scenedesmus bernardii*, 13. *Actinastrum hantzschii*, 14. *Trachalomonas volvocina*,,15. *Lepocinclis fusiformis*, 16 *Chroococcus disperses*, 17.*Gomphosphaeria lacustris*, 18. *Synedra ulna*.

5.5: Principal component analysis (PCA)

To determine the water quality in lake or pond, identification of phytoplanktons is very important (Rani and Sivakumar, 2012). Out of 125 phytoplanktons indentified, some played important role as principal component for each of the water body. Data pertaining to phytoplanktons was subjected to PCA using PAST. List of phytoplanktons used for PCA from Syngenta, Lotus and Cutorim Lakes is tabulated in **Table 36** and that for Khandola Pond is tabulated in **Table 37**.

5.5.1: PCA for Chlorophyceae

In Syngenta Lake, *Cosmarium ordinatum* was inversely proportional to *C. subretusiformae*. *Scenedesmus armatus, S. bernadii, S. dimorphus, Cosmarium contractum, C. regnellii, C. biloculatum, Closterium navicula, Oocysits gigas, O. solitaria* and *Actinastrumm hantzschii* were positively correlated to each other **(Fig. 20)**. In Khandola Pond, *Euastrum spinulosum* is inversely proportional to *Staurastrum thienemannii. Netrium digitus, Pediastrum obtusum, C. regnellii, C. dubium, C. punctatum* and *Pediastrum duplex* was positively correlated **(Fig. 21)**. *Ankistrodesmus falcatus, S. dimorphus* and *C. contractum* were principal components in the Lotus Lake **(Fig. 22)**. These were positively correlated to *S. quadriquada, C. regnellii, C. subretusuformae* and *C. baillyanum.* In Curtorim Lake *S. bernadii* and *A. hantzschii* were inversely proportional while *Cosmarium obsoletum, C. regnellii, Closterium bailyanum, C. navicula, P. duplex, Cosmarium ordinatum* and *C. contractum* were positively correlated **(Fig. 23)**.

Table 36: Phytoplankton species used for PCA of Syngenta, Lotus and Curtorim Lakes.

Sr. No.	CHLOROPHYCEAE
1	*Pediastrum duplex var. gracillimum*
2	*Closterium navicula*
3	*Cosmarium bioculatum*
4	*Scenedesmus dimorphus*
5	*Cosmarium ordinatum*
6	*Scenedesmus armatus*
7	*Cosmarium contractum*
8	*Cosmarium punctulatum*
9	*Coelastrum microporum*
10	*Netrium digitus*
11	*Cosmarium regnellii*
12	*Cosmarium subretusiforme*
13	*Cosmarium obsoletum*
14	*Scenedesmus bernardii*
15	*Scenedesmus quadricauda*
16	*Closterium baillyanum*
17	*Actinastrum hantzschii var elongatum*
18	*Ankistrodesmus falcatus*
19	*Oocystis gigas*
	EUGLENOPHYCEAE
1	*Euglena minuta*
2	*Trachalomonas volvocina*
3	*Lepocinclis fusiformis*
4	*Phacus asymmetrica*
	CYANOPHYCEAE
1	*Chroococcus dispersus*
2	*Merismopedia* sp.(unidentified)
3	*Spirulina nordestedii*
4	*Gomphosphaeria lacustris*
5	*Merismopedia tenuissima*
	BACILLARIOPHYCEAE
1	*Pinnularia graciloids*
2	*Pinnularia dolosa*
3	*Navicula halophila*
4	*Cocconeis placentula*
5	*Navicula mutica*
6	*Gomphonema parabolum*
7	*Cymbella chandolensis*
8	*Synedra ulna*
9	*Pinnularia gibba*
10	*Melosira islandica*
11	*Amphora ovalis*
12	*Stauroneis phoenicenteron*
13	*Navicula microcephala*
14	*Eunotia tumida*

Table 37: Phytoplankton species used for PCA of Khandola Pond.

Sr. No.	**CHLOROPHYCEAE**
1	*Pediastrum duplex var. gracillimum*
2	*Staurastrum thienemannii*
3	*Pediastrum tetras*
4	*Cosmarium punctulatum*
5	*Netrium digitus*
6	*Cosmarium regnellii*
7	*Pediastrum obtusum*
8	*Cosmarium dubium*
9	*Euastrum spinulosum*
	EUGLENOPHYCEAE
1	*Euglena minuta*
2	*Phacus asymmetrica*
3	*Euglena oxyuriss*
	CYANOPHYCEAE
1	*Chroococcus dispersus*
2	*Merismopedia* sp.(unidentified)
	BACILLARIOPHYCEAE
1	*Pinnularia dolosa*
2	*Navicula halophila*
3	*Navicula mutica*
4	*Navicula radiosa*
5	*Navicula rhynococephala*

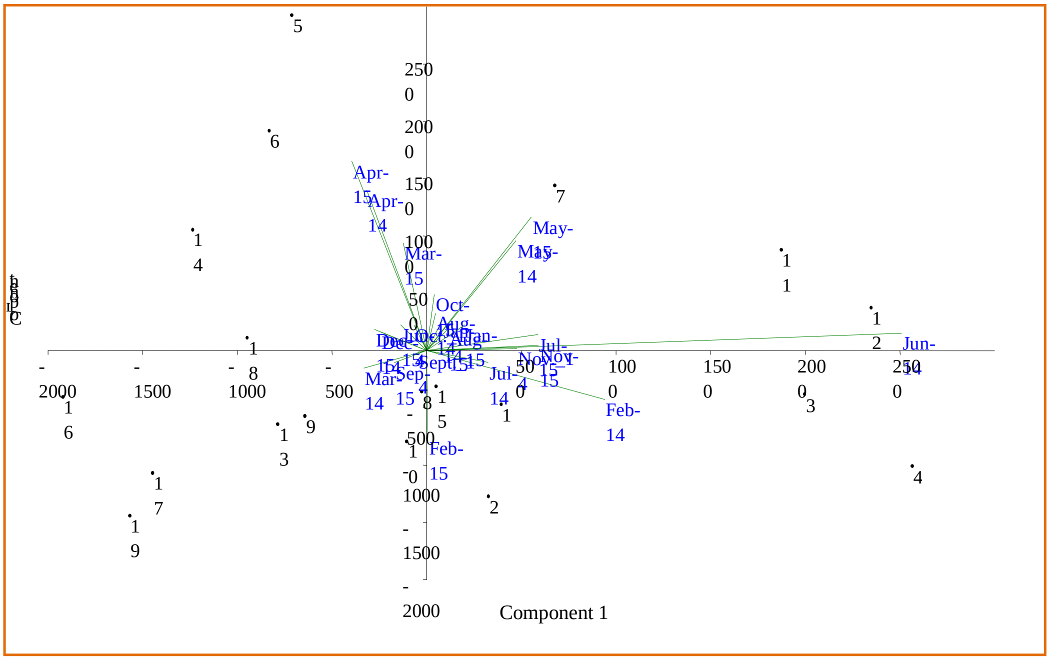

Fig. 20: Principle Component Analysis of Chlorophyceae members of Syngenta Lake 2014-15.

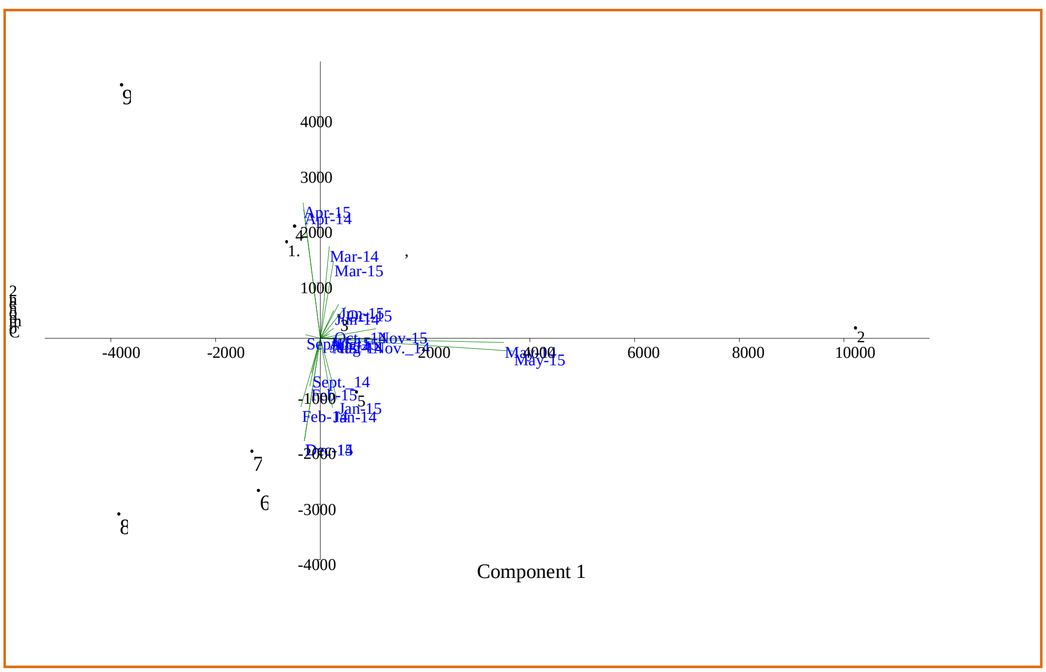

Fig. 21: Principle Component Analysis of Chlorophyceae members of Khandola Pond 2014-15.

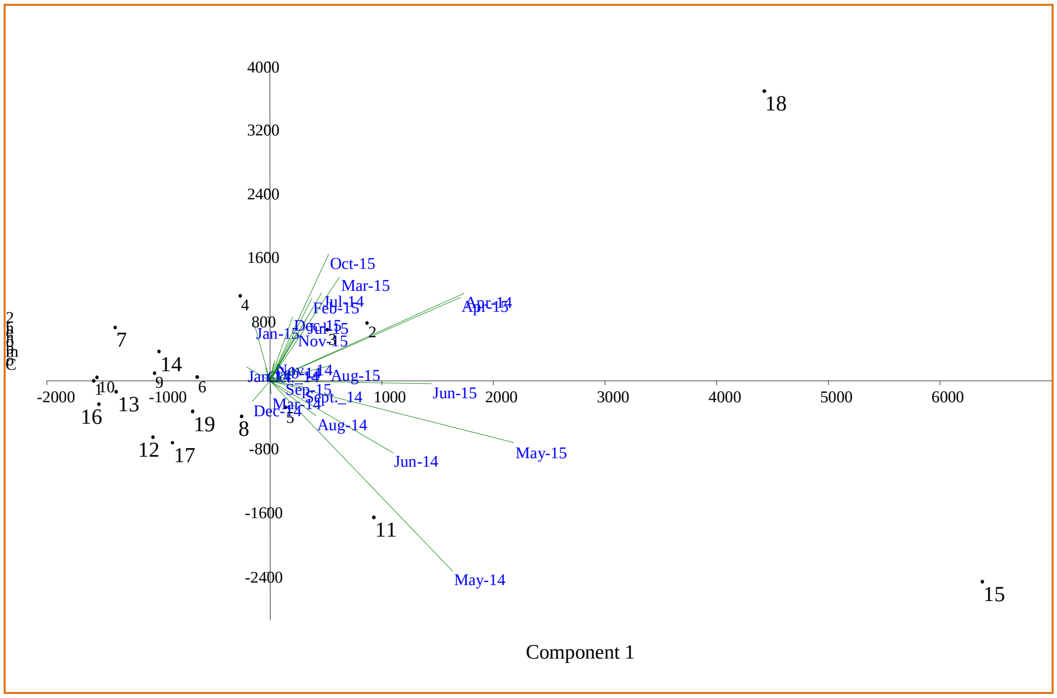

Fig. 22: Principle Component Analysis of Chlorophyceae members of Lotus Lake 2014-15.

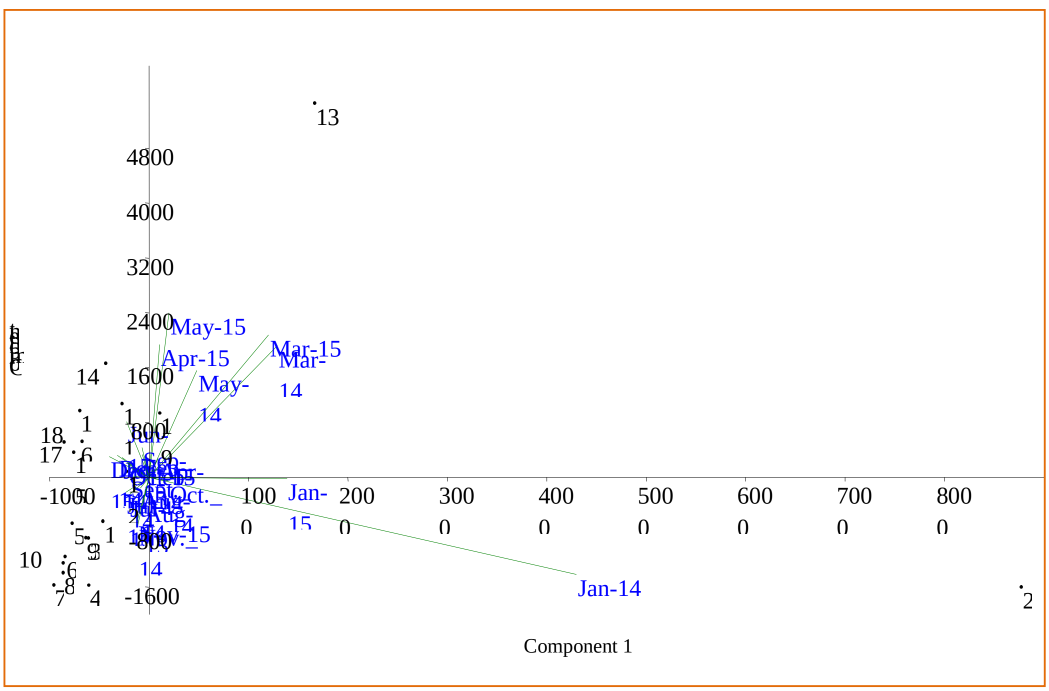

Fig. 23: Principle Component Analysis of Chlorophyceae members of Curtorim Lake 2014-15.

5.5.2: PCA for Euglenophyceae

In Syngenta Lake, positive correlation was observed between *Trachalomonas volvocina*, *Euglena minuta*, *Liponcinclis fusiformis* and *Phaus asymmerica* **(Fig. 24)**. In Khandola Pond *E. minuta* and *E. oxyuriss* played the role of principal components and were positively correlated to *Phacus asymmetrica* **(Fig. 25)**. In Lotus Lake, *T. volvocina*, *E. minuta* and *P. asymmetrica* were inversely proportional to each other and showed positive correlation with *L. fusiformis* **(Fig. 26)**. While in Curtorim Lake *T. volvocina* was principal component and was positively correlated to *L. fusiformis* and *E. minuta* **(Fig. 27).**

5.5.3: PCA for Cyanophyceae

In Syngenta Lake, *Spirulina nordestedii* and *Chroococcus disperus* were principal components and were positively correlated to *Merismopedia mayen, M. tenussima* and *Gomphonema lacustris* **(Fig. 28)**. *Merismopedia meyen, Ch. disperus* and *Go. lacustris* were principal components at Lotus Lake that were positively correlated to *M. tenuissima* and *S. nordestedi* **(Fig. 29)**. In Curtorim Lake, *Ch. disperus* was the principal component being positively correlated to *Go. lacustris, M. meyen, M. tenuissima* and *Phacus asymmetrica* **(Fig. 30)**. Khandola Pond recorded presence of only two Cyanophyceae members and hence data could not be computed for PCA.

5.5.4: PCA for Bacillariophyceae

In Syngenta Lake, a positive correlation was recorded between *N. microcephala, N. halophila, N. mutica, Pinuularia dolosa, P. graciloids, P. gibba, Enotia tumida, Stauroneis phoencentron, Synedra ulna, Cymbella chandolences, Coconeis placentula,*

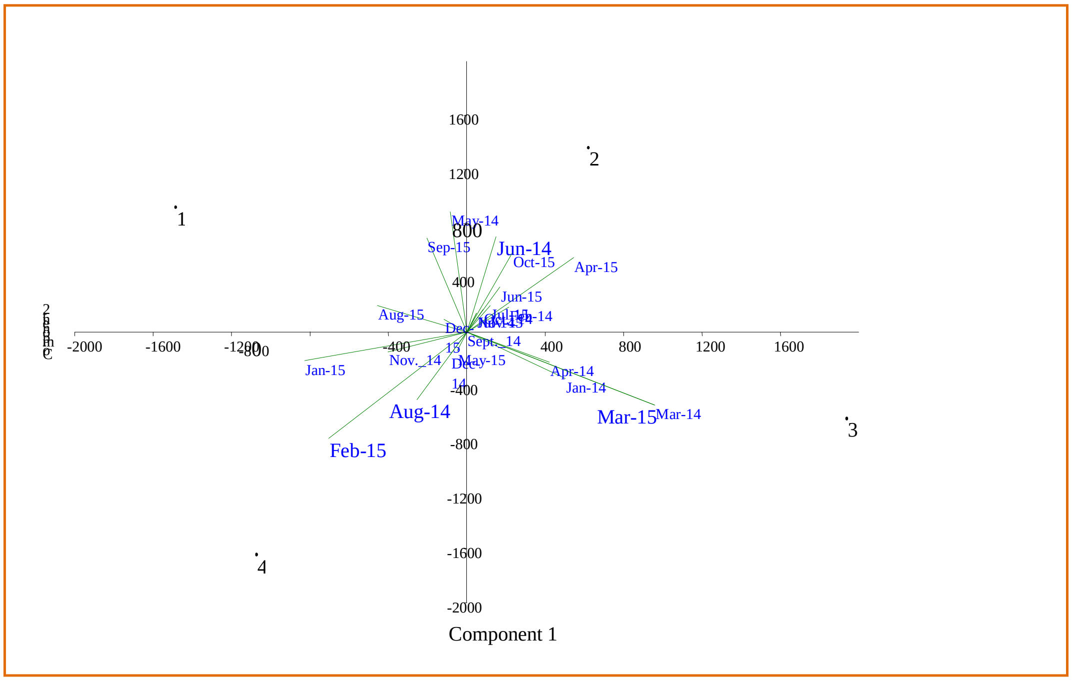

Fig. 24: Principle Component Analysis of Euglenophyceae members of Syngenta Lake 2014-15.

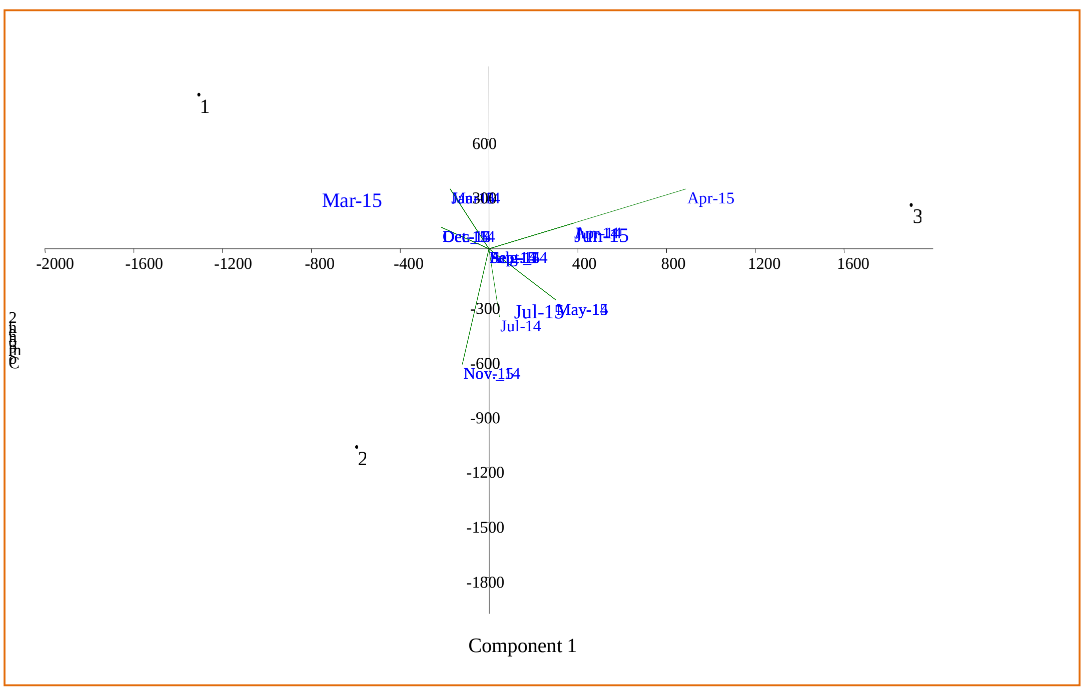

Fig. 25: Principle Component Analysis of Euglenophyceae members of Khandola Pond 2014-15.

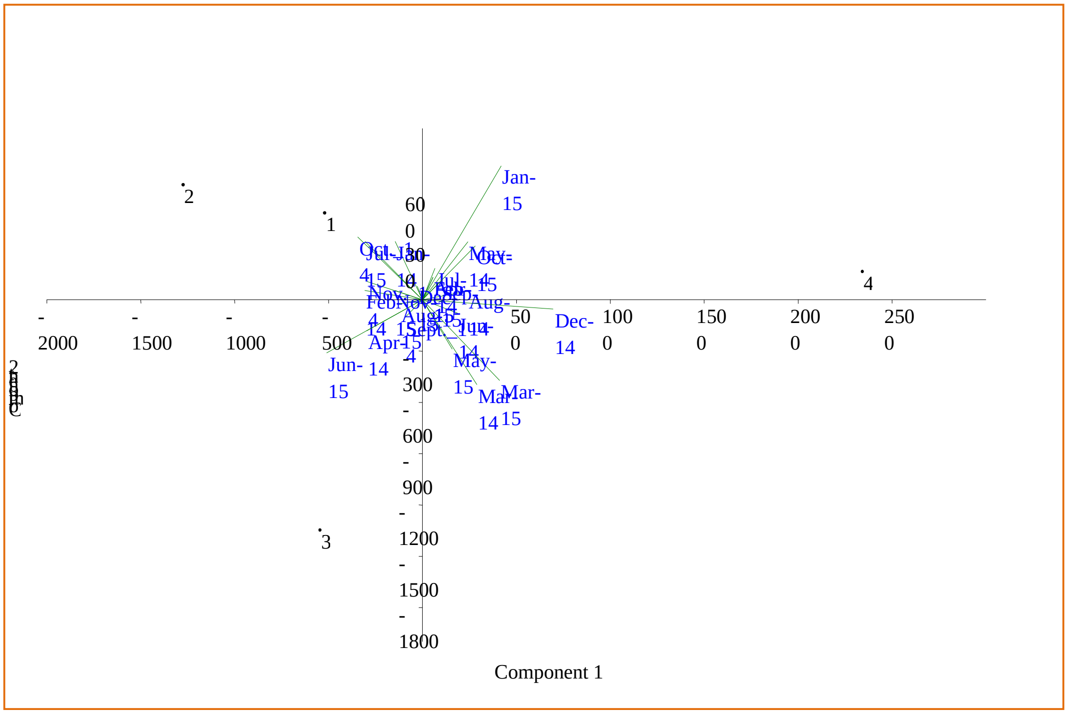

Fig. 26: Principle Component Analysis of Euglenophyceae members of Lotus Lake 2014-15.

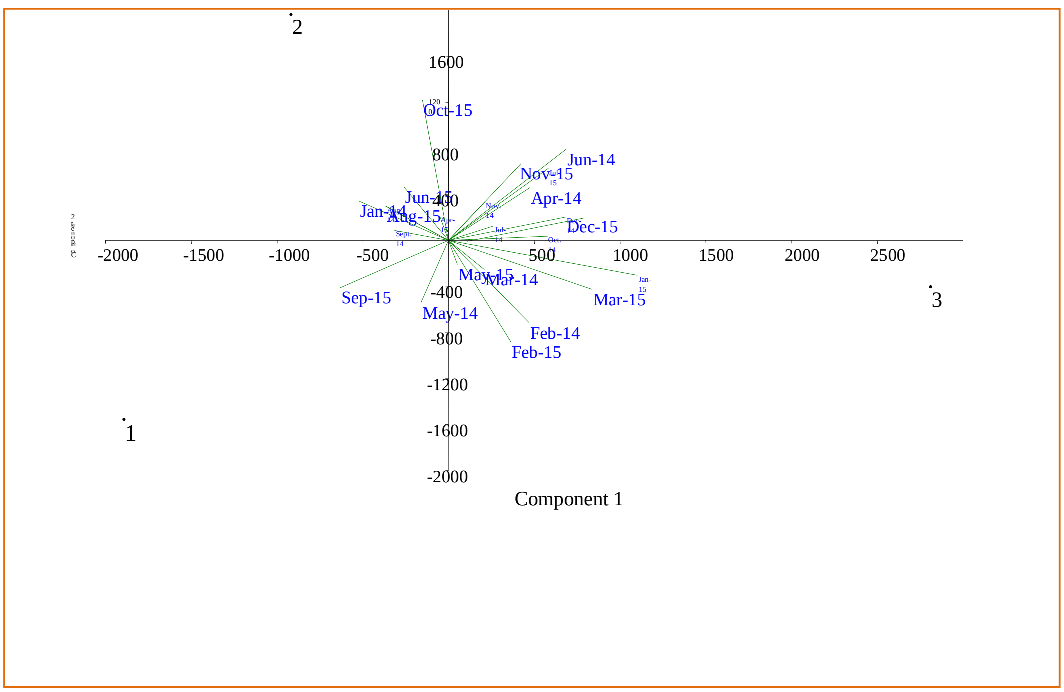

Fig. 27: Principle Component Analysis of Euglenophyceae members in Curtorim Lake 2014-15.

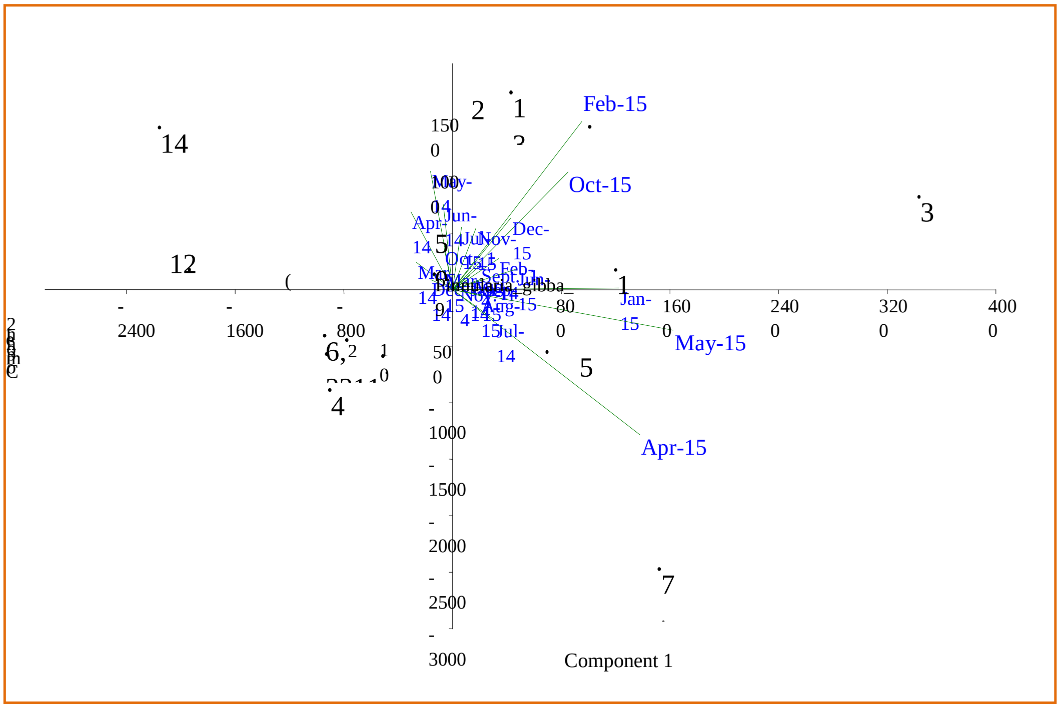

Fig. 28: Principle Component Analysis of Cyanophyceae members of Syngenta Lake 2014-15.

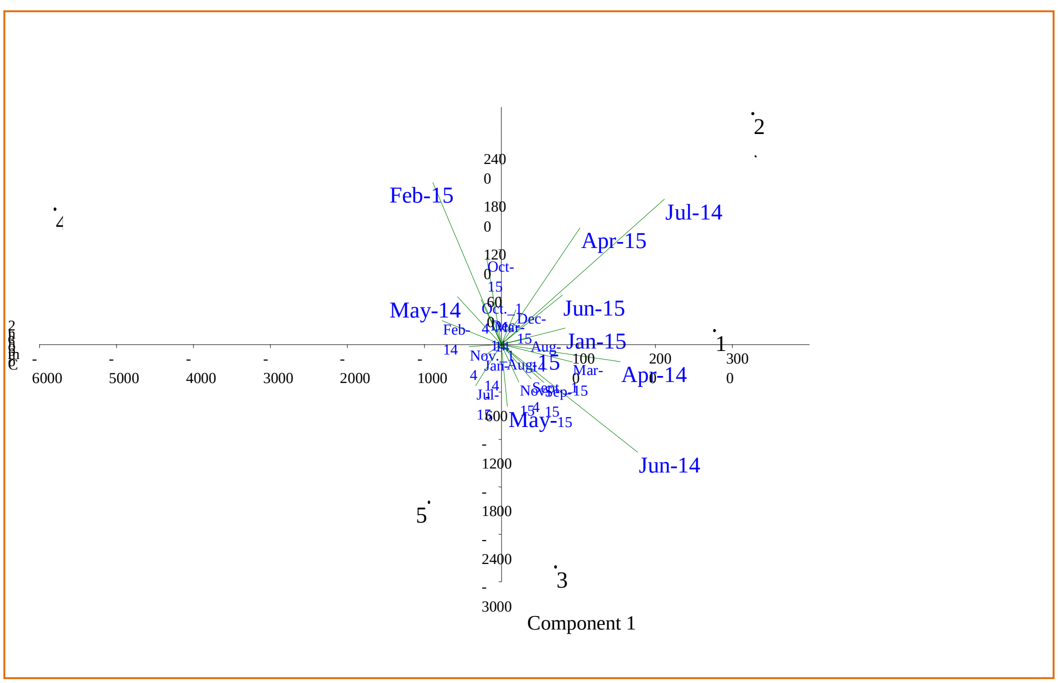

Fig. 29: Principle Component Analysis of Cyanophyceae members of Lotus Lake 2014-15.

Amphora ovalis, Meloseira islandica and *Gomphonema parabolum* **(Fig. 31)**. *Navicula rhynococephala*, *N. mutica,* and *N. radiosa* were principal components at Khandola Pond and were positively correlated to *P. dolosa* and *N. halophila* **(Fig. 32)**. At Lotus Lake, *G. parabolum, Navicula spharophora, N. mutica, N. halophila, S. ulna* and *Cy. chandolences* were principal components and were positively correlated with *P. gibba, P. dolosa, P. graciloides, Cocconeis placentuala, Amphora ovalis, Meloseira isalndica, S. phoencentron* and *E. tumida* **(Fig. 33)**. In Curtorim Lake, *S. ulna, S. phoencentron, P. dolosa,* and *N. mutica* were principal components and were correlated to *E. tumida, C. chandolenses* and *G. parabolum* **(Fig. 34)**.

Biomonitoring, allows detection of disturbances in a water body (Eckhout *et al.,* 1996). Diatoms are used in biomonitoring studies as they are ubiquitous in habit and are considered key organisms in ecological quality analyses of water (Solak and Acs, 2011). The list of diatoms encountered in selected water bodies with their acronyms are depicted in **Table 38**. Standard ecological values by Van Dam *et al.*, (1994) are presented in **Table 39 (39.1 - 39.7)**, while indicator species of organic and anthropogenic pollution, IDSE/5 Louis Leclercq index derived from OMNIDA software are presented in **Table 40**.

During the study period, 21 species of diatoms belonging to 12 genera were recorded. α-mesosaprobous forms were found occurring in Syngenta, Lotus and Curtorim Lakes while in Khandola pond, β-mesosaprobous forms were recorded. Both α- and β-mesosaprobous organisms indicate presence of moderately polluted water. Nautiyal and Mishra (2013) reported alkaliphilic, fresh-brackish, β-mesosaprobic and eutraphentic condition in a water body under anthropogenic influence. Trophic state was eutrophentic in Syngenta, Lotus and Curtorim Lakes and mesoeutrophantic in

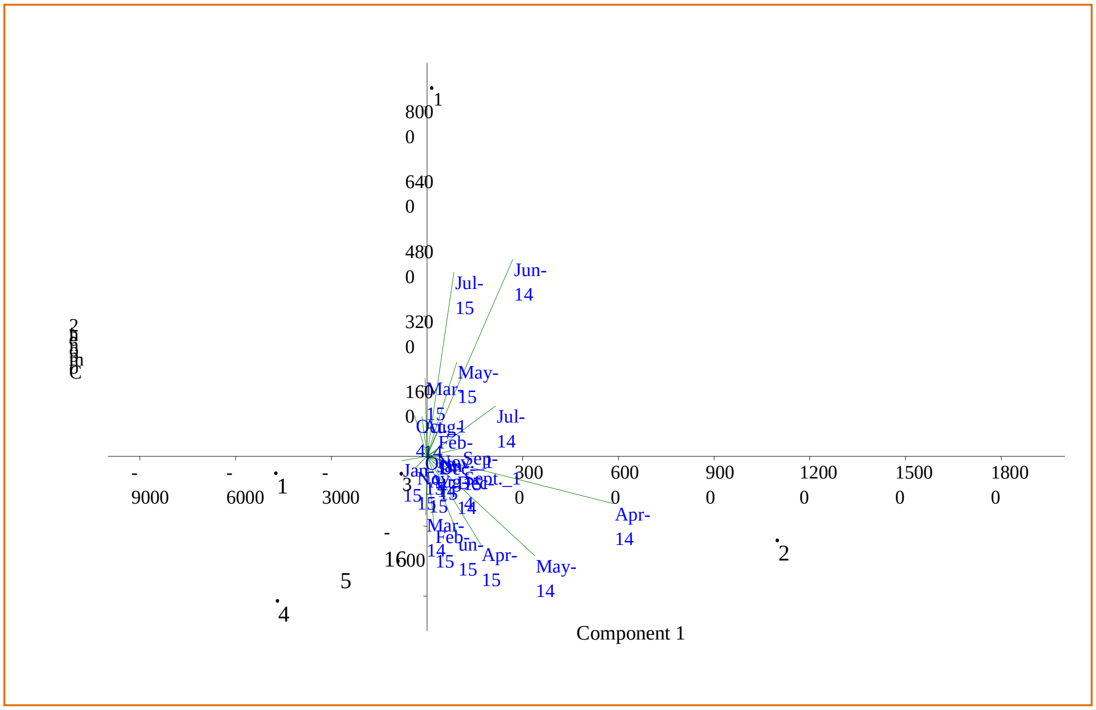

Fig. 30: Principle Component Analysis of Cyanophyceae members of Curtorim Lake 2014-15.

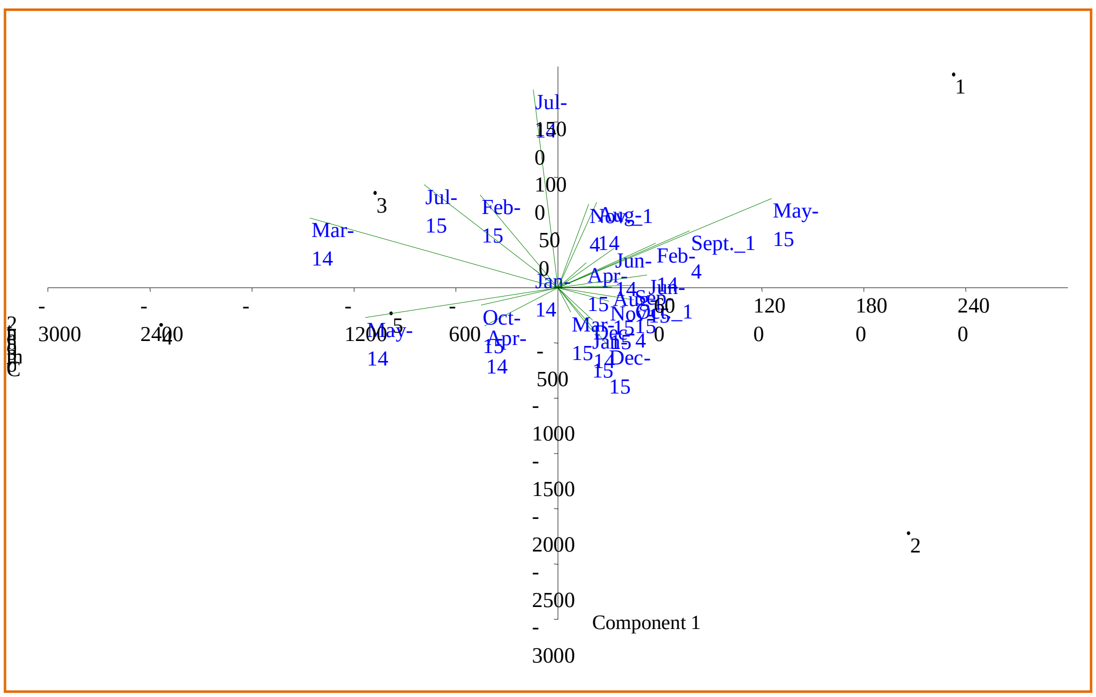

Fig. 31: Principle Component Analysis of Bacillariophyceae members of Syngenta Lake 2014-15.

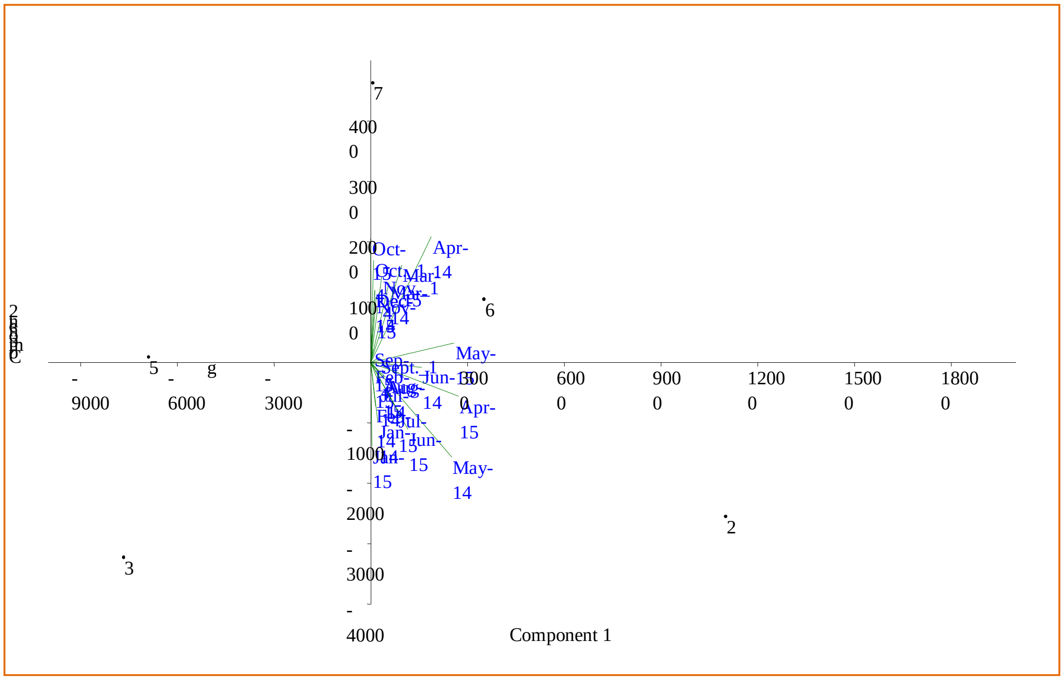

Fig. 32: Principle Component Analysis of Bacillariophyceae members of Khandola Pond 2014-15.

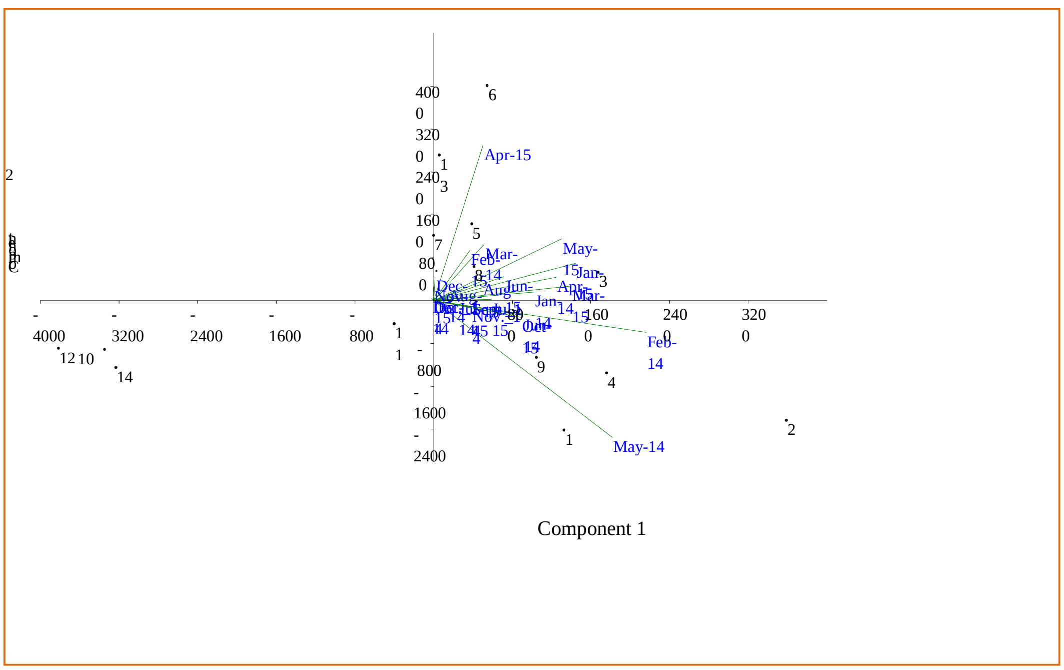

Fig. 33: Principle Component Analysis of Bacillariophyceae members of Lotus Lake 2014-15.

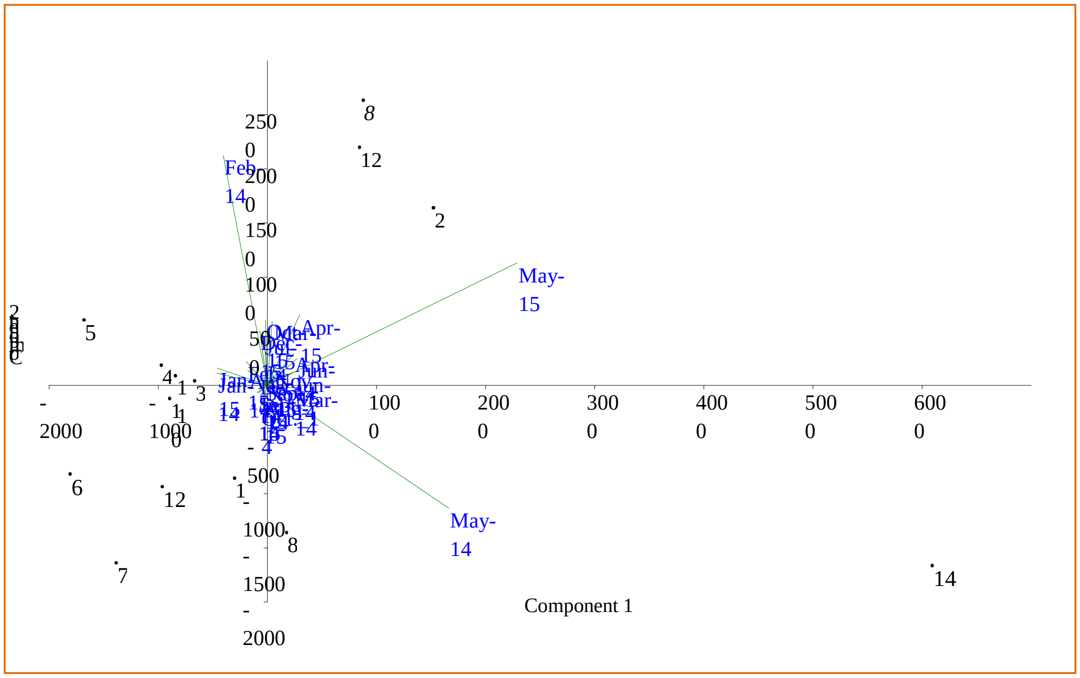

Fig. 34: Principle Component Analysis of Bacillariophyceae members of Curtorim Lake 2014-15.

Table 38: Diatom species isolated from study sites with their acronyms.

Sr. No.	Species	Acronym
1	*Pinnularia graciloids* Huste	PGRA
2	*Pinnularia dolosa* H. P. Gandhi	PDOL
3	*Navicula halophila* (Gurnow) Cleve	NHAL
4	*Cocconeis placentula* Ehrenberg	CPLA
5	*Navicula mutica* Kutzing	NMUT
6	*Gomphonema parabolum* Kutzing	GPAR
7	*Ahninthes exigua* Grunow	AEXI
8	*Cymbella chandolensis* Gandhi.	CCHA
9	*Synedra ulna* (Nitzsch) Ehrenberg.	SULN
10	*Pinnularia gibba* Ehrenberg	PGIB
11	*Melosira islandica* O. Muller	MISL
12	*Amphora ovalis* (Kutzing) Kutzing	AOVA
13	*Stauroneis phoenicenteron* (Nitzsch) Ehrenberg	SPHO
14	*Navicula microcephala* Grunow	NMIC
15	*Diploneis elliptica* (Kutzing) Cleve	DELL
16	*Stauroneis anceps* Ehrenberg	SANC
17	*Navicula sphaerophora* Kutzing	NSPH
18	*Navicula radiosa* Kutzing	NRAD
19	*Gomphonema subtiles* Ehrenberg	GSUB
20	*Navicula rhynococephala* Kutzing	NRHY
21	*Eunotia tumida* Gandhi	ETUM

Table 39: Classification of Ecological Indicator values (VanDam, Martens and Sinkeldam (1994).

Table 39.1: (R) pH (1-6)

1	Acidobiontic	Optional occurrence at pH <5.5
2	Acidophilous	Mainly occurring at pH <7
3	Circumneutral	Mainly occurring at pH – values about 7
4	Alkaliphilous	Mainly occurring at pH >7
5	Alkalibiontic	Exclusively occurring at pH >7
6	Indifferent	No apparent optimum

Table 39.2: (H) Salinity (1- 4)

	Water Quality	Cl- (mg/L)	Salinity
1	Fresh	<100	<0.2
2	Fresh brackish	<500	<0.9
3	Brackish fresh	500-1000	0.9-1.8
4	Brackish	1000-5000	1.8-9.0

Table 39.3: (N) Nitrogen Uptake (1-4)

1	Nitrogen-autotrophic taxa tolerating very small concentrations of orgaically bound nitrogen.
2	Nitrogen-autotrophic taxa tolerating elevated concentrations of organically bound nitrogen.
3	Facultatively bound nitrogen-heterotrophic taxa needing periodically elevated concentrations of organically bound nitrogen.
4	Obligately nitrogen-heterotrophic taxa needing continuously elevated concentrations of organically bound nitrogen.

Table 39.4: Saprobity (1-5)

1	Oligosaprobous
2	β-mesosaprobous
3	α-mesosaprobous
4	α-meso- /polysaprobous
5	Polysaprobous

Table 39.5: (M) Moisture (1-5)

1	Never or only very rarely occurring outside water bodies.
2	Mainly occurring in water bodies, sometimes on wet places.
3	Mainly occurring in water bodies also rather regularly on wet and moist places.
4	Mainly occurring on wet and moist or temporarily dry places.
5	Nearly exclusively occurring outside water bodies

Table 39.6: Trophic State (1-7)

1	Oligotrophentic
2	Oligo-mesotrophentic
3	Mesotrophentic
4	Meso-eutrophentic
5	Eutrophentic
6	Hypereutrophentic
7	Oligo-to eutrophentic (hypoeutrophentic)

Table 39.7: (O) Oxygen requirements (1-5)

1	Continuously high (about 100% saturation)
2	Fairly high (above 75% saturation)
3	Moderate (above 50% saturation)
4	Low (above 30% saturation)
5	Very low (about 10% saturation

Table 40: Ecological indicator values for selected water bodies (As per Van Dam *et al.*, 1994)
(Data derived from OMNIDA GB5.3 Software).

		January to December 2014				January to December 2015			
Sr.No.	**Parameter /criteria**	**SL**	**KP**	**LL**	**CL**	**SL**	**KP**	**LL**	**CL**
1	Number of genera	10	2	12	12	10	2	11	10
2	population	78862	96925	14155	10763	11124	95525	99119	13000
3	Diversity	3.64	2.07	3.65	3.7	3.65	2.05	3.72	3.62
4	Evenness	0.98	0.89	0.98	0.97	0.96	0.88	0.98	0.95
5	Number of species	13	5	14	14	14	5	14	14
6	pH (R)	4-Alkaliphilous mainly occurring at pH >7	3-Circumneutral mainly occurring at pH 7	3- Circumneutral mainly occurring at pH 7	3- Circumneutral mainly occurring at pH 7	3- Circumneutral mainly occurring at pH 7	3-Circumneutral mainly occurring at pH 7	3-Circumneutral mainly occurring at pH 7	3-Circumneutral mainly occurring at pH 7
7	Salinity (H)	Fresh to brackish	2-Fresh to brackish	2-Fresh to brackish	2-Fresh to brackish	2- Fresh to brackish	2, Fresh to brackish	2-Fresh to brackish	2-Fresh to brackish
8	Nitrogen Uptake metabolism (N)	2- Nitrogen autotrophic taxa tolerating elevated levels of organically bound nitrogen	2- Nitrogen autotrophic taxa tolerating elevated levels of organically bound nitrogen	2- Nitrogen autotrophic taxa tolerating elevated levels of organically bound nitrogen	2-Nitrogen autotrophic taxa tolerating elevated levels of organically bound nitrogen	2-Nitrogen autotrophic taxa tolerating elevated levels of organically bound nitrogen	2-Nitrogen autotrophic taxa tolerating elevated levels of organically bound nitrogen	2-Nitrogen autotrophic taxa tolerating elevated levels of organically bound nitrogen	2- Nitrogen autotrophic taxa tolerating elevated levels of organically bound nitrogen
9	Oxygen Requirement (O)	3-Moderate (above 50% saturation)	2- Fairly high(above 75% saturation)	3- Moderate (above 50% saturation)	3- Moderate (above 50% saturation)	2- Fairly high(above 75% saturation)	2- Fairly high(above 75% saturation)	3- Moderate (above 50% saturation)	3- Moderate (above 50% saturation)
10	Saprobity (S)	3-Alfa mesosaprobous	2- B mesosaprobus	3-Alpha mesosaprobous	3- Alpha mesosaprobous	3- Alfa mesosaprobous	2- B mesosaprobus	3-Alpha mesosaprobous	3-Alpha mesosaprobous
11	Trophic state	5-Eutrophantic	4-Mesoeutrophantic	5- Eutrophentic	5- Eutrophentic	5- Eutrophantic	4-Mesoeutrophantic	5- Eutrophentic	5- Eutrophentic
12	Moisture retention (M)	2- Mainly occurring in water bodies	2-Mainly occurring in water bodies	2- Mainly occurring in water bodies	2- Mainly occurring in water bodies	2- Mainly occurring in water bodies	2- Mainly occurring in water bodies	2- Mainly occurring in water bodies	2- Mainly occurring in water bodies
13	IDSE/5(Louis Leclercq Index)	3.31	3.52	3.53	3.46	3.47	3.52	3.16	3.47
14	% Indicators of organic pollution	30.65%	22.12%	21.23%	20.87%	19.63%	15.29%	32.59%	19.63%
15	Indicator organisms	GPAR, NHAL, NMIC, NMUT	NMUT	GPAR, NHAL, NMUT	GPAR, NHAL, NMUT	GPAR, NHAL, NMUT	NMUT	GPAR, NHAL, NMUT	GPAR, NHAL, NMUT
16	% indicators of anthropogenic eutrophications	27.19%	27.19%	15.28%	23.48%	15.32%	20.98%	18.71%	15.32%
17	Indicator organisms	AOVA,SPHO,SULN	NRHY	AOVA,SPHO,SULN	AOVA,SPHO,SULN	AOVA,SPHO,SULN	NRHY	AOVA,SPHO,SULN	AOVA,SPHO, SULN

Khandola Pond indicating the deteriorating water quality. This deteriorating water quality is mainly because of organic and anthropogenic pollution caused due to disturbances created by human activities such as cattle washing, fishing, unrestricted entry of huge quantity of sewage and effluents from the surrounding residential areas and industries. Such activities cause low DO levels and high BOD which turns the water bodies eutrophentic (Kavya and Savitha, 2014). Therefore, effective and strong conservative measures should be taken to prevent the lakes from entering hypereutrophentic state and to ensure the sustenance of aquatic flora and fauna. IDSE/5 index range of 3.31 to 3.53 in 2014 and 3.16 to 3.52 in 2015 indicate low to moderate degradation of all water bodies. The utilisation of indicator species is one of the water quality assessment defined by their optima and tolerances to environmental variables such as pH, temperature and P have been developed for many diatom taxa (Potapova, 2004). Indicator species of diatoms for organic pollution *viz.*, *G. parabolum*, *N. halophila*, *N. microcephala*, *N. mutica* and anthropogenic pollution *viz.*, *Amphora ovalis*, *Stauroneis phoenicenteron* and *S. ulna* were recorded in Syngenta, Lotus and Curtorim Lakes. Indicator species for organic pollution *viz.*, *N. mutica* and anthropogenic pollution *viz.*, *N. microcephala* was recorded in Khandola Pond. From the results it is concluded that there is deterioration of water quality as diatoms encountered during study proved to be the most powerful ecological indicators.

Nestedness is a measure of order in an ecological system **(Fig. 35)**. The nested patterns in selected water bodies are depicted in **Figures 36** to **39**. Matrix Reorganized vector are depicted in **Tables 41** to **44**. From the study it is concluded that the three lakes *viz.*, Syngenta, Louts and Curtorim Lakes are the most hospitable sites, while Khandola Pond is least in supporting the growth of diatoms. The niche requirements were common for *N. halophila, N. mutica, N. radiosa, N. rhynococephala, S. ulna, P. gibba,* A

	1	2	3	4	5
a	1	0	0	1	0
b	1	1	1	1	1
c	0	0	0	1	0
d	1	0	1	1	0

B

	4	1	3	5	2
b	1	1	1	1	1
d	1	1	1	0	0
a	1	1	0	0	0
c	1	0	0	0	0

Fig. 35: Species composition of a perfectly nested metacommunity.

(Numbered columns represent species and rows represent sites. Presences and absences of a species in a given site are denoted by 1 and 0, respectively: (A) species and sites sorted in an arbitrary order and (B) packed matrix, where nestedness is made evident after reordering species and sites by decreasing incidence and richness (McCoy and Heck, 1987).

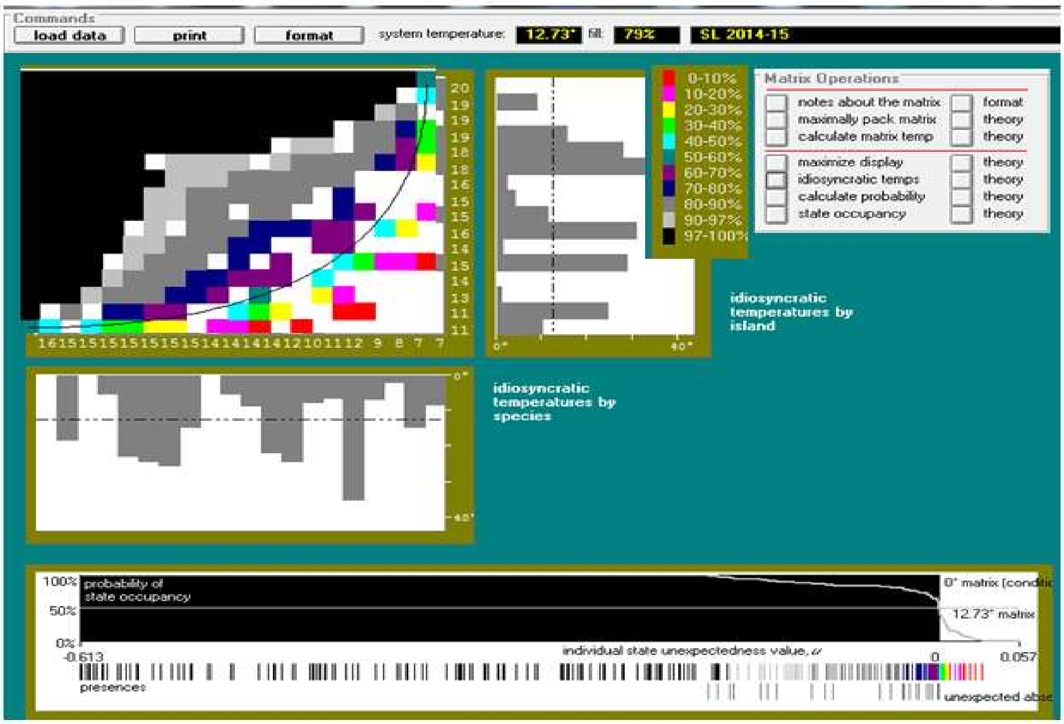

Fig. 36: Nestedness pattern in Syngenta Lake.

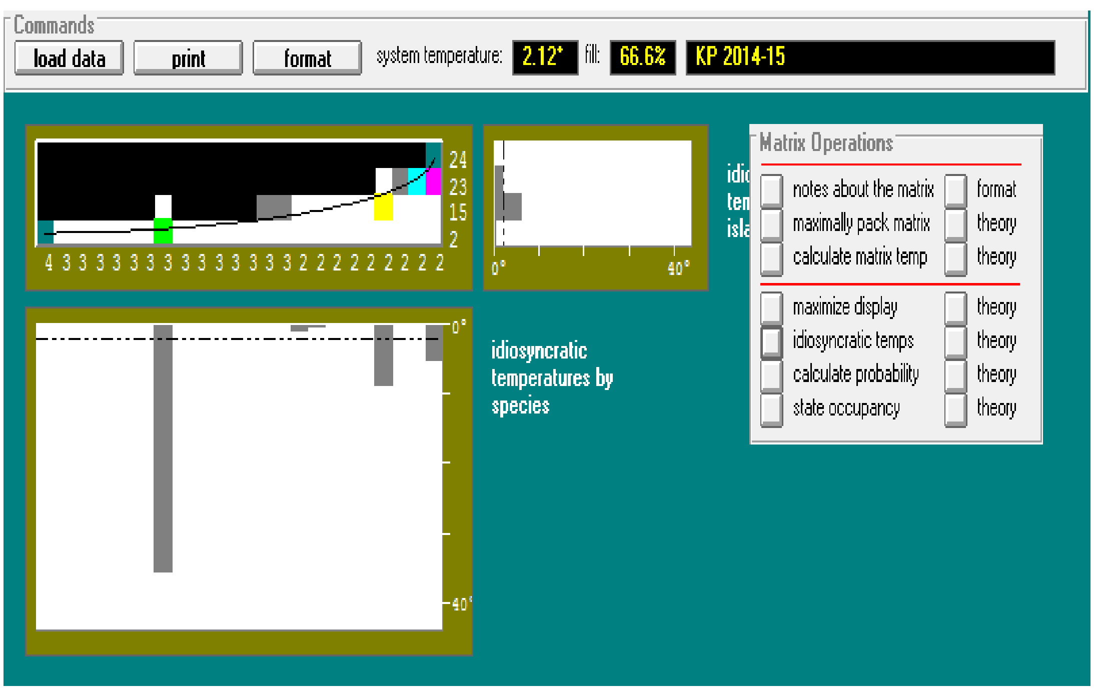

Fig. 37: Nestedness pattern in Khandola Pond.

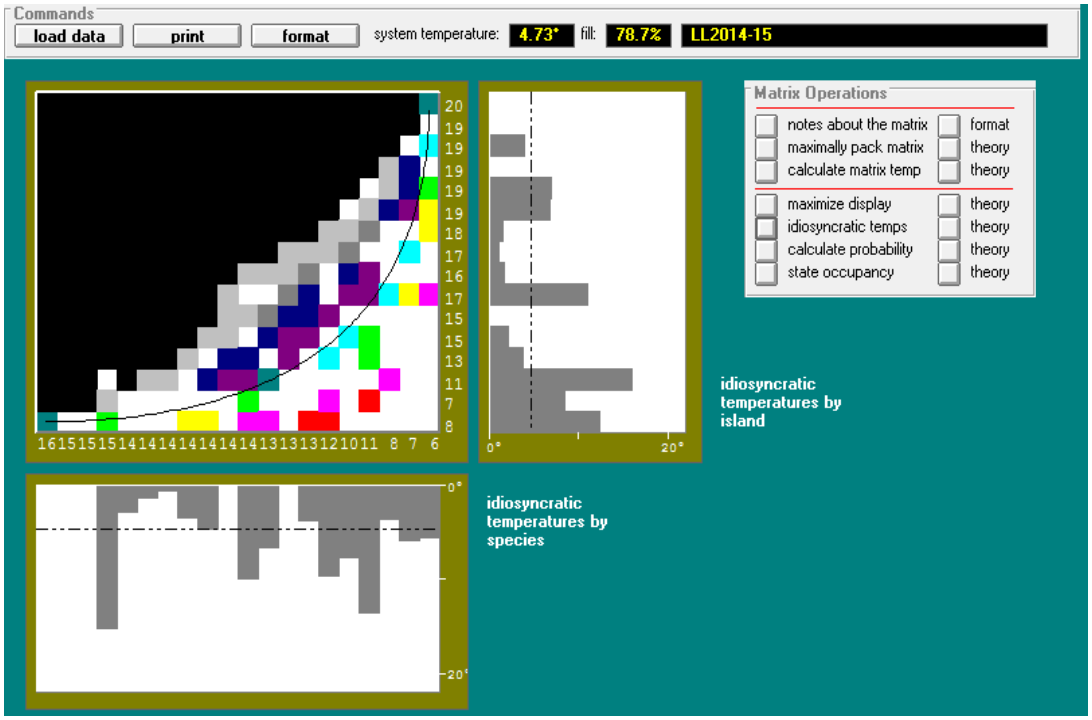

Fig. 38: Nestedness pattern in Lotus Lake.

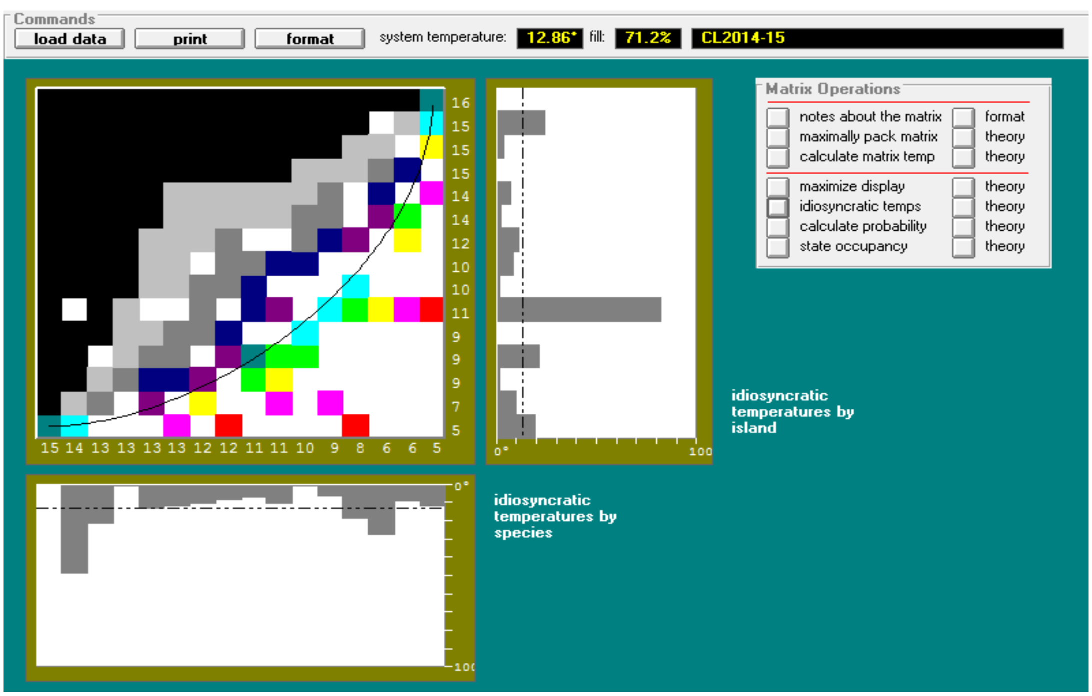

Fig. 39: Nestedness pattern in Curtorim Lake.

Table 41: Matrix Reorganized Vector for Syngenta Lake during 2014 - 15.

Island (organisms) Reorganization Vector **Species (months) Reorganization Vector**

Current Row Position	Original Row Position	Island (organisms) Name	Current Row Position	Original Row Position	Species Name (months of study)
1	1	*Pinnularia graciloids*	1	1	Jan' 2014
1	3	*Navicula halophila*	1	10	Oct' 2014
1	9	*Synedra ulna*	1	11	Nov' 2014
1	10	*Pinnularia gibba*	1	12	Dec' 2014
1	14	*Navicula microcephala*	1	24	Dec'2015
1	18	*Navicula radiosa*	2	23	Nov''2015
2	15	*Diploneis elliptica*	3	22	Oct' 2015
3	20	*Navicula rhynococephala*	4	13	Jan' 2015
4	2	*Navicula sphaerophora*	5	3	Mar' 2014
5	17	*Navicula sphaerophora*	6	14	Feb' 2015
6	8	*Cymbella chandolensis*	7	5	May' 2014
7	16	*Stauroneis anceps*	8	2	Feb' 2014
8	13	*Stauroneis phoenicenteron*	9	17	May' 2015
9	11	*Melosira islandica*	10	15	Mar' 2015
10	4	*Cocconeis placentula*	11	7	July' 2014
11	6	*Gomphonema parabolum*	12	6	June' 2014
12	5	*Navicula mutica*	13	4	April' 2014
13	19	*Gomphonema subtiles*	14	8	Aug' 2014
14	12	*Amphora ovalis*	15	18	June' 2015
15	21	*Eunotia tumida*	16	16	April' 2015
16	7	*Ahninthes exigua*	17	9	Sep' 2014
			18	20	Aug' 2015
			19	19	July' 2015
			20	21	Sep' 2015

Table 42: Matrix Reorganized Vector for Khandola Pond during 2014 - 15.

Island (organisms) Reorganization Vector **Species (months) Reorganization Vector**

Current Row Position	Original Row Position	Island (organisms) Name	Current Row Position	Original Row Position	Species Name (months of study)
1	2	*Pinnularia dolosa*	1	2	Feb' 2014
1	18	*Navicula radiosa*	1	13	Jan' 2015
1	20	*Navicula rhynococephala*	1	14	Feb' 2015
1	5	*Navicula mutica*	2	10	Oct' 2014
1	3	*Navicula halophila*	3	11	Nov' 2014
1	2	*Pinnularia dolosa*	1	2	Sep' 2014
1	18	*Navicula radiosa*	1	13	Dec' 2014
1	20	*Navicula rhynococephala*	1	14	Jul' 2014
1	5	*Navicula mutica*	2	10	Jan' 2014
1	3	*Navicula halophila*	3	11	Aug '2014
1	2	*Pinnularia dolosa*	1	2	Mar' 2015
1	2	*Pinnularia dolosa*	1	2	July'2015
1	18	*Navicula radiosa*	1	13	Sep' 2015
1	20	*Navicula rhynococephala*	1	14	Nov' 2015
1	5	*Navicula mutica*	2	10	Dec' 2015
1	3	*Navicula halophila*	3	11	June' 2015
1	3	*Navicula halophila*	3	11	May' 2015
2	4	*Cocconeis placentula*	16	4	April' 2014
2	4	*Cocconeis placentula*	16	4	Aug' 2015
3	1	*Pinnularia graciloids*	18	3	Oct' 2015
					Apr' 2015
					May' 2014
					Jun' 2014
					Mar' 2014

Table 43: Matrix Reorganized Vector for Lotus Lake during 2014 - 15.

Island (organisms) Reorganization Vector **Species (months) Reorganization Vector**

Current Row Position	Original Row Position	Island (organisms) Name	Current Row Position	Original Row Position	Species Name (months of study)
1	1	*Pinnularia graciloids*	1	10	Oct' 2014
1	3	*Navicula halophila*	1	11	Nov' 2014
1	5	*Navicula mutica*	1	22	Oct' 2015
1	9	*Synedra ulna*	1	23	Nov' 2015
1	10	*Pinnularia gibba*	1	24	Dec' 2015
1	18	*Navicula radiosa*	2	15	Mar' 2015
2	15	*Diploneis elliptica*	3	14	Feb' 2015
3	17	*Navicula sphaerophora*	4	12	Dec' 2014
4	14	*Navicula microcephala*	5	2	Feb' 2014
5	2	*Pinnularia dolosa*	6	3	Mar' 2014
6	20	*Navicula rhynococephala*	7	4	April' 2014
7	4	*Cocconeis placentula*	8	8	Aug' 2014
8	16	*Stauroneis anceps*	9	7	Jul' 2014
9	7	*Ahninthes exigua*	10	1	Jan' 2014
10	8	*Cymbella chandolensis*	11	5	May' 2014
11	19	*Gomphonema subtiles*	12	6	June' 2014
12	6	*Gomphonema parabolum*	13	13	Jan' 2015
13	12	*Amphora ovalis*	14	18	June' 2015
14	21	*Eunotia tumida*	15	17	May' 2015
15	11	*Melosira islandica*	16	19	July' 2015
16	13	*Stauroneis phoenicenteron*	17	16	Apr' 2015
			18	9	Sep' 2014
			19	21	Sep' 2015
			20	20	Aug' 2015

Table 44: Matrix Reorganized Vector for Curtorim Lake during 2014 - 15.

Island (organisms) Reorganization Vector **Species (months) Reorganization Vector**

Current Row Position	Original Row Position	Island (organisms) Name	Current Row Position	Original Row Position	Species Name (months of study)
1	1	*Pinnularia graciloidis*	1	3	Mar’ 2014
1	2	*Pinnula riadolosa*	1	6	June’ 2014
1	3	*Navicula halophila*	1	10	Oct’2014
1	5	*Navicula mutica*	1	11	Nov’ 2014
1	9	*Synedra ulna*	1	14	Feb’ 2015
1	18	*Navicula radiosa*	1	15	Mar’ 2015
1	20	*Navicular hynococephala*	1	22	Oct’ 2015
2	17	*Navicula sphaerophora*	1	23	Nov’ 2015
3	10	*Pinnularia gibba*	1	24	Dec’ 2015
4	15	*Pinnularia gibba*	2	2	Feb’ 2014
5	4	*Cocconeis placentula*	3	13	Jan’ 2015
6	14	*Navicula microcephala*	4	12	Dec’ 2014
7	11	*Melosira islandica*	5	1	Jan’ 2014
8	16	*Stauroneis anceps*	6	5	May’ 2014
9	13	*Stauroneis phoenicenteron*	7	16	April’ 2015
10	8	*Cymbella chandolensis*	8	4	Apr’ 2014
11	12	*Amphora ovalis*	9	7	July’ 2014
12	19	*Gomphonema subtiles*	10	8	Aug’ 2014
13	7	*Ahninthes exigua*	11	17	May’ 2015
14	6	*Gomphonema parabolum*	12	18	June’ 2015
15	21	*Eunotia tumida*	13	9	Sep’ 2014
			14	19	July 2015
			15	21	Sep’ 2015
			16	20	Aug’ 2015

P. dolosa and *P. graciloidis.* These forms were present throughout the study and hence described as *autochthonous* species. The nestedness shown by the diatom community was highly significant, even though there were idiosyncratic species like *G. subtiles, G. parabolum, P. graciloids, Eunotia tumida, Melosira islandica* and N. *microcephala*. Among the environmental variables analyzed, PCA identified turbidity, temperature, nitrates and phosphates as the principal components that controlled diatom community structure. These were the possible drivers of nested patterns in the water bodies studied. In perfectly nested meta communities, the richest site contains the complete set of species. In contrast, real imperfectly nested meta communities could contain poor sites with particular species compositions (Cabeza and Moilanen, 2001). Species occupying in lower rows, appeared occasionally. The matrix fill of the species in the Syngenta Lake was 79% with system temperature 12.73°, at Lotus Lake it was 78.7% with temperature 4.73°, at Curtorim Lake it was 71.2% matrix fill with 12.86°system temperature with high nestedness index. Even though very few species were present at Khandola Pond, the matrix fill was 66.6% with highly nested species with cooler system's temperature of 2.12°C. This may be due to lack of species distribution in the waterbody. According to Lampert (1987) ecological factors such as nutrient limitation and predation pressure constitute main biotic determinants of population abundance and persistence in freshwaters. Declerck *et al*. (2007) observed a nested pattern in plankton communities and concluded that high-productivity systems contained fewer species which were subsets of larger species pools from lower productivity communities. According to Atmar and Patterson (1995) matrix is ordered according to the marginal row and column sums, with common species placed in the upper rows, and species rich sites placed in the left hand columns. The top most sites are judged to be the most hospitable and the left most species are the ones where niche requirements are not common.The results of present study are in agreement with these studies.

Syngenta, Lotus and Curtorim Lakes were organically as well as anthropogenically polluted and diatoms like *Pinnularia*, *Navicula* and *Synedra* were the top indicators of the water quality. From present study it is concluded that cooler system temperatures have a highly packed matrix. Thus, the biomonitoring and nestedness study proved to be useful in identifying the tropic status of water bodies along with the indicator species of pollution.

CHAPTER - 6

To analyze the trace metals present in the water bodies and their accumulation by aquatic macrophytes.

6.1 INTRODUCTION

Water is the most crucial substance for health, prosperity, and sustenance of living beings. Although Earth seems to have an almost inexhaustible amount of water, only about 0.01% of all water is potentially available for human uses (Zeman *et al.*, 2006). Aquatic environment is being contaminated worldwide by direct and/or indirect input of pollutants into aquatic ecosystems with long-term implications on ecosystem functioning (Smolders *et al.*, 2004). Metals are introduced into the environment either by natural means or anthropogenic activities. Excessive levels of trace metals are caused by volcanic eruptions, weathering of rocks and leaching into rivers, lakes and oceans due to action of winds. With industrial revolution, metals are extracted from natural resources and processed in industries from where they leak into the atmosphere (Hariprasad and Dayananda, 2013). Activities like processing of metal ores, mining, burning of fossil fuels such as coal, petrol and kerosene oil, discharge of agricultural, industrial and domestic waste, auto exhaust and pesticides containing compounds of trace metals are also responsible for trace metal contamination of aquatic environment (Hutchinson, 1993). Trace metals are also widely used in household appliances, paints, photographic paper, and photo chemicals, *etc.*, Pollution of ground water and surface water systems through anthropogenic activities is the major environmental problem faced all around the globe (WHO, 1988).

Small quantities of trace metals are present in the water naturally and are further added due to soil erosion and leaching of minerals. Trace metals like Mn, Fe, Ni, Cu, Zn and Cr are essential for the growth of organisms, whereas Pb, Cd, Hg and Ag are non-essential. Essential metals beyond optimum threshold levels are hazardous and toxic. After entering the water, metals may precipitate, become adsorbed on solid surfaces, remain suspended in water or are taken up by fauna. A very important biological property of metals is a tendency to accumulate (Eralagere and Bhadravathi, 2008). Increase in the levels of trace metals is a growing concern. When trace metals occur in very low concentrations there are no health risks to human and aquatic life. Direct discharge or wet and dry depositions of contaminants increase the concentrations of trace elements in aquatic systems, thus resulting in their accumulation in sediments (Sinicrope *et al.,* 1992). Metals or their compounds when discharged from sources like industries, farmlands, municipal urban water runoffs, and agricultural activities into surface water result in alteration of water chemistry (Dixit and Tiwari, 2008). Once released into the aquatic environment, these elements undergo transformation and eventually become associated with suspended particulate matter that settles and accumulates in the bottom sediments (Miretzky *et al.,* 2004). Trace metals belong undoubtedly to the most significant inorganic contaminants of the ecosystem of surface waters. The measurement of trace metal concentrations in water provides advantage of evaluating the quality and state of water distribution (Maitera *et al.,* 2011). The concentration of pollutants in an aquatic environment relies primarily upon both the chemical composition of sediment and amount of absorbed pollutants (Chambers and Prepas, 1994).

The degradation of water bodies due to trace metal pollution depends upon the degree and extent of exposure of the water body to anthropogenic activities, size of the water body and erratic rainfall, life cycle of an exposed plant species and even the age of the sampled plant species from particular sampling point (Tu *et al.*, 2004). Light intensity, temperature, oxygen and pH also play important roles in metal uptake (Roy *et al.*, 2005). Macrophytes are important as they provide food and shelter for fish and aquatic invertebrates. Besides they produce oxygen, that helps in overall lake functioning. They also act as biological filters and play an important role in the maintenance of aquatic ecosystems. Certain species of plants are able to absorb metal ions and store them in their tissues (Specie and Hamelink, 1985). Aquatic plants absorb and accumulate trace elements from water and sediments therefore, can be used as a biomonitoring tool of polluted waters (Zurayk *et al.*, 2001). It is important to identify the hyperaccumulators that can be effectively used in cleaning up aquatic ecosystems. This process is known as phyto-decontamination technique, or phyto-remediation.

When the water, sediments and plants from water bodies receive urban runoff containing higher levels of trace metals, macrophytes take them up mainly through the roots. As aquatic plants die and decay, accumulated metals in the decaying plant bodies increase the concentration of trace metals in the sediments. Aquatic plants often grow more vigorously where nutrient loading is high (Ho, 1988). Different macrophytes have been used to study trace metal accumulation from water bodies. The success of trace metal accumulation by aquatic plants depends on proper selection of plant species that have high growth rate in the contaminated environment, large surface area of the portion in contact with water, and high translocation potential (Hadad *et al.*, 2011). The aim of the present research was to know whether the selected water bodies are contaminated with trace metals and also to know whether the selected aquatic macrophytes naturally growing in study sites can effectively absorb trace metals. The 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 the individual plant species for a possible use of in phytoremediation technique.

6.2 MATERIALS AND METHODS

Present investigation has been carried out in three different seasons *viz.*, pre-monsoon, monsoon and post-monsoon season. The trace metals *viz.*, Fe, Mn, Cu, Ni, Zn and Pb were analyzed from water, sediment samples and aquatic plants using standard protocols.

6.2.1 Extraction of metals from water

For trace metal extraction, one litre of water sample was collected in sterile plastic container that was pre-washed with detergent and deionized water, and later rinsed with 1:1 nitric acid. Water sample was collected at a depth of 25 cm below the water and transported to laboratory in cool conditions. The sample was filtered using 0.45 microns pore (Millipore) filter and fixed with 2ml of HNO_3. From this 500 ml of water sample was taken in 1000 ml separating funnel and pH was adjusted to 4 - 5 with dilute NH_3. Trace metals from water were extracted using APDC (Ammonium Pyrorolidene dithio Carbamate) and MIBK (Methyl Isobutyl Ketone) (APHA, 2012). To this sample 10 ml of APDC and 15 ml MIBK was added. The mixture was shaken for two minutes. The two phases were allowed to separate after 15 - 30 minutes.

Upper organic layer was drained into 100ml separating funnel (ensuring that MIBK extract was free from water sample). The procedure was continued by adding 5 ml APDC and 10 ml MIBK to water sample and the contents were transferred in a separating funnel. The contents were shaken again for 2 minutes and both the extracts were combined. The extract was aspirated using AAS **(Plate 16).**

Plate 16

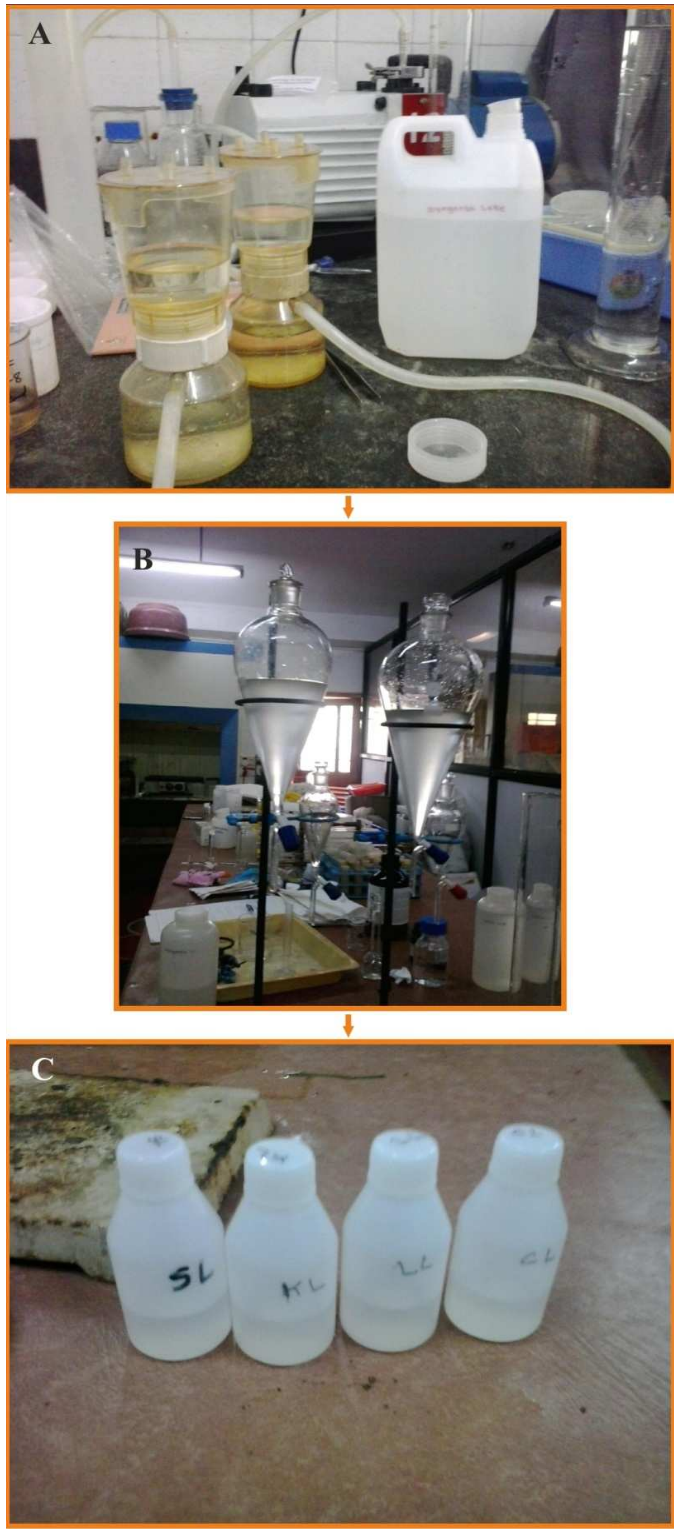

Plate 16

Extraction of trace metals from water samples

A. Filtration of water sample using Millipore filter.

B. Extraction of trace metals using separation funnels.

C. Extract for aspiration.

6.2.2 Extraction of metals from sediments

Core was collected in triplicate using plastic corer from upper 10 cm layer of the bottom sediments. Each sediment core was packed separately in acid soaked zip-lock plastic bag and stored in ice box until transported to laboratory**.** Sediment samples were oven-dried at 105 °C and sieved through a 2 mm mesh screen to remove coarse materials like small stones, wood, and detrital materials. Other visible impurities were removed prior to grinding and the sample was made into a homogenous mixture using mortar and pestle (Mudroch *et al.*, 1997).

Digestion of sediment for total metal analysis was carried out as per the following protocol (APHA, 2012). Finely ground sediment sample (0.2 g) was transferred into clean chromic acid washed teflon beaker. To this, a mixture of 10 ml Hydrofluoric acid, Nitric acid and Perchloric acid in the proportion of (7:3:1) was added slowly to avoid excessive frothing and was completely dried on the hot plate at 150 °C. After drying, again 5ml of the above mixture was added and dried on the hot plate for 1h and then 2ml conc. HCl was added and dried completely. Final residue was dissolved in the 10 ml of $HClO_4$ and HNO_3. (1:1). After ensuring complete digestion (clear solution) of sediment sample, the content from teflon beakers was transferred into the acid washed polypropylene volumetric flask and the solution was made up to 50 ml with milique water **(Plate 17).**

6.2.3 Extraction of metals from aquatic macrophytes

The three aquatic species *viz.*, *Salvinia molesta*, *Eichhornia crassipes* and *Pistia stratiotes* were handpicked from the habitat and identified using standard taxonomic

Plate 17

Plate 17

Collection of sediment and processing

A. Core collection using plastic corer.

B. Core cutting.

C. Packing of core in plastic bags.

D. Storing of core in ice box.

E. Core portions for drying.

F. Digestion of sediment samples.

G. Filtration of extract.

manuals. Individual species were washed with water carefully. Roots and shoots were separated, washed in distilled water and dried at 70°C in hot air oven for 48 hours. Dried samples were homogenized and ground to yield fine powder.

Digestion:

Nitric acid digestion method (Zheljazkov and Nielson, 1996) was followed for extraction of trace metals from plants. One gram of powdered sample was taken to which 10 ml of concentrated HNO_3 was added. The sample was heated for 45 minutes 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 (5 ml) was added thrice to the sample. 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. It was then transferred to a 25 ml volumetric flask by adding milique water. The digested samples were analyzed for trace metals using Atomic Absorption Spectrophotometer (AAS).

6.3 RESULTS AND DISCUSSION

The present study revealed that the concentration of trace metals varied in all the water bodies. These variations in water were compared with standard values of WHO (2008) for drinking water (**Table 45**) and in sediments were compared with provisional sediment quality guidelines for metals MoE 1993 Ontario **(Table 46)**. It was observed that there were significant differences in the metal concentration content among the water bodies **(Tables 47** to **50)**.

Table 45: Maximum permissible limit of metals in water (WHO, 2008).

Sr. No.	Metal	mg/L
1	Fe	0.30
2	Mn	0.10
3	Cu	0.05
4	Ni	0.05
5	Zn	5.00
6	Pb	0.05

Table 46: Provisional sediment protection guidelines for metals (MoE, 1993 Ontario).

Sr. No.	Metal	ppm
1	Fe	2
2	Mn	460
3	Cu	16
4	Ni	16
5	Zn	120
6	Pb	31

Table 47: Trace metal concentration (water and sediment) in Syngenta Lake and phytoaccumulation by *Salvinia molesta.*

Sr. No.	Metal	Pre-monsoon				Monsoon				Post-monsoon			
		Water	sediment	*Salvinia* (Brown Frond)	*Salvinia* (Shoot)	Water	sediment	*Salvinia* (Brown Frond)	*Salvinia* (shoot)	Water	sediment	*Salvinia* (Brown Frond)	*Salvinia* (Shoot)
1	Fe	4.60	8.10	4.49	0.78	0.38	7.75	1.93	0.30	0.80	9.56	4.29	1.42
2	Mn	BDL	4.40	3.22	1.20	0.42	10.07	3.04	0.62	0.01	7.76	4.75	1.10
3	Cu	BDL	0.31	0.10	0.06	0.40	5.50	0.16	0.10	0.04	7.36	1.70	0.20
4	Ni	0.019	0.45	0.04	BDL	0.30	1.75	0.07	BDL	BDL	2.49	0.55	0.12
5	Zn	0.45	8.47	3.62	1.02	4.45	7.00	1.93	0.30	1.27	0.95	0.25	0.10
6	Pb	0.16	2.71	BDL	BDL	BDL	2.50	BDL	BDL	BDL	3.32	0.39	0.10

Table 48: Trace metal concentration in water and sediment in Khandola Pond.

Sr. No.	Metal	Pre - monsoon		Monsoon		Post - monsoon	
		water	sediment	water	sediment	water	sediment
1	Fe	0.26	5.49	0.61	2.16	3.37	5.78
2	Mn	BDL	2.57	0.03	2.74	0.20	3.00
3	Cu	BDL	0.43	0.04	0.26	3.00	6.10
4	Ni	BDL	3.11	0.00	1.86	2.50	9.25
5	Zn	0.09	0.96	1.01	1.28	3.35	5.25
6	Pb	0.12	0.76	0.00	0.23	1.65	3.02

Legend : BDL = below detectable level; Fe - Iron, Mn - Manganese, Cu - Copper, Ni -Nickel, Zn - Zinc, Pb – Lead; units –ppm

Table 49: Trace metal concentration (water and sediment) in Lotus Lake and phytoaccumulation by *Eichhornia crassipes.*

Sr. No.	Metal	Pre - monsoon				Monsoon				Post - monsoon			
		Water	Sediment	*Eichhornia* (Root)	*Eichhornia* (Shoot)	Water	Sediment	*Eichhornia* (Root)	*Eichhornia* (Shoot)	Water	Sediment	*Eichhornia* (Root)	*Eichhornia* (Shoot)
1	Fe	1.03	12.27	7.32	0.37	1.35	2.94	1.19	0.16	8.61	22.46	12.36	4.29
2	Mn	0.22	0.88	0.43	0.30	0.22	7.75	1.22	0.09	0.004	3.08	1.40	0.02
3	Cu	BDL	0.02	0.01	BDL	1.72	5.14	0.20	0.01	0.014	4.00	2.25	0.31
4	Ni	BDL	0.26	BDL	BDL	1.32	3.03	0.29	0.05	BDL	2.75	1.10	0.06
5	Zn	BDL	0.02	0.01	BDL	2.52	3.25	1.00	0.30	1.69	2.82	1.31	0.49
6	Pb	0.27	1.50	0.41	0.01	0.32	1.45	0.05	0.02	BDL	2.11	0.74	0.51

Table 50: Trace metal concentration (water and sediment) in Curtorim Lake and phytoaccumulation by *Pistia stratiotes.*

Sr. No.	Metal	Pre - monsoon				Monsoon				Post - monsoon			
		Water	sediment	*Pistia* (Root)	*Pistia* (Shoot)	Water	sediment	*Pistia* (Root)	*Pistia* (Shoot)	Water	sediment	*Pistia* (Root)	*Pistia* (Shoot)
1	Fe	0.42	0.83	0.37	0.04	3.10	5.6	1.04	0.59	3.31	6.19	2.01	1.26
2	Mn	BDL	5.72	0.92	0.34	0.40	1.05	0.37	0.06	0.60	7.93	2.65	1.06
3	Cu	BDL	5.01	3.06	0.40	1.47	7.29	2.45	0.10	0.018	0.24	0.08	0.01
4	Ni	BDL	0.52	0.04	0.01	1.40	5.25	BDL	BDL	BDL	6.41	BDL	BDL
5	Zn	0.65	3.53	0.49	0.30	0.90	2.50	0.31	0.16	0.26	0.41	0.25	0.04
6	Pb	0.21	0.30	0.10	0.02	0.20	1.50	BDL	BDL	BDL	2.00	BDL	BDL

Legend : BDL = below detectable level; Fe - Iron, Mn - Manganese, Cu - Copper, Ni -Nickel, Zn - Zinc, Pb – Lead; units -ppm

6.3.1 Iron

In natural conditions, Fe primarily comes from the products of weathered rocks and soil around watersheds, controlled by many factors, such as geological process, soil composition, environmental temperature, precipitation, and hydrology (Harris, 1992). Iron content in water ranged from 0.38 to 4.60 ppm at Syngenta Lake, 0.26 to 3.37 ppm at Khandola Pond, 1.03 to 8.61 ppm at Lotus Lake and 0.42 to 3.31 ppm at Curtorim Lake. Maximum Fe concentration was recorded at Lotus Lake while minimum was recorded at Khandola Pond. In present study Fe concentration exceeded WHO drinking water limit. According to Trivedi and Gurudeepraj (1992) surface water generally contains less than 1 mg/l of iron and waters containing more than 2 mg/L iron cause staining and imparts a bitter astringent taste to water.

Iron concentration in sediments ranged from 7.75 to 9.56 ppm at Syngenta Lake, 2.16 to 5.78 at Khandola Pond, 2.94 to 22.46 ppm at Lotus Lake and 0.83 to 6.19 ppm at Curtorim Lake. The maximum Fe concentration was recorded in Lotus Lake. Lakes fed with huge amounts of raw sewage contain high amount of Fe (Abdel-Moati and El-Sammak, 1997). Sediments act as traps for most of the heavy metals by forming stable complexes with sediment organic matter, carbonates, and (Fe) - (Mn) oxides (Rajendran *et al.,* 1992). Total concentration of Fe in the sediments of the study sites exceeded MoE of Ontario sediment protection guidelines there by indicating contamination.

Iron concentration ranged from 1.49 to 4.49 ppm in brown fronds of *S. molesta*, 1.19 to 12.36 ppm in *E. crassipes* roots and 0.37 to 2.01 ppm in *P. stratiotes* roots while it ranged from 0.30 to 1.42 ppm, 0.16 to 4.29 ppm, and 0.04 to 1.26 ppm in shoots of *S.*

molesta, E. crassipes and *P. stratiotes* respectively. Total concentration of Fe was highest in *E. crassipes* (25.69 ppm), followed by *S. molesta* (13.21 ppm) and least in *P. stratiotes* (5.31 ppm). Earlier study suggested *E. crassipes* is the best candidate species for Fe accumulation Ndimele *et al.*, (2014).

6.3.2 Manganese

Manganese is an essential trace element in physiological processes, in plants (Doyle *et al.,* 2003). Besides its natural occurrence, the contamination of aquatic ecosystems by Mn is due to human activities (Banks *et al.,* 1997). Manganese concentration in water ranged from 0.01 to 0.42 ppm at Syngenta Lake, 0.03 to 0.20 ppm at Khandola Pond, 0.004 to 0.22 ppm in Lotus Lake and 0.40 to 0.60 ppm in Curtorim Lake. Highest concentration was recorded at Curtorim Lake while lowest at Lotus Lake. The total Mn concentration exceeded WHO drinking water limit.

Manganese concentration in sediments varied from 4.40 to 10.07 ppm at Syngenta Lake, 2.74 to 3.0 ppm at Khandola Pond, 0.88 to 7.75 ppm at Lotus Lake and 1.05 to 7.93 ppm at Curtorim Lake. Syngenta Lake showed highest Mn concentration amongst all study sites. The study revealed that the Mn concentration lower than the MoE of Ontario sediment protection guidelines.

Manganese concentration ranged from 3.04 to 4.75 ppm in brown fronds of *S. molesta,* 0.43 to 1.40 ppm in *E. crassipes* roots and 0.37 to 2.65 ppm in *P. stratiotes* roots while it varied from 0.62 to 1.20 ppm, 0.02 to 0.30 ppm, and 0.06 to 0.34 ppm in shoots *S. molesta, E. crassipes* and *P. stratiotes* respectively. Highest concentration of Mn was recorded in *S. molesta* (13.93 ppm) followed by *P. stratiotes* (5.1 ppm) and *E. crassipes*

(3.46 ppm). According to Kipriyanova (1997), *S. molesta* being a floating hydrophyte, has the highest trace metal accumulating capabilities.

6.3.3 Copper

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). Copper concentration in water varied from 0.04 to 0.40 ppm at Syngenta Lake, 0.03 to 0.20 ppm at Khandola Pond, 0.014 to 1.72 ppm at Lotus Lake and 0.018 to 1.47 ppm at Curtorim Lake. Highest Cu concentration was recorded at Lotus Lake while lowest at Khandola Pond. The study revealed that the maximum permissible range exceeded as per BIS (Bureau of Indian Standards) limit. Copper concentration in sediment was 0.31 to 7.36 ppm at Syngenta Lake, 0.26 to 6.10 ppm at Khandola Pond, 0.02 to 5.14 ppm at Lotus Lake and 0.24 to 7.29 ppm at Curtorim Lake. The Cu concentration sediment was lower than the prescribed limits as per concentration sediment protection guidelines of MoE, Ontario.

Copper concentration ranged from 0.10 to 1.70 ppm in brown fronds of *S. molesta* 0.01 to 2.45 ppm in *E. crassipes* roots and 0.08 to 3.06 ppm in *P. stratiotes* roots while it varied from 0.06 to 0.20 ppm, BDL to 0.31 ppm, and 0.01 to 0.40 ppm in the shoots *S. molesta, E. crassipes* and *P. stratiotes* respectively. Highest concentration of Cu was recorded in *P. stratiotes* (6.1 ppm) followed by *E. crassipes* (2.78 ppm) and *S. molesta* (2.32 ppm). According to Qin Lu *et al.,* (2011) *P. stratiotes* is a hyper accumulator for Cu and can be applied for the remediation of surface waters.

6.3.4 Nickel

Nickel is released into the environment from a variety of natural and anthropogenic sources. Among industrial sources, considerable amount of environmental Ni is derived from the combustion of coal, oil, and other fossil fuels, mining and refining processes, Ni alloy manufacturing (steel), electroplating, and incineration of municipal wastes (Ensink *et al.,* 2007). Nickel concentration in water varied from 0.019 to 0.30 ppm at Syngenta Lake, BDL to 2.50 ppm at Khandola Pond, BDL to 1.32 ppm at Lotus Lake and BDL to 1.40 ppm at Curtorim Lake. Lowest concentration (0.0019 ppm) was reported at Syngenta Lake and highest at (2.50 ppm) at Khandola Pond. These levels were above drinking water standards by WHO.

Sediment concentration showed the variations as 0.45 to 2.49 ppm at Syngenta Lake, 1.86 to 9.25 ppm at Khandola Pond, 0.26 to 3.03 ppm at Lotus Lake and 0.52 to 6.41 ppm at Curtorim Lake. Highest concentration of Ni was recorded at Khandola Pond. The study revealed that the total concentration in all three seasons exceeded sediment protection guidelines of MoE, Ontario Canada.

Nickel concentration ranged from 0.04 to 0.55 ppm in brown fronds of *S. molesta,* BDL to 1.10 ppm in *E. crassipes* roots and BDL to 0.04 ppm in *P. stratiotes* roots while it varied from BDL to 0.12 ppm, BDL to 0.06 ppm and BDL to 0.01 ppm in shoots of *S. molesta, E. crassipes* and *P. stratiotes* respectively. Highest concentration of Ni was recorded in *E. crassipes* (1.5 ppm) followed by *S. molesta* (0.78 ppm) and *P. stratiotes* (0.05 ppm). Syed *et al.,* (2010) reported that *E. crassipes* as a hyperaccumulator of Ni.

6.3.5 Zinc

The largest natural emission of Zn to water results from erosion, waste disposal, incineration, and the use of Zn-containing fertilizers and pesticides composted materials, sewage effluent, and agrochemical runoff land fill leachates, urban storm water, poultry sewage and compost (Boxall *et al.*, 2000). Zinc concentration in water ranged from 0.09 to 4.45 ppm at Syngenta Lake, 0.09 to 3.35 ppm at Kahndola Pond, BDL to 2.52 ppm at Lotus Lake and 0.26 to 0.90 pmm at Curtorim Lake. Highest concentration was reported in Syngenta Lake that exceeded the FAO limit. Sediments of Syngenta Lake showed maximum Zn concentration and ranged from 0.95 to 8.47 ppm, at Khandola Pond it ranged from 0.96 to 5.25 ppm, 0.02 to 3.25 ppm at Lotus Lake while at Curtorim Lake it was 0.41 to 3.53 ppm. In Syngenta Lake Zn appears to have originated from agrochemical sewage from the vicinity. However the concentration was low compared to sediment protection guidelines of MoE, Ontario Canada.

Zinc concentration ranged from 0.25 to 3.62 ppm in brown fronds of *S. molesta*, 0.01 to 1.31 ppm in *E. crassipes* roots and 0.25 to 0. 49 ppm in *P. stratiotes* roots while it varied from 0.10 to 1.02 ppm, BDL to 0.71 ppm, and 0.04 to 0.30 ppm in shoots of *S. molesta*, *E. crassipes* and *P. stratiotes* respectively. Highest Zn concentration was recorded in *S. molesta* (7.22 ppm) followed by *E. crassipes* (3.51 ppm) and *P. stratiotes* (1.55 ppm). George and Gabriel (2017), reported that *S. molesta* effectively accumulated Zn from municipal waste water sample within five days after which the concentration was found below detectable level.

6.3.6 Lead

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 (Mathew *et al*., 2003). Lead concentration in water ranged from BDL to 0.16 ppm at Syngenta Lake, BDL to 1.65 ppm at Khandola Pond, BDL to 0.32 ppm at Lotus Lake and BDL to 0.21 ppm at Curtorim Lake. The total concentration of Pb in water exceeded the WHO limit in all water bodies.

In sediment the Pb concentration varied from 2.71 to 3.32 ppm at Syngenta Lake, 0.76 to 3.02 ppm at Khandola Pond, 1.45 to 2.11 ppm at Lotus Lake and 0.30 to 2.00 ppm at Curtorim Lake. Highest concentration was recorded in Syngenta Lake which however was lower than the sediment protection guidelines of MoE, Ontario Canada.

Lead concentration ranged from BDL to 0.39 ppm in brown fronds of *S. molesta,* 0.05 to 0.74 ppm in *E. crassipes* roots and BDL to 0.10 ppm in *P. stratiotes* roots while it varied from BDL to 0.10 ppm, 0.01 to 0.51 ppm, and BDL to 0.02 ppm in shoots of *S. molesta, E. crassipes* and *P. stratiotes* respectively. Highest concentration of Pb was recorded in *E. crassipes* (1.74 ppm) followed by *S. molesta* (0.49 ppm) and *P. stratiotes* (0.12 ppm). Jeffery *et al.*, (1976) reported that *E. crassipes* and *S. molesta* as hyperaccumulators of Pb.

Waste discharges cause eutrophication of water bodies and water borne diseases. The treatment of waste water using phytoremediation the most desirable treatment technology in recent use (George and Gabriel, 2017). The cleanup of most of the contaminated sites is necessary in order to reclaim the area and to reduce the entry of toxic metals into the food chain. Since the last few decades phytoremediation (bioremediation) has emerged eco friendly, energy efficient, aesthetically pleasing method of remediating sites (Malik and Biswas, 2012).

Trace metal concentration was below detectable level many a times in water, continuous results could not be obtained, and hence only the data pertaining to sediments was subjected to SPPSS 19 software to draw correlations between the metals. Positive correlations were observed between trace metals like**:** Mn - Fe, Cu - Fe, Pb - Fe, Mn - Pb, Ni - Pb at **Syngenta Lake (Table 51)**, Mn - Fe, Pb - Cu, Zn - Cu , Ni - Pb, Zn - Pb at **Khandola Pond (Table 52)**, Mn - Cu, Ni - Mn, Ni - Cu, Zn - Cu, Ni - Zn, Pb - Fe, Ni - Pb at **Lotus Lake (Table 53)** and Ni - Fe, Pb - Fe, Zn - Cu, Ni - Pb at **Curtorim Lake (Table 54).** This could be attributed to the common sources responsible for metal release in the water bodies. Present study revealed that the selected species exhibited variations in trace element accumulation. Metal concentration in selected macrophytes was in the following order-

- *S. molesta* - Mn >Fe> Zn >Cu>Ni >Pb
- *E. crassipes* - Fe>Cu>Mn>Zn>Ni>Pb
- *P. stratiotes* - Cu>Mn>Fe> Zn>Pb>Ni

It was observed that the metal uptake was more during dry season compared to monsoon. Temperature and pH played an important role in the metal uptake. Agricultural activities near Khandola Pond, Lotus and Curtorim Lakes and, industrial activities near Syngenta Lake have contributed to high levels of metals as these metals are known to occur as impurities in fertilizers, metal-based pesticides, compost and manure.

Table 51: Pearson's correlation matrix for sediment of Syngenta Lake.

Metal	Fe	Mn	Cu	Ni	Zn	Pb
Fe	1					
Mn	**.785****	1				
Cu	**.730****	.825**	1			
Ni	**.779****	.831**	.990**	1		
Zn	.475	.492	.152	.236	1	
Pb	**.913****	**.807****	**.793****	**.848****	.498	1

Table 52: Pearson's correlation matrix for sediment of Khandola Pond.

	Fe	Mn	Cu	Ni	Zn	Pb
Fe	1					
Mn	.736	1				
Cu	.665	.368	1			
Ni	.835*	.692	.911*	1		
Zn	.664	.380	**.980****	.881*	1	
Pb	.769	.429	**.986****	**.933****	**.962****	1

Legend: *. Significant at the 0.05 level (2-tailed); **. Significant at the 0.01 level (2-tailed). Fe - Iron, Mn - Manganese, Cu - Copper, Ni -Nickel, Zn - Zinc, Pb - Lead.

Table 53: Pearson's correlation matrix for sediment of Lotus Lake.

Metal	Fe	Mn	Cu	Ni	Zn	Pb
Fe	1					
Mn	.162	1				
Cu	.393	**.871****	1			
Ni	.424	**.848****	**.987****	1		
Zn	.286	.682*	**.861****	**.878****	1	
Pb	**.738****	.629*	**.718****	**.755****	.458	1

Table 54: Pearson's correlation matrix for sediment of Curtorim Lake.

Metal	Fe	Mn	Cu	Ni	Zn	Pb
Fe	1					
Mn	.469	1				
Cu	.249	.114	1			
Ni	**.894****	.580*	.370	1		
Zn	.177	.362	**.829****	.292	1	
Pb	**.847****	.637*	.360	**.987****	.313	1

Legend: *. Significant at the 0.01 level (2-tailed); **. Significant at the 0.05 level (2-tailed). Fe - Iron, Mn - Manganese, Cu - Copper, Ni -Nickel, Zn - Zinc, Pb - Lead.

CHAPTER - 7

To study the restoration measures using phyto-remediation process in selected water bodies.

7.1: INTRODUCTION

Large scale industrialization and production of various chemical compounds have lead to trace metal pollution and ecological degradation of aquatic environment (Baldantoni *et al.,* 2004). The persistence of trace metals in the ecosystem and their bioaccumulation through food chains causes health hazards to humans (Wagner, 1993). Plants that absorb and accumulate trace metals are used to remove pollutants from the ecosystem. Various species show different capacities for metal uptake (Marchand *et al.,* 2010). Aquatic plants can accumulate trace metals in roots, stems and/or leaves (Jakson *et al.,* 1998). In aquatic systems, where pollutant inputs are discontinuous and pollutants are quickly diluted, analyses of plant tissues provide vital information of metal accumulation (Baldantoni *et al.,* 2005). Aquatic macrophytes are widely distributed in various wet environments, from fresh to salt water (Bonanno and Guidice, 2010). Various studies have indicated (Vahdati and Khara, 2012; Rai and Singh, 2016) that aquatic plants can improve the lake ecosystem by mitigating pollutant concentrations in contaminated soils and water (Odjegbal and Fasidi, 2004). In order to qualify as bioindicator species, plants must be able to grow without any effect in the presence of the pollutant, accumulate the pollutant in its tissue and concentrate the pollutant in its tissues to a significant level (Ugya *et al.,* 2015).

Phytoremediation using aquatic plants is evolving as a cost-effective alternative, thus considered as 'Green Revolution' in the clean-up technologies (Guittonny-Philippe *et al.,* 2014). Accumulator species accumulate relatively large amounts of pollutants, without obnoxious effects (Ravera *et al.,* 2003). The bio-accumulation factor (BAF) and translocation factor (TF) are most important plant features in phytoremediation with respect to uptake of metals, their mobilization into plant tissues, and storage in the aerial plant biomass (McGrath and Zhao, 2003). Plants with more than one BAF and high root-to-shoot metal translocation are ideal for phytoremediation and called hyper-accumulators (Garbisu and Alkorta, 2001). In the aquatic systems, hydrophytes have the potential to uptake heavy metals and extract large concentrations of metals into their roots and translocate them to surface biomass (Ghosh and Singh, 2005).

The ecological tolerance of different categories of aquatic plant species vary depending on their specific habits and habitats (Lu *et al.*, 2010). Macrophytes are used in remediation of polluted water bodies because of their high capability to accumulate toxic elements (Skinner *et al.*, 2007).

Many water bodies in the state of Goa are infested by macrophytes like *Salvinia molesta, Eichhornia crassipes, Hydrilla verticillata, Pistia stratiotes, Heterophyllum ceratophyllum etc*. The present study was carried out to test the suitability of three dominant macrophytes *viz., S. molesta, E. crassipes* and *P. stratiotes* for trace metal accumulation in selected water bodies. Also, the BAF of trace metals like Fe, Mn, Cu, Ni, Zn and Pb in the selected plant roots and shoots was calculated. Besides, the capability of these macrophytes in translocating analyzed trace metals in their aerial parts was determined by calculating TF.

7.2: MATERIALS AND METHODS

The trace metal analyses from water, sediment and the three dominant aquatic macrophytes *viz., S. molesta, E. crassipes* and *P. stratiotes* were carried out during pre-monsoon, monsoon and post-monsoon seasons. The BAF and TF were calculated as follows:

1. BAF= Metal concentration in plant tissue / Metal concentration in water (Klavins *et al.,* 1998).

2. TF= Metal concentration in root / Metal concentration in shoot (Wu and Sun, 1998).

7.3: RESULTS AND DISCUSSION

7.3.1: Bioaccumulation factor (BAF)

The ratio between trace metal concentration in plant and that of the media (water/sediment) expresses the BAF (Abd-Elmoniem, 2003). This reflects the affinity of an aquatic macrophyte to a specific metal element or pollutant. Metal accumulations by macrophytes are affected by metal concentrations in water and sediments (Lu *et al.,* 2004). The ambient metal concentration in water can be the major factor influencing the metal uptake efficiency (Rai and Chandra, 1992).

Good accumulator is recognized by its ability to absorb/uptake continuous metal and to bio accumulates it in its tissues (Zhu, *et al.,* 1999). BAF values calculated for selected aquatic plants are depicted in **Table 55**. During present study BAF for Fe was 0.77 in *P. stratiotes,* 2.28 in *S. molesta* and 2.33 in *E. crassipes*. Highest BAF was recorded in *E. crassipes* followed by *S. molesta* whereas the least BAF was recorded in *P. stratiotes* indicating poor accumulation ability for Fe.

BAF for Mn in *P. stratiotes* was 5.40 followed by *E. crassipes* (7.86) while it was highest in *S. molesta* (32.32). Thus, it is concluded that *S. molesta* is hyperaccumulator of Mn followed by *E. crassipes* and *P. stratiotes*. Lowest BAF for Cu was recorded in *S. molesta* (1.60) followed by *E. crassipes* (4.12) while being highest in *P. stratiotes* (5.22) indicating *P. stratiotes* as the highest accumulator of Cu. Ni was accumulated in lower concentration by *P. stratiotes* (0.03) followed by *E. crassipes* (1.14) whereas *S. molesta* accumulated highest amount of this element with a BAF of 2.51.

Zn accumulation was lowest in *E. crassipes* (0.73) followed by *P. stratiotes* (0.85) while *S. molesta* accumulated highest amount with BAF of 1.07. BAF for Pb was 2.48 in *P. stratiotes* followed by *E. crassipes* (2.94) while *S. molesta* (3.06) a better accumulator. These metals occur as impurities in fertilizers, metal-based pesticides, compost, manure and solid waste that get into the water bodies. Aquatic plants growing in the study area exhibited variations in trace metal concentrations. The roots/brown fronds *S. molesta* absorbed more amounts of metals compared to shoots. According to Abdel-sabour (2010) roots of aquatic plants accumulate greater amount of trace metals than the stems and leaves. Zhu *et al.* (1999) reported the main route of heavy metal uptake in aquatic plants is through the roots. According to Deng *et al.* (2004) metals get accumulated in roots but sometimes shoots of macrophytes may show levels far above the toxic concentration indicating an internal detoxification metal tolerance mechanism.

The present study revealed that the metal uptake was more during the dry season than in monsoon, which is in confirmation with the observation of Gulati *et al.* (1979). This can be attributed to elevated temperatures in dry season that enhances evapo-transpiration which transports metals at a faster rate from the soil solution to roots, leaves and stems. Low water pH during dry season is known to increase metals bioavailability in hydrophytes. 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, besides light intensity, oxygen and even the age of the sampled plant from that particular sampling point (Siriwan *et al.,* 2006). The macrophytes analyzed in the present study were found suitable for phytoremediation process as they were found to be potential scavengers of trace metals from water.

Bio-accumulation factor (BAF) of trace metals is highest within the selected free floating plants. It is mainly influenced by bioavailability of the metals in both external (sediment and water-associated) and internal (plant and animal-associated) environmental factors (Ndeda and Manohar, 2014). George and Gabriel (2017) reported that *S. molesta* accumulated Mn, Ni, Zn and Pb effectively. Abdel-Sabour *et al.* (2010) reported that *E. crassipes* has been intensively studied as a bioindicator, and is reported to effectively concentrate a number of contaminants within a broad concentration range. Odjegbal and Fasidi (2004) reported that *P. stratiotes* was found suitable for accumulation of Cu and Zn.

In the present study, the BAF for analyzed 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*

7.3.2: Translocation factor (TF)

The movement of metal-containing sap from root to shoot of aquatic macrophytes is termed as translocation which is primarily controlled by processes like root pressure and leaf transpiration (Lasat, 2000). Some metals are accumulated in roots, due to physiological barriers against their transport to the aerial parts, while others are easily transported (Lu *et al.*, 2004). TF being the ratio between concentrations of a trace element accumulated in root tissues by that accumulated in shoot tissues and higher TF implies poorer translocation capability. Translocation of metals by macrophytes takes time and varies with species, presence of metal transporters and availability of binding sites, energy, environmental conditions like pH, photosynthesis, temperature *etc.* metabolic levels and regulatory proteins present in plants (Williams *et al.* 2000; Ghosh and Singh, 2005). Yanqun *et al.* (2005) reported that when the TF value is greater than 1, the plants are considered as 'accumulator species', whereas when TF value is less than 1 the plants are considered as excluder species. TF values greater than 1 indicate that there is transport of metal from root to leaf (Zhao *et al.*, 2003) and sequestration in leaf vacuoles and apoplast (Lasat *et al.*, 2000).

TF of metals in the studied macrophytes are presented in **Table 56**. TF for Fe was 1.9 in *P. stratiotes* followed by *E. crassipes* (2.88) while it was highest in *S. molesta* (3.20). Mn recorded a TF value of 1.43 in *E. crassipes* followed by *S. molesta* (2.12) and *P. stratiotes* (2.50). TF for Cu was 1.66 in *S. molesta* followed by *E. crassipes* (7.25) and *P. stratiotes* (7.65). TF for Ni was 4.0 in *P. stratiotes* followed by *S. molesta* (4.58) and *E. crassipes* (5.8). Zn recorded a TF value of 1.40 in *E. crassipes* followed by *P. stratiotes* (1.63) and *S. molesta* (2.5). Pb recorded TF value of 1.45 in *E. crassipes* followed by *S. molesta* (3.9) and *P. stratiotes* (5.0).

Results showed differences in TF values thereby indicating the preferential accumulation/uptake and translocation of metals. In the present study, all the plant species showed a root to shoot translocation factor greater than 1 for all the metals. This

Table 55: Bioaccumulation factor of selected macrophytes.

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

Table 56: Translocation factor of selected macrophytes.

Metal	*Salvinia molesta*	*Eichhornia crassipes*	*Pistia stratiotes*
Fe	3.02	2.88	1.59
Mn	2.12	1.43	2.5
Cu	1.66	7.25	7.65
Ni	4.58	5.8	4.0
Zn	2.5	1.40	1.63
Pb	3.9	1.45	5.0

suggests that these macrophytes can be effectively used for the phytoremediation of aquatic water bodies contaminated with heavy metals.

Lower TF values of 1.59 for Fe in *P. stratiotes*, 1.43 for Mn in *E. crassipes*, 1.66 for Cu in *S. molesta*, 1.40 for Zn in *E. crassipes* and 1.45 for Pb in *E. crassipes* were recorded during pre- and post-monsoon season indicating better translocation of metals. Amongst the three selected macrophytes, *E. crassipes* recorded maximum translocation. This may be attributed to unique morphological and anatomical peculiarities of the plant (Akinbile and Yusoff, 2012). Metal uptake by aquatic plants involves transport across the plasma membrane of root cells, loading in xylem tissues, translocation, detoxification, and subsequently metal sequestration at cellular levels (Lombi *et al.*, 2002). A good hyperaccumulator is recognized by its ability to amass metals primarily in the shoots, both at low and high exogenous metal concentrations (Antosiewicz, 1992). Translocation was also favoured by factors like low pH and high temperature of water. The elevated temperatures in dry season enhance evapotranspiration, thereby transporting metals at a faster rate from the water to roots and shoots. Besides, low water and sediment pH during dry season increases metal bioavailability in hydrophytes (Rai *et al.*, 1995).

In the present study, the TF for analysed metals was in following order**:**

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

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

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

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

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

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

Brun *et al.* (2001) observed that the mobility of metals in aquatic plant species varies among species. In the present study, all three species proved to be good accumulators. After assessing the potential of selected aquatic macrophytes as a tool to reduce trace metal contamination and as remediator species, the awareness on technical information related to phytoremediation will greatly increase. However, care should be taken while selecting the contaminated site, target contaminant, and efficacy of the aquatic plant selected.

In future, additional studies are required to understand the mechanism of action of the aquatic plants. With the advancement in the field of genetic recombination technology, genetically engineered plants can be instrumental in the phytoremediation approaches towards cleaning of aquatic environment. Also combined use of other approaches like phytostabilization, phytofiltration, phytovolatilization, phytodegradation and phytotransformation besides phytoremediation need to be attempted.

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.

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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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PHYSICO-CHEMICAL CHARACTERISTICS AND PHYTOPLANKTON DIVERSITY IN SOME FRESH WATER BODIES OF GOA, INDIA

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ABSTRACT

The freshwater bodies on the surface of globe are environmental assets. They harbour organisms that generate oxygen in the surrounding environment which is utilized by members of all trophic levels. These aquatic assets also provide habitats to a large number of diverse aquatic organisms. Rapid industrialization and urbanization has greatly decreased the available water resources in India. This paper describes physico-chemical characteristics of four fresh water bodies viz., Syngenta Lake, Khandola Pond, Lotus Lake and Curtorim Lake in Goa, India along with their phytoplankton diversity. Seventy one algal species belonging to five classes were identified from the study sites. Seasonal variations were observed in most of the physico-chemical parameters and they were above environmentally acceptable limits. Excepting Khandola Pond, the sites were affected by pollution.

Key Words : Eutrophication, Fresh water bodies, Phytoplanktons, Pollution, Urbanization

INTRODUCTION

Lakes are ecological security zones and true indicators of sustainable urban development. They provide opportunities for recreation, study of local aquatic life and ornamental purposes. As a result of increasing land use conflicts and effluent disposal, water bodies and their catchments in the urban regions have become the ultimate casualties[1]. Yet conservation of water bodies is in the interest of mankind in ecological, cultural and tourism values. As they are so important, it is imperative and challenging to assess their present condition. In the present paper, physico-chemical characteristics and phytopla-nkton diversity of four fresh water bodies are presented.

MATERIAL AND METHODS

Two water bodies each from North Goa (Syngenta Lake and Khandola pond) and South Goa (Lotus Lake and Cutorim Lake) were selected for the study from Jan-Oct 2014. Water samples were collected in the early hours as daily vertical migrations of organisms occur in response to sunlight and nutrient concentrations from the surface near the landward margins. Monthly analyses of water samples from all the selected water bodies were carried out for a period of ten months using standard procedures[2]. In the phytoplan-kton study one litre of water sample was collected in sterile plastic bottles and Lugol's solution (0.7 ml/100 ml of sample) added immediately for sedimentation. The bottles were subsequently left undisturbed for 24 h. The phytoplankton fixed and settled at the bottom of the containers after decanting the supernatant fluid were collected and preserved in bottles containing 4% formaldehyde preservative. The remaining sample was concentrated by centrifugation at 1500 rpm and the total volumes made to 10ml. Algal samples were examined immediately after fixation using a light microscope. Dimensions were measured using a micrometry technique and photomicrographs were taken using Nikon DS Fi 2camera. Identification was carried out using standard bibliographies and monogr-aphs[3-8].

RESULTS AND DISCUSSION

Phytoplankton ecology plays an important role for indicating the eutrophication. Their distribution is majorly forced by seasonal

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fluctuations in physic-chemical parameters. Factors such as seasonality, period of sunshine, wind patterns, depth of lake, temperature, pH, turbidity, dissolved oxygen, nutrient enrichment like phosphate ultimately influence the occurrence phytoplankton in the lake[9].

The results of the phytoplankton diversity recorded during the study are shown in **Table 1**. In all 71 algal species belonging to five classes viz., Cyanophyceae (15spp.), Dinophyceae (1sp.), Bacillariophyceae (17spp.), Eugleno - phyceae (5spp.) and Chlorophyceae (33spp.) were identified from the study sites. Some of the genera known to be indicators of organic pollution viz., *Scenedesmus, Chroococcus, Melosira* and *Navicula* were recovered from Syngenta, Lotus and Curtorim Lakes. Khirsagar[10] determined water quality of river Mula and reported that *Scenedesmus, Pediastrum, Oscillat oria, Melosira, Navicula* and *Nitzschia* are indica tors of organic pollution. Palmer[11] stated that pre sence of *Scenedesmus* indicates eutrophic water.

Table 1 : Phytoplankton diversity in the study sites

S/N	Species	Study sites			
		Syngenta Lake	Khandola Pond	Lotus Lake	Curtorim Lake
1.	*Euglena acus* (Muller) Ehrenberg	+	-	+	+
2.	*Euglena minuta* Prescott	+	-	+	+
3.	*Euglena oxyuris*s Schmarda	+	-	+	+
4.	*Ankistrodesmus falcatus* (Corda) Ralfs	+	-	+	+
5.	*Tetralantus lagerheimii* Teiling	-	-	+	-
6.	*Cruciginia quadrata* Morren	-	-	+	+
7.	*Pinnularia gibba* Ehrenberg	+	-	+	+
8.	*Pinnularia graciloids* Huste	+	-	+	+
9.	*Sehroederia indica* Philipose	+	-	+	+
10.	*Melosira islandica* Muller	-	-	+	+
11.	*Nostoc muscorum* Agardh ex Bornet and Flahault	+	-	+	+
12.	*Clostredium diane* Ehrenberg	+	-	+	+
13.	*Trachalomonas volvocina* Ehrenberg	-	-	+	+
14.	*Oocystis gigas* Archer	+	-	+	+
15.	*Phacus asymmetrica* Prescott	+	-	+	+
16.	*Cymbella chandolensis* Gandhi	+	-	+	+
17.	*Chroococcus limnaticus* Lemmermann	+	-	+	+
18.	*Chroococcus minor* (Kutzing) Nageli	+	-	+	+
19.	*Closterium dianae* var. Minus (Schroder) Willi Krieger	+	-	+	+
20.	*Closterium baillyanum* (Breb.) Breb.	+	-	+	+
21.	*Gomphonema parabolum* Kutzing	+	-	+	+
22.	*Oscillatoria princeps* Vaucher *ex* Gomont	+	-	+	+
23.	*Oscillatoria tenuissima* (Smith and Sowerby) C. Agardh ex Forti	+	-	+	+
24.	*Merismopedia punctata* Meyen	+	-	+	+
25.	*Scenedesmus quadricauda* (Trupin) Brebisson	+	-	+	+
26.	*Actinastrum hantzschii* var elongatum G. M. Smith	+	-	+	+
27.	*Pediastrum tetras* (Ehrenberg) Ralfs	+	-	+	+
28.	*Scenedesmus bernardii* G. M. Smith	+	-	+	+
29.	*Anabaena circinalis* Rabenhorst ex Bornet	+	-	+	+

	and Flahault				
30.	*Navicula halophila* (Gurnow) Cleve	+	+	+	+
31.	*Navicula rediosa* (Kuetz.)	+	+	+	+
32.	*Cosmarium ceylanicum* West and G. S. West	+	-	+	+
33.	*Cosmarium cucurbitinum* A.M. Scott and R.Gronblad	+	-	+	+
34.	*Pinnula ria dolosa* Gandhi	+	+	+	+
35.	*Bulbochaete setigera* C. Agardh ex Hirn.	+	-	+	+
36.	*Euastrum ansatum* Ehrenberg	+	-	+	+
37.	*Netrium digitus* (Ehrenberg) Itzigsohn and Rothe	+	-	+	+

Variations in physico-chemical characteristics of the selected water bodies are presented in **Table 2** to **Table 5**. The pH of water ranged from5.9 to 7.8. Maximum range was recorded in Lotus Lake, from 5.9 to 7.8. The phytoplankton diversity also showed variations that may be attributed to the changes in pH values. Physico-chemical and biological characteristics of water bodies are known to influence each other[12] and pH range of 5 to 8.5 was reported to be ideal for phytoplankton growth[13].

Table 2 : Physico-chemical analysis of water samples of Syngenta Lake (Jan. – Oct. 2014)

Parameter	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.
pH	6.10 ±0.05	5.90 ±0.11	6.20 ±0.02	6.20 ±0.02	6.30 ±0.01	6.40 ±0.01	6.80 ±0.17	6.40 ±0.00	6.23 ±0.01	6.09 ±0.00
Temp. (^oC)	25.00 ±1.2	28.00 ±0.20	28.00 ±0.20	30.00 ±0.45	31.00 ±0.8	30.80 ±0.72	28.40 ±0.06	27.40 ±0.40	28.40 ±0.06	29.00 ±0.10
TDS (mg L^{-1})	620.00 ±8.76	745.00 ±32.90	685.00 ±12.90	634.00 ±4.10	645.00 ±0.42	621.00 ±8.43	687.00 ±13.56	606.00 ±13.43	616.00 ±10.10	604.00 ±14.10
DO (mg L^{-1})	8.11 ±0.06	6.80 ±0.50	6.80 ±0.50	6.08 ±0.73	6.01 ±0.76	6.89 ±0.46	9.60 ±0.42	10.54 ±0.74	12.06 ±1.25	10.20 ±0.63
Nitrates (mg L^{-1})	0.20 ±0.09	0.72 ±0.08	0.82 ±0.10	0.31 ±0.05	0.54 ±0.02	0.33 ±0.05	0.41 ±0.02	0.50 ±0.006	0.53 ±0.01	0.48 ±0.00
Phosphates (mg L^{-1})	0.10 ±0.02	0.12 ±0.02	0.23 ±0.01	0.10 ±0.02	0.24 ±0.02	0.27 ±0.03	0.25 ±0.02	0.19 ±0.03	0.20 ±0.00	0.15 ±0.01

Legend : values are mean of three replicates. ± = Standard deviation

Table 3 : Physico-chemical analysis of water samples of Khandola Pond (Jan. – Oct. 2014)

Parameter	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.
pH	7.14 ±0.24	6.10 ±0.07	6.00 ±0.10	6.10 ±0.07	6.00 0±0.1	6.80 ±0.14	6.40 ±0.01	6.20 ±0.04	6.40 ±0.01	6.40 ±0.01
Temp. (^oC)	25.00 ±0.22	28.00 ±0.76	28.00 ±0.76	30.00 ±1.43	31.00 ±1.76	30.80 ±1.70	30.80 ±1.70	28.40 ±0.90	27.40 ±0.56	28.40 ±0.90
TDS (mg L^{-1})	41.20 ±1.08	49.60 ±1.71	40.23 ±1.40	43.70 ±0.24	51.54 ±0.00	38.70 ±1.91	32.60 ±3.94	47.60 ±1.04	50.21 ±1.91	49.30 ±1.61
DO (mg L^{-1})	7.20 ±0.59	7.40 ±0.52	8.60 ±0.10	7.90 ±1.08	8.00 ±0.310	7.20 ±0.59	9.32 ±0.20	10.95 ±0.64	11.97 ±0.98	11.44 ±0.81
Nitrates (mg L^{-1})	0.27 ±0.12	0.23 ±0.04	0.56 ±0.05	0.47 ±0.02	0.36 ±0.03	0.50 ±0.031	0.58 ±0.042	0.34 ±0.01	0.38 ±0.00	0.31 ±0.08
Phosphates (mg L^{-1})	0.01 ±0.02	0.02 ±0.02	0.01 ±0.02	0.04 ±0.01	0.02 ±0.02	0.02 ±0.02	0.30 ±0.2	0.25 ±0.05	0.15 ±0.02	0.15 ±0.02

Legend : values are mean of three replicates. ± = Standard deviation

The water temperature throughout the sites varied from 25 to 31°C, maximum in May (late summer and early rainy season) and minimum in January (the late rainy and winter season). Water temperature plays an important role in controlling the occurrence and abundance of phytoplanktons[14].

The Total Dissolved Solids (TDS) were least at Khandola Pond (32.60 to 51.45 mg L^{-1}), greater at Syngenta Lake (604 to745 mg L^{-1}), greater still at Lotus Lake (616 to 1078 mg L^{-1}) and highest at Curtorim Lake (922 to 1389 mg L^{-1}). Beeton[15] attributed an increase in TDS in St. Lawrence Great Lakes to cultural eutrophication and suggested the separation of Oligotrophic and Eutrophic lakes based on TDS values. Oligotrophic lakes have TDS less than 100 ppm, while eutrophic lakes have TDS more than 100 ppm. This increase in TDS above 100 ppm in Syngenta, Lotus and Curtorim lakes indicate cultural eutrophic-ation.

Table 4 : Physico-chemical analysis of water samples of Lotus Lake (Jan. – Oct. 2014)

Parameter	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.
pH	7.80 ±0.46	6.60 ±0.06	6.46 ±0.02	6.00 ±0.10	5.90 ±0.14	6.00 ±0.10	6.73 ±0.10	6.00 ±0.10	6.50 ±0.03	6.00 ±0.10
Temp. (°C)	25.50 ±1.10	29.00 ±0.14	29.00 ±0.14	30.00 ±0.38	31.00 ±0.72	30.00 ±0.38	30.00 ±0.38	26.20 ±0.86	28.40 ±0.10	29.00 ±0.14
TDS (mg L^{-1})	616.50 ±83.15	673.20 ±64.15	782.00 ±27.88	968.00 ±34.10	997.00 ±43.77	962.00 ±32.10	1078.00 ±70.77	910.00 ±14.77	825.00 ±13.55	845.00 ±6.88
DO (mg L^{-1})	6.07 ±0.63	6.60 ±0.44	6.79 ±0.38	8.12 ±0.04	5.68 ±0.76	9.22 ±0.41	10.30 ±0.77	9.44 ±0.48	9.35 ±0.45	8.14 ±0.05
Nitrates (mg L^{-1})	1.43 ±0.14	1.58 ±0.33	1.66 ±0.30	1.76 ±0.26	1.81 ±0.20	2.16 ±0.14	4.55 ±0.64	3.16 ±0.24	3.38 ±0.24	4.45 ±0.61
Phosphates (mg L^{-1})	0.01 ±0.20	0.03 ±0.20	0.10 ±0.17	0.25 ±0.010	0.25 ±0.10	0.30 ±0.10	2.41 ±0.58	1.92 ±0.41	0.78 ±0.03	0.60 ±0.02

Legend : values are mean of three replicates. ± = Standard deviation

Table 5 : Physico-chemical analysis of water samples of Curtorim Lake (Jan. – Oct. 2014)

Parameter	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.
pH	6.80 ±0.09	6.90 ±0.06	6.70 ±0.10	6.90 ±0.06	6.72 ±0.10	7.60 ±0.14	7.68 ±0.17	7.52 ±0.14	7.68 ±0.03	6.40 ±0.05
Temp. (°C)	25.50 ±1.10	29.00 ±0.14	29.00 ±0.14	30.00 ±0.38	31.00 ±0.72	30.00 ±0.38	30.00 ±0.38	26.20 ±0.86	28.40 ±0.10	29.00 ±0.14
TDS (mg L^{-1})	1124 ±17.66	1207 ±45.33	1308 ±79.00	1240 ±56.33	1285 ±71.33	1389 ±106.00	1317 ±82.00	1210 ±46.32	1118 ±15.65	922.00 ±49.65
DO (mg L^{-1})	8.95 ±0.20	8.14 ±0.47	8.51 ±0.34	8.94 ±0.20	7.98 ±0.52	8.55 ±0.33	9.19 ±0.10	11.76 ±0.72	11.03 ±0.47	12.77 ±1.06
Nitrates (mg L^{-1})	0.80 ±0.28	1.27 ±0.10	1.50 ±0.06	1.78 ±0.03	2.57 ±0.28	1.32 ±0.01	2.27 ±0.17	2.76 ±0.34	1.43 ±0.08	1.27 ±0.10
Phosphates (mg L^{-1})	0.01 ±0.00	0.02 ±0.10	0.01 ±0.00	0.04 ±0.10	0.12 ±0.07	0.15 ±0.06	1.72 ±0.45	0.49 ±0.14	0.55 ±0.06	0.30 ±0.01

Legend : values are mean of three replicates. ± = Standard deviation

Dissolved oxygen (DO) ranged between 6.01 mg L^{-1} and 12.06 mg L^{-1} at Syngenta Lake, 7.20 to 11.97 mg L^{-1} at Khandola Pond, 5.68 to 10.30 mg L^{-1} at Lotus Lake and 8.14 to 12.77 mg L^{-1} at Curtorim Lake. Dissolved oxygen acts as a regulator of metabolic activities of organisms and thus governs metabolism of biological community as a whole. It is also used as an indicator of trophic status of the water[16]. Increased amount of dissolved oxygen observed during monsoon is known to be due to increased solubility of oxygen[17], lower levels of dissolved oxygen in summer is due to higher temperature and low solubility of oxygen in water[18].

The nitrate levels showed variations in the water bodies and ranged from 0.20 to 0.54 mg L^{-1} in Syngenta Lake, 0.23 to 0.58 mg L^{-1} in Khandola

Pond, 1.43 to 4.55 mg L^{-1} in Lotus Lake and 0.80 to 2.76 mg L^{-1} in Curtorim Lake. Phosphate concentrations also showed variations and ranged from 0.10 to 0.25 mg L^{-1} in Syngenta Lake, 0.01 to 0.30 mg L^{-1} in Khandola Pond, 0.01 to 2. 41 mg L^{-1} in Lotus Lake and 0.01 to 0.55 mg L^{-1} in Curtorim Lake. The study has revealed that during monsoon season, pollutants like nitrates and phosphates are entering the water bodies from the surrounding area, especially from farmlands, resulting in elevated concentrations of nitrates and phosphates. Eutrophic conditions are observed during pre- and post-monsoon seasons at Syngenta, Lotus and Curtorim Lakes, supporting the growth of phytoplankton. Increased levels of nitrates and phosphates indirectly harm the environment by causing bacterial growth and huge algal blooms[19]. Studies suggest that due to continuous runoff of high-mineral content into the water form the quality of water-dwelling organisms in lakes[20]. Higher concentrations of nitrates are useful in irrigation, but entry into water resources increases the growth of nuisance algae and triggers pollution due to increases in algal density[21-32].

CONCLUSION

Results of the physico-chemical profile of the water bodies present an enigmatic picture with certain parameters indicating an oligotrophic regime, others pointing towards eutrophy. The analysis of water quality suggests that most of the parameters are above the required 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 not affected by any of the above anthropogenic stresses. Further, studies on continuous monitoring of these water bodies to collect further data on physical, chemical and biological characteristics needs to be undertaken. Conservation of water bodies is imperative for ecological, cultural and touristic values, as are important to mankind in various ways.

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Biomonitoring of Selected Freshwater Bodies Using Diatoms as Ecological Indicators

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Abstract

Lakes supply water for irrigation, drinking, fisheries, etc. and thus have significant economic and recreational value. In order to determine impacts of human activities on aquatic ecosystem it is important to distinguish anthropogenic impact and natural variation. In limnetic ecosystem, water quality is influenced by physical, chemical, and biological factors. Freshwater communities are very much sensitive to environmental variables. The algal flora constitutes a vital link in the food chain and its productivity depends on water quality at a given time. Diatoms in particular are of utmost importance, as potential indicators of water quality due to their sensitivity and strong response to many physical, chemical and biological changes. Occurrence of diatom communities in selected fresh water bodies of Goa along with physico-chemical parameters have been studied for a period of two consecutive years and the data has been used in biomonitoring. Using OMNIDIA GB 5.3 software, Louis Leclercq IDSE/5 index is derived and the level of degradation due to organic and anthropogenic pollution has been found out. Findings showed seasonal variations in physico-chemical parameters and diatom population. The diversity of diatoms was considerably high in Syngenta, Lotus and Curtorim lakes compared to Khandola Pond. *Gomphonema parabolum*, *Navicula halophila*, *Navicula microcephala*, *Navicula mutica* indicates organic pollution in the water bodies. *Amphora ovalis*, *Stauroneis phoenicenteron, Synedra ulna* indicates anthropogenic pollution in Syngenta, Lotus and Curtorim lakes while *Navicula rhynococephala* indicate anthropogenic pollution in Khandola Pond. Biomonitoring has been proven to be necessary and hence the importance of diatoms as ecological indicators of water quality has been stressed.

Keywords: Anthropogenic pollution; Biomonitoring; Diatoms; Ecological indicators; Louis-Laclercq; Organic pollution

Introduction

Freshwater communities are very much sensitive to environmental variations [1]. Phytoplankton dynamics influence trophic levels and portability of water for human uses [2,3]. Monitoring of water quality with regards to physical and chemical parameters reflects instantaneous measurements while, biotic parameters developed during the recent years have served as an excellent tool in the area of water pollution studies and provides better evaluation of environmental changes [4]. Diatoms are potential indicators of water quality due to their sensitivity and strong response to physico-chemical and biological changes [5]. Juttner et al. [6] studied environmental changes using diatom assemblages, relationship between diatoms and the water chemistry parameters. According to him fluctuation of diatom species to various environmental changes can be early warning towards freshwater ecological problems. Their sensitivity to small changes in water quality makes them powerful indicators. Several studies on diatoms as bioindicators of pollution have been carried out earlier [7-12].

Biological monitoring is a fast and cost-effective approach for assessing the effects of environmental stressors, making it an essential tool [13]. Various indices have been developed for monitoring pollution in water bodies. One of the simplest and effective water quality index, utilizing diatom population is IDSE/5-the index of Saprobity-Eutrophication. 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. The design of OMNIDA Software for computation of diatom indices has facilitated the use of diatom based biomonitoring [14]. The software is a comprehensive data base having an inbuilt ecological data for 13,000 diatom species. Present study discusses diatoms as indicators of water quality of selected water bodies using Louis-Leclercq Diatomic Index of Saprobity-Eutrophication (IDSE/5) and the quality of water in terms of organic pollution as well as anthropogenic eutrophication.

Materials and Methods

Two water bodies each from North Goa (Syngenta Lake and Khandola Pond) and South Goa (Lotus Lake and Curtorim Lake) were selected for the study from January 2014 to December 2015 on monthly basis. Water samples were collected in the early hours as daily vertical migrations of organisms occur in response to sunlight and nutrient concentrations from the surface near the landward margins. Physico-chemical parameters such as pH, temperature, nitrates and phosphates were analysed using standard procedures [15]. For phytoplankton study one litre of water sample was collected in sterile plastic bottles (three replicates were taken) and Lugol's solution (0.7 mL/100 mL of sample) added immediately for sedimentation. The bottles were subsequently left undisturbed for 24 h. The phytoplankton fixed and settled at the bottom of the containers after decanting the supernatant fluid were collected and preserved in bottles containing 4% formaldehyde. Enumeration of diatoms was done by modified Lackey's drop method [16]. Dimensions were measured using micrometry technique and photomicrographs were taken using Nikon DS Fi 2 camera. Various taxonomic guides were consulted [17-20]. Each taxon was coded

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with acronyms as per the rules of OMNIDA GB 5.3 software. Diatom species counts were entered into diatom database and index calculation tool, OMNIDIA version 5.3 [14]. The output of the software provides various metrics of water quality through the indices and ecological characteristics. The Louis Leclercq IDSE/5 index was calculated using this software [21]. Seven ecological indicator values given by Van Dam et al. [8] were derived for selected water bodies using the OMNIDIA GB 5.3 software and were used for interpretation of results. These values indicate the conditions required for growth and survival of diatoms. These include pH, salinity (H), nitrogen uptake (NU), oxygen requirements (OR), saprobity (SP), trophic state (TS) and moisture (M) and also determine the water quality. Each parameter is measured on a scale of 1-7. OMNIDIA is also used to compute degradation (D) using IDSE/5 Louis Leclercq index for organic pollution (OP) and anthropogenic eutrophication (AE).

Syngenta Lake is in the premises of M/s Syngenta Agro Chemicals at Corlim Tiswadi taluka located on the banks of Cumbarjua canal. Khandola pond is situated between 15.5^{0}N Latitude 73.9^{0}E Longitude of Marcela. It is a source of irrigation to areca nut plantation in surrounding areas. Lotus Lake is situated between 15.2^{0}N Latitude and 73.9^{0}E Longitude, Lake is polluted and has abundant growth of aquatic weeds. Curtorim lake is Situated between 15.2^{0}N Latitude and 74.0^{0}E Longitude. All four water bodies differ in dimensions, size, nutrients concentration, nature of aquatic life, usage and level of human disturbance.

Results and Discussion

The list of diatoms encountered in selected water bodies with their acronyms are tabulated in Table 1. Indicator species of organic and anthropogenic pollution, IDSE/5 Louis Leclercq index derived from OMNIDA software are presented in Table 2, while standard ecological values by Van Dam et al. [8] are presented in Table 3. Variations in pH, temperature, nitrate and phosphate levels are presented in Tables 4-7. The pH of water varied in different water bodies *viz.*

Syngenta Lake (5.9-6.8), Khandola Pond (6.0-7.1), Lotus Lake (5.7-7.8) and Curtorim Lake (5.5-7.7) with pH range given in parenthesis. Similarly the phytoplankton diversity varied in different water bodies. Physico-chemical and biological characteristics of water bodies are known to influence each other and pH range of 5 to 8.5 was reported to be ideal for phytoplankton growth [22].

The water temperature of study sites ranged from 25 to 32°C, with maximum temperature recorded in May (late summer and early rainy season) and minimum in January (winter season). Water temperature of water plays an important role in controlling the occurrence and abundance of phytoplanktons [23]. Nitrate levels in all the selected water bodies varied and ranged from 0.20 to 0.73 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 2.76 mg/L in Curtorim Lake. Similarly phosphate concentrations also 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. It was observed that during monsoon season, pollutants like nitrates and phosphates enter the water bodies from the surrounding area, especially from farmlands, resulting in elevated concentrations of nitrates and phosphates [24]. Eutrophic conditions are observed during pre- and post-monsoon seasons at Syngenta, Lotus and Curtorim Lakes, supporting the growth of phytoplankton. During the study period 21 species of diatoms belonging to 12 genera were recorded. An α-mesosaprobous form were found to be occurring in Syngenta, Lotus and Curtorim Lakes while in Khandola pond β-mesosaprobous forms were recorded. Both α and β mesosaprobous organisms indicate presence of moderately polluted water. Nautiyal and Mishra [25] reported alkaliphilic, fresh-brackish, β-mesosaprobic and eutraphentic condition in water body that is under anthropogenic influence. 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 huge quantity of sewage and effluents from the surrounding residential areas and industries. Such activities caused low dissolved oxygen levels and high biological oxygen demand (BOD) which in turn is making the water bodies eutrophentic [26].

S. No.	Species name	Acronym
1	*Pinnularia graciloids* Huste	PGRA
2	*Pinnularia dolosa* H.P.Gandhi	PDOL
3	*Navicula halophila*(Gurnow)Cleve	NHAL
4	*Cocconeis placentula* Ehrenberg	CPLA
5	*Navicula mutica* Kutzing	NMUT
6	*Gomphonema parabolum* Kutzing	GPAR
7	*Ahninthes exigua* Grunow.	AEXI
8	*Cymbella chandolensis* Gandhi.	CCHA
9	*Synedra ulna* (Nitzsch) Ehrenberg.	SULN
10	*Pinnularia gibba* Ehrenberg	PGIB
11	*Melosira islandica* O.Muller	MISL
12	*Amphora ovalis* (Kützing) Kutzing	AOVA
13	*Stauroneis phoenicenteron*(Nitzsch) Ehrenberg	SPHO
14	*Navicula microcephala* Grunow	NMIC
15	*Diploneis elliptica* (Kutzing) Cleve	DELL
16	*Stauroneis anceps* Ehrenberg	SANC
17	*Navicula sphaerophora* Kutzing	NSPH
18	*Navicula radiosa* Kutzing	NRAD
19	*Gomphonema subtiles* Ehrenberg	GSUB
20	*Navicula rhynococephala* Kutzing	NRHY
21	*Eunotia tumida* Gandhi	ETUM

Table 1: Diatom species with their acronyms.

		January to December 2014				January to December 2015			
Sr.No.	**Parameter / criteria**	**SL**	**KP**	**LL**	**CL**	**SL**	**KP**	**LL**	**CL**
1	Number of genera	10	2	12	12	10	2	11	10
2	population	78862	96925	14155	10763	11124	95525	99119	13000
3	Diversity	3.64	2.07	3.65	3.7	3.65	2.05	3.72	3.62
4	Evenness	0.98	0.89	0.98	0.97	0.96	0.88	0.98	0.95
5	Number of species	13	5	14	14	14	5	14	14
6	pH (R)	4-Alkaliphilous mainly occurring at pH >7	3-Circumneutral mainly occurring at pH 7	3- Circumneutral mainly occurring at pH 7	3- Circumneutral mainly occurring at pH 7	3- Circumneutral mainly occurring at pH 7	3-Circumneutral mainly occur-ring at pH 7	3-Circumneutral mainly occurring at pH 7	3-Circum-neutral main-ly occurring at pH 7
7	Salinity (H)	Fresh to brackish	2-Fresh to br brackish	2-Fresh to brackish	2-Fresh to brackish	2- Fresh to brackish	2, Fresh to brackish	2-Fresh to brackish	2-Fresh to brackish
8	Nitrogen Uptake metabolism (N)	2- Nitrogen autotrophic taxa tolerating elevated levels of organically bound nitrogen	2- Nitrogen autotrophic taxa tolerating elevated levels of organically bound nitrogen	2- Nitrogen autotrophic taxa tolerating elevated levels of organically bound nitrogen	2-Nitrogen autotrophic taxa tolerating elevated levels of organically bound nitrogen	2-Nitrogen autotrophic taxa tolerating elevated levels of organically bound nitrogen	2-Nitrogen autotrophic taxa tolerating elevated levels of organically bound nitrogen	2-Nitrogen autotrophic taxa tolerating elevated levels of organically bound nitrogen	2- Nitrogen autotrophic taxa tolerating elevated levels of organically bound nitrogen
9	Oxygen Requirement (O)	3-Moderate (above 50% saturation)	2- Fairly high(above 75% saturation)	3- Moderate (above 50% saturation)	3- Moderate (above 50% saturation)	2- Fairly high(above 75% saturation)	2- Fairly high(above 75% saturation)	3- Moderate (above 50% saturation)	3- Moderate (above 50% saturation)
10	Saprobity (S)	3-Alfa mesosaprobous	2- B mesosaprobus	3-Alpha mesosap-robous	3- Alpha meso-saprobous	3- Alfa mesosap-robous	2- B mesosaprobus	3-Alpha meso-saprobous	3-Alpha me-sosaprobous
11	Trophic state	5-Eutrophantic	4-Mesoeutrophantic	5- Eutrophentic	5- Eutrophentic	5- Eutrophantic	4-Mesoeutro-phantic	5- Eutrophentic	5- Eutrophentic
12	Moisture retention (M)	2- Mainly occurring in water bodies	2-Mainly occurring in water bodies	2- Mainly occurring in water bodies	2- Mainly occurring in water bodies	2- Mainly occurring in water bodies	2- Mainly occurring in water bodies	2- Mainly occurring in water bodies	2- Mainly occurring in water bodies
13	IDSE/5(Louis Leclercq Index)	3.31	3.52	3.53	3.46	3.47	3.52	3.16	3.47
14	% Indicators of organic pollution	30.65%	22.12%	21.23%	20.87%	19.63%	15.29%	32.59%	19.63%
15	Indicator organisms	GPAR, NHAL, NMIC, NMUT	NMUT	GPAR, NHAL, NMUT	GPAR, NHAL, NMUT	GPAR, NHAL, NMUT	NMUT	GPAR, NHAL, NMUT	GPAR, NHAL, NMUT
16	% indicators of anthropogenic eutrophications	27.19%	27.19%	15.28%	23.48%	15.32%	20.98%	18.71%	15.32%
17	Indicator organisms	AOVA, SPHO, SULN	NRHY	AOVA, SPHO, SULN	AOVA, SPHO, SULN	AOVA, SPHO, SULN	NRHY	AOVA, SPHO, SULN	AOVA, SPHO, SULN

Table 2: Ecological indicator values for selected water bodies (data derived from OMNIDA GB5.3 Software).

Therefore, effective and strong conservative measures should be taken to prevent the lakes from entering hypereutrophentic state and to ensure the sustenance of aquatic flora and fauna. IDSE/5 index range of 3.31 to 3.53 in 2014 and 3.16 to 3.52 in 2015 indicate low to moderate degradation of all water bodies. The utilisation of indicator species is one of the water quality assessment defined by their optima and tolerances to environmental variables such as pH, temperature and phosphorus have been developed for many diatom taxa [27]. Indicator species of diatoms for organic pollution *viz. Gomphonema parabolum, Navicula halophila*, *Navicula microcephala, Navicula mutica* and anthropogenic pollution *viz. Amphora ovalis, Stauroneis phoenicenteron, Synedra ulna* were recorded in Syngenta, Lotus and Curtorim lakes. Indicator species for organic pollution *viz. Navicula mutica* and anthropogenic pollution *viz. Navicula microcephala* was recorded in Khandola pond.

Conclusion

From the results it is concluded that there deterioration of water quality of the water bodies undertaken for the study. Diatoms encountered during study are most powerful ecological indicators of degradation levels and also the ecological conditions of selected water bodies. They are right tools for biomonitoring, as indicator value of diatoms is well accepted and highly used across the continents. It is an ideal means by which progress towards integrated water resources management can be monitored.

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1	Acidobiontic	Optional occurrence at pH <5.5
2	Acidophilous	Mainly occurring at pH <7
3	Circumneutral	Mainly occurring at pH – values about 7
4	Alkaliphilous	Mainly occurring at pH >7
5	Alkalibiontic	Exclusively occurring at pH >7
6	Indifferent	No apparent optimum

pH (R).

S.No.	Water quality	Cl (mg/L)	Salinity
1	Fresh	<100	<0.2
2	Fresh brackish	<500	<0.9
3	Brackish fresh	500-1000	0.9-1.8
4	Brackish	1000-5000	1.8-9.0

Salinity (H).

S. No.	Nitrogen uptake
1	Nitrogen-autotrophic taxa tolerating very small concentrations of organically bound nitrogen
2	Nitrogen-autotrophic taxa tolerating elevated concentrations of organically bound nitrogen
3	Facultatively bound nitrogen-heterotrophic taxa needing periodically elevated concentrations of organically bound nitrogen
4	Obligately nitrogen-heterotrophic taxa needing continuously elevated concentrations of organically bound nitrogen

Nitrogen uptake (NU).

1	Oligosaprobous
2	β-mesosaprobous
3	α-mesosaprobous
4	α-meso-/polysaprobous
5	Polysaprobous

Saprobity (SP).

1	Never or only very rarely occurring outside water bodies
2	Mainly occurring in water bodies, sometimes on wet places
3	Mainly occurring in water bodies also rather regularly on wet and moist places
4	Mainly occurring on wet and moist or temporarily dry places
5	Nearly exclusively occurring outside water bodies

Moisture (M).

1	Oligotrophentic
2	Oligo-mesotrophentic
3	Mesotrophentic
4	Meso-eutrophentic
5	Eutrophentic
6	Hypereutrophentic
7	Oligo-to eutrophentic (hypoeutrophentic)

Trophic State (TS).

1	Continuously high (about 100% saturation)
2	Fairly high (above 75% saturation)
3	Moderate (above 50% saturation)
4	Low (above 30% saturation)
5	Very low (about 10% saturation)

Oxygen requirements (OR).

Table 3: Classification of ecological indicator values.

Months of study	Syngenta Lake	Khandola Pond	Lotus Lake	Curtorim Lake
Jan'14	6.1	7.14	7.8	6.8
Feb'14	5.9	6.1	6.6	6.9
Mar'14	6.2	6	6.46	6.7
Apr'14	6.2	6.1	6	6.9
May'14	6.3	6	5.9	6.72
June'14	6.4	6.8	6	7.60
July'14	6.8	6.4	6.73	7.68
Aug'14	6.4	6.2	6	7.68
Sept'14	6.23	6.4	6.5	7.52
Oct'14	6.09	6.4	6	7.68
Nov'14	6.5	6.45	6.6	6.4
Dec'14	6.7	6.47	6	6.9
Jan'15	6.12	7.12	6.8	6.6
Feb'15	6	6.15	6.66	6.7
Mar'15	6.2	6.1	6.46	7.19
Apr'15	6.22	6.1	6	6.7
May'15	5.9	6	5.87	6.89
June'15	6.2	6.19	6	6.72
July'15	6.25	6.3	6.7	6.6
Aug'15	6.45	6.2	6.78	6.68
Sept'15	6.47	6.4	6	6.5
Oct'15	6.3	6.38	5.4	6.18
Nov'15	6.17	6.4	6.2	5.45
Dec'15	6.37	6.44	6.5	6.33

Table 4: Variations in pH of selected water bodies.

Months of study	Syngenta Lake	Khandola Pond	Lotus Lake	Curtorim Lake
Jan'14	25	25	25.5	25.5
Feb'14	28	28	29	29
Mar'14	28	28	29	29
Apr'14	30	30	30	30
May'14	31	31	31	31
June'14	30.8	30.8	30	30
July'14	28.4	30.8	30	30
Aug'14	27.4	28.4	26.2	26.2
Sept'14	28.4	27.4	28.4	28.4
Oct'14	29	28.4	29	29
Nov'14	29	29	29	29
Dec'14	28	28	28	28
Jan'15	23	23	25	25
Feb'15	25	25	29	29
Mar'15	29	29	29	29
Apr'15	30	30	30	30
May'15	32	32	32	32
June'15	31	31	31	31
July'15	28	28.2	30	30
Aug'15	27.5	27.5	26	26
Sept'15	28	28.1	28.4	28.4
Oct'15	29	29	29.1	29
Nov'15	29	29	29	29.1
Dec'15	28	28	28.4	31

Table 5: Variations in temperature (^{0}C) of selected water bodies.

Months of study	Syngenta Lake	Khandola Pond	Lotus Lake	Curtorim Lake
Jan'14	0.2	0.27	1.43	0.8
Feb'14	0.72	0.23	1.58	1.27
Mar'14	0.82	0.56	1.66	1.5
Apr'14	0.31	0.47	1.76	1.78
May'14	0.54	0.36	1.81	2.57
June'14	0.33	0.5	2.16	1.32
July'14	0.41	0.58	4.55	2.27
Aug'14	0.5	0.34	3.16	2.76
Sept'14	0.53	0.38	3.38	1.43
Oct'14	0.48	0.31	4.45	1.27
Nov'14	0.31	0.3	3.06	1.19
Dec'14	0.29	0.29	2.38	1.27
Jan'15	0.21	0.21	1.76	0.93
Feb'15	0.34	0.23	1.65	1.43
Mar'15	0.73	0.5	1.75	1.67
Apr'15	0.24	0.49	1.7	1.51
May'15	0.32	0.32	1.81	1.55
June'15	0.37	0.35	2.24	2.3
July'15	0.43	0.28	2.95	2.45
Aug'15	0.59	0.33	3.19	2.64
Sept'15	0.57	0.38	3.38	2.4
Oct'15	0.53	0.32	2.55	1.73
Nov'15	0.45	0.29	2.17	1.65
Dec'15	0.37	0.27	2.02	2.57

Table 6: Variations in nitrates (in mg/L) of selected water bodies.

Months of study	Syngenta Lake	Khandola Pond	Lotus Lake	Curtorim Lake
Jan'14	0.1	0.01	0.01	0.01
Feb'14	0.12	0.02	0.03	0.02
Mar'14	0.23	0.01	0.1	0.01
Apr'14	0.1	0.04	0.25	0.04
May'14	0.24	0.02	0.25	0.12
June'14	0.27	0.02	0.3	0.15
July'14	0.25	0.3	2.41	1.72
Aug'14	0.19	0.25	1.92	0.49
Sept'14	0.2	0.15	0.78	0.55
Oct'14	0.15	0.15	0.6	0.3
Nov'14	0.19	0.1	0.19	0.19
Dec'14	0.1	0.02	0.1	0.1
Jan'15	0.11	0.01	0.27	0.19
Feb'15	0.07	0.02	0.2	0.3
Mar'15	0.09	0.01	0.21	0.48
Apr'15	0.1	0.04	0.18	0.4
May'15	0.2	0.02	0.25	0.47
June'15	0.25	0.02	0.39	1.15
July'15	0.29	0.01	1.01	1.22
Aug'15	0.31	0.02	1.62	1.54
Sept'15	0.28	0.04	1.7	0.95
Oct'15	0.22	0.03	1.03	0.4
Nov'15	0.17	0.02	0.17	0.2
Dec'15	0.12	0.01	0.11	0.12

Table 7: Variations in phosphates (in mg/L) of selected water bodies.

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