

**INVESTIGATION ON HYDROBIOLOGY AND WATER
QUALITY PARAMETERS OF PERIYAR LAKE,
THEKKADY, KERALA**

THESIS SUBMITTED TO
MAHATMA GANDHI UNIVERSITY, KERALA
AS PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
**Doctor of Philosophy in
Botany**
IN THE FACULTY OF SCIENCE

BY

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JANUARY 2008

Dedicated
To
My parents and wife

DECLARATION

I, **Jithesh Krishnan. R**, do here by declare that the thesis entitled “**Investigation on hydrobiology and water quality parameters of Periyar Lake, Thekkady, Kerala**” is an authentic record of research work done by me under the guidance and supervision of **Dr. J.G Ray**, Reader, Environmental Science Research Lab, Department of Botany, St. Berchmans College, Changanacherry. This work has not been submitted for the award of any other degree or diploma earlier.

Changanacherry
Date:

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CERTIFICATE

I certify that the thesis entitled “**Investigation on hydrobiology and water quality parameters of Periyar Lake, Thekkady, Kerala**” is an authentic record of research work carried out by **Mr. Jithesh Krishnan. R** in the Environmental Science Research Lab, Department of Botany, St. Berchmans College, Changanacherry, under my guidance and supervision. I further certify that this work is original, and no part of this has been presented for the award of any degree or diploma of this or any other universities.

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ABSTRACT

This is the case study of anthropogenic impacts on the hydrobiology of a Lake, which is commercially exploited over a hundred years and is integral to a wildlife sanctuary. A comprehensive and systematic analysis of the physico-chemical environmental complex, nutrient and pollution status, phytoplankton density and community structure are critically examined in the thesis. Pertinent literature related to all the aspects of the problem are reviewed in the beginning.

Regular monthly investigations from six permanent sampling stations for three years were carried out to collect baseline data on the seasonal changes in climate, hydrology, physico-chemical water quality parameters, nutrient content, primary productivity, pollution status and hydrobiology in relation to tourism in the Lake. Yearwise and seasonwise variations in total density and also density of different species of phytoplankton were found out. The significance of such variations of each particular parameter across the stations and that over the seasons and the years were calculated.

The observations point to the significance of considering reservoirs and the surrounding forested watershed systems as integrated whole systems requiring careful management and continuous monitoring. Overall, the discussions explain how the environmental complex of a precious tropical biological system is disturbed under the pressure of developmental activities such as tourism.

KEYWORDS

Periyar Lake, freshwater lake, physico-chemical parameters, nutrient status, pollution status, productivity, BOD, COD, oil and grease, hydrology, hydrobiology, phytoplankton density, community structure, periphyton, benthon, *Chlorophyta*, *Bacillariophyta*, *Cyanophyta*, *Euglenophyta*, desmids, diatoms, *Chlorococcales*.

ABBREVIATIONS USED

PTR	Periyar Tiger Reserve
TN	Tamil Nadu
KTDC	Kerala Tourism Development Corporation
KFD	Kerala Forest Department
PDS	Peermade Development Society
PWD	Public Works Department
RRI	Rubber Research Institute
PM	Pre-monsoon
SWM	South-West-Monsoon
NEM	North-East-Monsoon
P₁	Pre-monsoon-1
P₂	Pre-monsoon-2
P₃	Pre-monsoon-3
S₁	South-West-monsoon-1
S₂	South-West-monsoon-2
S₃	South-West-monsoon-3
N₁	North-East-monsoon-1
N₂	North-East-monsoon-2
N₃	North-East-monsoon-3
FRL	Full Reservoir Limit
MCFT	Million Cubic Feet
PPM	Parts Per Million
μS	Micro Siemens

ANOVA	Analysis Of Variance
S	Surface-water
B	Bottom-water
TS	Total Solids
TSS	Total Suspended Solids
TDS	Total Dissolved Solids
EC	Electric Conductivity
Ca	Calcium
Mg	Magnesium
Na	Sodium
K	Potassium
Cl	Chloride
C	Carbon
P	Phosphorus
N	Nitrogen
DO	Dissolved Oxygen
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
MPN FC	Maximum Possible Number of Fecal Coli form
GPP	Gross Primary Productivity
CR	Community Respiration
NPP	Net Primary Productivity
L	Litre

ACKNOWLEDGEMENTS

I like to express my gratefulness, first to my esteemed teacher Dr. J.G Ray, Reader, Environmental Science Research Lab, Department of Botany, St. Berchmans College, Changanacherry for his esteemed guidance, supervision and valuable suggestions at each and every step. The ever memorable hours which I shared with him helped me a lot in developing a patient and calm mind, that a researcher should possess. I also wish to express my thanks to his spouse and family for their hospitality during the period of this research.

The fellowship received during the project period under the major project of the UGC, Govt. of India is gratefully acknowledged.

I remember with gratitude Dr. K.S. Unni, Retired Professor, Ravishankar University, Raipur for his valuable advice and support. My special thanks are also due to Dr. K.J Joseph, Retired Professor, Department of Marine Biology, Cochin University of Science And Technology, and Mr. Sanil Kumar, Research Scholar of the same Department for their advice and help in the identification of micro algae.

I am thankful to the Principal, Head of the Department of Botany, and the management of St. Berchmans College for all the necessary facilities provided in the College to carry out this work. I also gratefully acknowledge the teachers of the Department of Botany and Chemistry who helped me during the period of my research in the College.

I wish to express my sincere thanks to Prof. Dr. C.C Thomas, Dept. of English for the thesis manuscript correction and Mr. M.C Jose, Lecturer, Selection grade, Dept. of Mathematics, for the assistance in statistical analysis.

Kerala Forest Department provided necessary facilities for water sample collection, Tamilnadu PWD provided the rainfall data, RRI, Kottayam helped in bacterial analysis. All are greatly acknowledged.

I also express my heartfelt appreciation to my fellow researchers in the Department for lending a helping hand in need and to all those who rendered immense help directly or indirectly in the completion of the study.

Words cannot express heartfelt gratitude towards my dearest family members for bearing all the inconveniences in the due course of completion of this work. My father Mr. R.K. Nair, my mother Mrs. Lalitha my sister Miss. Jisha and my wife Mrs. Resmy have many personal sacrifices towards the completion of this work. Without their support this thesis would not have seen the light of the day. I am grateful to each and every one of my family for their valuable prayers.

Above all I am thankful to God Almighty, who blessed me to find solutions to difficult circumstances, in successfully completing this work.

Jithesh Krishnan. R

LIST OF PAPERS PUBLICATION/COMMUNICATED

1. Ray, J. G. & J. Krishnan, 2003. Recent studies on the hydrobiology and water quality parameters of Periyar Lake, Thekkady, Western Ghats, Kerala, Procee. of International Congress on Sustainable Development and Management of Natural Resources, Holy Cross College, Thiruchirappalli.
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SEMINAR PRESENTATIONS

1. Krishnan, J., J. G. Ray, K. S. Unni, 2003. A report on the ecology of Periyar Lake, Paper presented in the National level Seminar (Technofest-23rd to 25th July) held at CUSAT.

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Chapter-I

INTRODUCTION

1.1. Introduction of the problem

The present work deals with water quality parameters in relation to hydrobiology of the *Periyar* Lake (a unique man-made freshwater resource over a hundred years), *Thekkady*, Kerala. This Lake is central to one of the very famous wildlife sanctuaries of India, the 'PTR'. The Lake supports precious wildlife in the sanctuary and it is the key attraction for tourists all over. This water is the sole source of drinking and irrigation for many districts of TN and they use it for generation of electricity. Though believed as one of the very clean waters of the country, the Lake is presently subjected to anthropogenic pressures such as tourism activities in and around. No serious studies have so far been conducted on the pollution status and hydrobiology of this Lake. The significance and the background of this research work cannot be appreciated without discussing some of the basic issues of freshwater resources in the world over, India in general and the State of Kerala in particular.

1.2. Water, the elixir of nature

Water is a necessity for all living beings, without it; there would be no life. Life originated in water and the ultimate basis of it, the protoplasm, is a colloidal solution of complex organic molecules in a watery medium (70 to 90% water). Most of the biological phenomena take place in water medium. Moreover, wherever water exists in nature it always holds life. So the study of a water body is the study of life as well. Water is essential at all levels of life, cellular to ecosystem. It is essential to circulation of body fluids in plants and animals, and it stands as the key substance for the existence and continuity of life through reproduction and different cyclic process in nature; it plays the central role in mediating global scale ecosystem processes, linking atmosphere, lithosphere, and biosphere, by moving substances among them, and enabling chemical reactions to occur. Humans depend on this resource for all their needs of existence and

survival. Nature has an innate mechanism to maintain its purity after every natural use. But it is unable to do this at the rate at which modern humans add dirt to it. Nature does not know how to deal with several toxins and pollutants that are flowing from industrial and other wastes. Therefore, humans are bound to monitor the impact of this activity on natural freshwaters continuously.

1.3. Global freshwater resources

Globally, fresh water has become the fastest depleting natural resource nowadays. Only a small percentage of water exists as fresh water, and the portion accessible to human is again a negligible part of its global stock – the surface water bodies such as rivers and lakes. However, knowingly or unknowingly, it is this rarest of resource, which we abuse severely. Elaborate studies are required regarding the water management activities of lakes, rivers, and reservoirs to ensure our survival on earth. Ignorant, irresponsible, and careless management has brought the waters of the world to pathetic a situation, with severe water shortage at present in different parts of the world. The available freshwater in this world is not equally accessible to all people. This is due to differences in geographical, geological, climatic, and demographic reasons.

The world is fast growing with its technologies and the population on earth is increasing tremendously. So the dependence as well as exploitation of freshwater resources is also increasing rapidly. It is not just the population increase alone but also the technology-aided excessive uses, abuses and, misuses of water resources that break the natural water cycle. Modern humans cannot advance without determining the right levels of uses for various purposes. We have also to learn the secret of all the methods and all the agents involved in the process of natural water cycle.

Globally, 3240 km³ of fresh water is drawn, and used annually; 69% of this is used for agriculture, 23% for industry, and 8% for domestic purposes (WRI, 1992). Agriculture consumes a major share of fresh water. More than half the water diverted or pumped for irrigation, does not reach the crop; and problems of water logging and salination due to this, are increasing. The second largest consumer of fresh water is industry. In the developing countries 95% of the used water is not subject to cleansing treatment before it is released to surface waters (Karagul *et al.*, 2005). So we must look

into all the aspects of water uses to ensure the quality of water available for all the present and future needs.

Owing to population explosion pressure, and increasing pollution of water resources, at least 30,000 human deaths are caused daily by contaminated water and poor sanitation. More than 1.7 billion people have no direct access to freshwater; this number is likely to double within the next 25 years (WHO, 1992). The demand for fresh water has already exceeded its supply in different parts of the world. This will be a major crisis of the world over, in developed, developing or underdeveloped countries.

Among the fresh water resources of the world, lakes, reservoirs and wetlands are important because they supply water for the population in the whole year. This they do by collecting rainwater through the water cycle, and sustain the stationary component of the hydrological cycle. They maintain the balance of the ecosystem components on which other systems depend. The lakes and reservoirs represent very complex and fragile ecosystems. As part of the industrial development in most places fresh water bodies are dumped with highly toxic chemicals along with effluents, to a dangerous level. Nutrients washed down from the irrigated fields and drainage channels reach our freshwater bodies (Chapman and Reiss, 1995).

Many small lakes and ponds in different parts of the world have been drained, or reclaimed to extend arable land. This has caused unusual fluctuations in water-level, the impact of which is tremendous. Many natural populations of commercially important freshwater species have been over exploited. Some stocks, especially in river and lake fisheries, appear to be in decline. The aquatic organisms, and ecosystem in which they participate, represent a substantial sector of the earth's biological diversity. So the fresh water habitats are considered worthwhile not only as a supply resource but as a living system by which the global ecosystem is balanced.

The need for the integrated development and management of the lakes, reservoirs, river basins, and wetlands has been recognized not only to harness the optimal benefits of these systems but also to maintain the ecosystem that they represent (James, 2005). Every natural system has the capacity to purify itself. Biota of a water body is basically responsible for its natural renewal of purity. The capacity of a system to purify waters is

an important issue to be investigated in the context of water resources management. The study of biota holds the basic clue to this. Conservation of fresh water, therefore, is an absolute necessity today (WHO, 1992).

Studies of fresh water systems, and the human impact on such systems, are quite timely. Such studies pave the way to prime regulatory mechanism for the ecosystem as a whole, and may reveal both the rate and direction of whatever changes take place within the system (Varshney, 1989). The biodiversity and dynamics of different phytoplankton populations, and their role in natural water cycle, are one of the least explored areas in Aquatic Biology. All the developmental activities have immediate effects on various water quality parameters, including hydrobiology.

World's lakes and reservoirs are distributed in Africa-31240 km³, Europe-2449km³, Asia-29132km³, Australia-192km³, North Ammerica-26573km³, and South Ammerica-1199km³ respectively (Korzun *et al.*, 1978). Lakes and wetlands have been recognized worldwide as extremely important biogeography zones (Nameer, 2005). These lentic water bodies are common and stable habitats of the biosphere (Radhika *et al.*, 2004). In spite of the fundamental importance of lakes, reservoirs, and wetlands to humans as life-supporting systems, and as systems providing recreation facilities for the people, these have severely been affected by a multitude of anthropogenic disturbances which have led to serious negative effects on the structure of these ecosystems worldwide (Bronmark and Hansson, 2002).

1.4. Freshwater resources in India

India receives more rainfall per unit area than elsewhere in the world. In spite of her enormously large population she receives more per capita rainfall than in the developed countries like Germany and Japan (Abbasi, 1997). Rainfall in India is dependent on southwest and northeast monsoons. According to Bose (2003), the average annual precipitation of the country is estimated to be 4000billion m³ but only 1000billion m³ per year is available as usable surface water and ground water. The country supports 1/6th of world population, 1/50th of worlds land and 1/25th of world's water resources (Kumar *et al.*, 2005). The same author has also given that the present water consumption in India is about 750 billion m³ per year for needs such as domestic, agricultural,

industrial, and commercial. But many parts of the country, including Kerala, face severe water shortage problems especially during certain seasons. No doubt, it is overuse, mismanagement, ignorance and irresponsible conservation efforts that cause all these problems.

The overall water demand of the country will increase from 552 billion m³ to 1050 billion m³ by 2025, which will require the use of all the available water resources in the region (World Bank Report, 1999). The increase of human population beyond the carrying capacity of a watershed with respect to the resources available will destabilize the ecosystem balance in the watershed, causing pollution and other environmental problems. The problem of pollution in the fresh water systems in our country is mainly because of anthropogenic activities (Haniffa *et al.*, 1993). Domestic and industrial effluents pollute majority of freshwater resources in India (Jain *et al.*, 1995). Moreover, natural aquatic ecosystems are being used as disposal sites for a wide variety of wastes (Sarojini, 1996). The toxic chemicals from industries, agricultural run-off of pollutants and chemicals, human wastes, and sewage etc affect the natural rhythm of the system by affecting all the species interactions in them. The increasing human influences in recent years in and around our aquatic systems and their catchment areas, have led to the deterioration of water quality and eutrophication (Bhatt *et al.*, 1999).

Studies on fresh water lakes and reservoirs in our country have gained momentum in recent years. In India reservoirs, which cover three million hectares of surface area (**Figure-1**), are considered the prime resource, with regard to aquatic production potentials and more than 56% of the total reservoir area in the country is found in Orissa, Maharashtra, and in the Southern States (Sugunan, 1997). Indian lakes can be classified geographically into Himalayan, peninsular, and coastal; limnologically into, fresh water and brackish water lakes. Indian lakes can also be considered as urban lakes, non-urban lakes, coastal estuarine lakes and ephemeral lakes (Reddy and Char, 2004). The ecological monitoring of these systems, are very significant in the sustainable use and protection of water resources in this country. Herein lays the relevance of the present study.

1.5. Freshwater resources in the Western Ghats

Majority of the south Indian reservoirs and lakes are situated in the Western Ghats region. The Western Ghats is a 1600km long unbroken chain of mountains (average height is 1000 m) along the west coast of peninsular India. It spreads over the states of Maharashtra, Goa, Karnataka, TN and Kerala (**Figure-2**). The Ghats extend from the mouth of the *Tapti* (Maharashtra) in the north to *Agastheeswaram* (TN) in the south. The Ghats is divided into 3 major realms (Pascal, 1988). The first region extends from *Surat* to Goa, with an average elevation of 700-1000m. The second region stretches from Goa to the *Nilgiri* Mountain up to *Palghat*, with certain mountains reaching an altitude of 2339 meters. The third part of the Western Ghats forms the south of *Palghat* gap, with an interruption of hills about 30km wide. The Ghats reappears abruptly as the *Anamalai* hills, and *Palani* hills, with a plateau of a height of 2995m. Towards the south, there is another plateau, slanting towards the northwest, the *Periyar* plateau, where the *Periyar* and several Indian west flowing rivers take their origin.

The forest ecosystem in the Western Ghats is one among the 18 biodiversity hotspots of the world selected for conservation. According to Devagiri (2004), 23% of biodiversity of India occurs in the Western Ghats. This account does not include the phytoplankton diversity of the aquatic systems of the region. Negligible are the literature available on the biodiversity of phytoplankton of fresh water bodies in the region.

The Western Ghats forms the major water shed in peninsular India. Limited basic data exists on more than 30 reservoirs in the Western Ghats region of Kerala, which are the major projects of hydroelectric power generation in the State. The reservoirs in the Western Ghats in Kerala are unique ecosystems controlled by rainfall rather than temperature; these are oligotrophic having least production potentials, and are physico-chemically and biologically different (Khatri, 1987). Most of the reservoirs and lakes in this region of Kerala are highly productive, a large number of wild animals and tribal populations depend on the resources of the lakes and forests here (Arun, 1999).

Forty-four rivers of Kerala originate in the southern Western Ghats. Except the three freshwater lakes - the *Vellayani*, *Sasthamkottah* and *Muriyad*, most of the reservoirs in the State are also located in and around the Western Ghats. In Kerala, total number of

reservoirs is 30, and total area of reservoirs is 20635ha (Sugunan, 1997). All these reservoirs in the Western Ghats region of Kerala have high quality water than in other reservoirs of the country, but the quality is deteriorating fast due to the large-scale anthropogenic activities in this region (Basha, 1997). Habitat loss and ecosystem degradation are the prime factors responsible for biodiversity decline in the freshwater habitats in this region (Kumar and Kurup, 2005). Sedimentation survey in one of the reservoirs in the Western Ghats shows that almost 20% of total capacity (121mm³) of these reservoirs has been lost mainly because of deforestation in the catchments and change in the cropping pattern (James, 2005). Apart from about 500,000 cubic meters of trade effluents that are being allowed into rivers and other water bodies of the State every day, community waste, and chemicals also reach these water bodies (Elangovan, 2005).

No serious research work has been undertaken for assessing the hydrobiology of these lakes and reservoirs. Only limited investigation has been carried out so far on the hydrobiology, flora and fauna of the reservoirs and lakes in this region. Detailed investigations of anthropogenic influences on water quality and hydrobiology of these reservoirs are very essential; these can help the conservation of aquatic systems, much needed for the sustainable development of this area. As one of the world's most important biodiversity zones, reservoirs in the southern Western Ghats are biologically very significant. Planning for sustainable management of the Western Ghats can be carried out only if the ecology of the lake systems of the region is also well understood. This is very essential for obtaining maximum benefits from these systems through proper conservation efforts.

1.6. The Periyar Lake

Among the lakes and reservoirs of the State, the *Mullaperiyar* reservoir, in the southern Western Ghats, is the oldest and broadest. It is situated inside the largest of all protected areas in Kerala, the PTR. It forms 35% of the total protected sites in the State. Recognizing the importance of the reserve it was brought under the "Project Tiger" in 1978. In 1991-92, Government of India designated the sanctuary as a "Project Elephant Reserve" as well (Basha, 1997). This Sanctuary has been getting much international importance recently because of its unique tourist potential. The domestic as well as

international tourists select this place as their tourist destination because of its luxuriant vegetation, cool climate and natural beauty. The Periyar sanctuary is one of the most protected sites of India, with many endangered and endemic flora and fauna. It is a noteworthy National Park (World Geographical Encyclopedia, 1995).

A large number of rivers of Kerala originate in the *Periyar* plateau of the Western Ghats. The *Periyar* is the largest river in Kerala (244km). Before entering the *Mullaperiyar* Reservoir in the PTR, it flows for 43 km between the *Sivagiri* range and the *Sabarimala*. The river flows down a moderate steep gradient in a well-preserved tract (Arun, 1999). Construction of a dam across the *Periyar* River created the reservoir known as *Periyar* Lake. It is the main attraction of tourists in the sanctuary and is at the receiving end of a large number of anthropogenic influences. Although Kerala has 14 protected sites, it does not have a similar system that conserves also the wetland habitat (Nameer, 2005). There is an obvious need for better planning so that this most sensitive biodiversity hot spot in the State can be protected.

The oldest of the existing dams, the *Mullaperiyar* is the first commissioned inter-basin-diversion project, completed in 1895, to divert water in the uppermost reaches of the *Periyar* to the *Vaigai* basin in TN (Kerala State Gazetteer, 1986). This Lake is one of the major irrigation and drinking water sources for TN. About five districts in the TN use this water for drinking and irrigation. Large-scale production of vegetables and food grains of these districts, depend on the Lake. This water is the source of 11% of the total hydro-electricity produced in TN. The reservoir controls the water regime of the tract, provides cruising facilities and it beautifies the Tiger Reserve (Surendranathanasari, 1996).

Most of the research works related to the sanctuary system so far have been on the flora and fauna of the region. No specific literature is available on phytoplankton in the Lake. Long-term water quality parameters and the seasonal dynamics of the lake ecosystem are some of the least investigated characteristics of the lakes of the Western Ghats in general. Sugunan (1995) stressed detailed investigations of the reservoirs in the Western Ghats.

The geo-climatic conditions of the *Periyar* Lake are significantly different from those of the other reservoirs in the State. The increased boat plying and other anthropogenic influences, such as sewage disposal, active tribal fishing in the Lake, can affect the system. Another important problem associated with this system, is the fast development of *Kumily* township in connection with the recently received importance to tourism in this region. The waste from the sewage channels of the town merges with the Lake in more than one location. The importance of this Lake water is that it is not just the key attraction to tourists but it is also the core environment of the precious wildlife of the “Project Tiger” and “Project Elephant” sanctuary. This Lake contains a lot of precious fresh water flora and fauna, many of which are endemic and needs investigation to reveal their role as indicators of anthropogenic disturbances as well as key natural resources to be understood better. Therefore, a comprehensive study of Lake was made for three-years (2002-2005), so as to reveal its significant hydrobiology, and to learn its water-quality parameters. The significance and objectives of the present research work were as follows.

1.7. Significance of the study

This detailed investigation enabled a comprehensive and systematic analysis of the seasonal physico-chemical and biological characteristics of *Periyar* Lake over different years.

1. This provides necessary basic data on the seasonal dynamics of phytoplankton in relation to the various water quality parameters of the Reservoir waters.
2. This enables to account for spatial variations in water-quality parameters as well as phytoplankton in relation to difference in the degree of human disturbance.
3. Analysis and interpretation of the data on phytoplankton and water quality dynamics enable us to assess the impact of tourism on the hydrobiology of the *Periyar* Lake.
4. The baseline data generated would help planning and future policy decisions, using the reservoir as an eco-tourist center, and also in the better conservation and management of the precious wildlife.

1.8. Objectives of the study

1. Collection of baseline data on the structure and function of the Reservoir/Lake.
2. Assessment of seasonal changes in water quality parameters.
3. Study of seasonal fluctuations in nutrient load and productivity of the system.
4. Analysis of pollution status of the Reservoir/Lake.
5. Assessment of changes in phytoplankton community structure and its changes in relation to seasonal fluctuations in physico-chemical parameters.
6. Understanding the periphytic and benthic algal community of the Reservoir/Lake.
7. Overall assessment of the impact of tourism on hydrobiology of the Reservoir/Lake.

1.9. Important findings and achievements

1. Prepared a comprehensive review of literature on the entire freshwater researches in the state in general and researches on *Periyar* Lake in particular.
2. Described climate and hydrology of the Reservoir/Lake.
3. Found out seasonal dynamics of various physico-chemical water quality parameters such as temperature, secchi depth, conductivity, pH, TDS, TS, dissolved O₂, dissolved CO₂, and dissolved mineral ions (Ca, Mg, K, Na and Cl).
4. Discovered nutrient load such as total nitrogen, nitrate nitrogen, phosphorus, silica and the seasonal dynamics of all of them.
5. Revealed primary productivity and its seasonal dynamics in this Reservoir/Lake.
6. Found out pollution load characteristics such as BOD and COD, and the seasonal dynamics of these parameters.
7. Examined anthropogenic impact due to tourism such as oil spill from boat.
8. Analyzed public health parameter such as *Coli form* and *E. coli* count in different seasons.
9. Discovered phytoplankton density and community structure, periphytic and benthic algal community structure and its seasonal dynamics in the system.
10. Analyzed the correlations of the different water quality parameters and hydro-biological characteristics measured in different seasons.

Chapter- II

REVIEW OF LITERATURE

2. 1. Introduction

Ecological studies give humans a deep insight into the principles of life; its forms and levels of existence and immortality on earth. Ecology reveals to us the truth that there is only “one life” on earth. Life exists infinitely in interrelations of diverse species in space and time. Ecology provides us with the wisdom that the supremacy and freedom, which humans enjoy over the diverse forms of life, are subject to the limits of nature’s constitutions. Nature shows no special concern for any individual species, humans or otherwise unless and until the species prove to be successful in nature’s quest for stability and sustenance of life on earth. Therefore, the primary social need of every sustainable society is to protect and utilize all their natural resources in a wise manner.

Fresh water resources are most precious to earth: they are the basic ingredient to life. Increased demands on the resources have impacted heavily on natural aquatic ecosystems. Fresh and pure water is limited in quantity indicates the need for comprehensive water management (WHO, 1992). So researches on the impacts of anthropogenic and technological factors on fresh water resources are imperative. Such studies provide us with information of our limits in nature (Ray, 1992). We have several examples of civilizations, which have suffered by going into eclipse or extinction due, in great part, to a lack of stewardship and or knowledge of their water resources.

The living communities of waters, their functional relationships, productivity, physical, chemical environment are all dealt in aquatic ecology. Study of all inland aquatic environments like; streams, rivers, lakes, reservoirs, and wetlands are called Limnology. The history of the discipline of Limnology dates back to Lake Geneva, the best known and one of the beautiful lakes in the world, since the 17th century. Bertola (1998), observed that between 1892 and 1904, Francois-Alphonse Forel, a Swiss naturalist carried out a major research work in this Lake and, laid the basis of Limnology.

As the supply of fresh water around the world continues to dwindle because of increased use and pollution, lakes of the world will undoubtedly be viewed as potential water reservoirs of convenience for human use (Odada *et al.*, 2004). The author emphasized that basic research on the lakes of the world lags far behind similar researches on the oceans. Lakes have a more complex and fragile ecosystem and they easily accumulate pollutants (Bhatt *et al.*, 1999). According to him several characteristics of lakes make them ideal study sites to advance our basic understanding of ecosystem dynamics. Therefore, lakes in the world are in dire need of major new research initiatives. Bronmark and Hansson (2002) found that biodiversity of lakes and pond ecosystems are currently threatened by a number of human disturbances. The growing concern for environmental problems, implementation of new environmental strategies and administrations, international agreements, are positive signs of changes that should improve the ability to manage old as well as new, yet undiscovered threats in these systems.

Lewis (1987) noted that in the absence of protective management, tropical lakes would decline greatly in their utility for water supply, production of commercially useful species, and recreation, because tropical lakes are more sensitive than temperate lakes to pollution. So management programs for tropical lakes will focus on interception of nutrients, protection of aquatic habitats from invasive species, and minimization of hydrological changes in rivers to which lakes are connected. The awareness of the scientific community and the public of the manner in which the fresh water systems functions as a whole and their collective opinions are important in the determination of public policy and consequent management of these systems. All these authors have thus emphasized the significance of ecological investigations of freshwater, especially that in the tropics.

2.2. Ecology of major freshwater resources of the world

Finlayson *et al.* (1980) studied the importance of aquatic vegetation in controlling the nutrient enrichment in an artificial high altitude Lake, *Moondarra* in the North-Western Queensland, and found that cessation of the sewage input along with regular harvest of macrophytes could assist in reducing the internal nutrient and metal load in the Lake. In South America, Heide (1982) carried out a detailed study of Limnology of a

man made Lake Brokopondo, the first tropical reservoirs of over 1000km² surface areas, built in the *Suriname* River. General environmental peculiarities of tropical lakes are described in this work. According to the author periods of rainfall seem to exert little influence upon mixing of water in the lake. He stressed that the same situation exist in African lakes also. In almost all lakes mentioned by the author wind is an important mixing agent and the rainwater has a great influence in determining the quality of water in tropical freshwater bodies. Hart *et al.* (1987) made a detailed study of the Magela Creek Wetland System in Australia. According to the author rain water has a great influence in the quality of water in freshwater bodies. Hilton and Phillips (1982) observed algae and boat activity as the two major contributors of turbidity in a water body which influence the growth of macrophytes vegetation.

Weiss *et al.* (1991) analyzed deep-water renewal and biological production in Lake *Baikal* in the southern USSR. The study revealed that the mixing in deep temperate lakes is strongly constrained by the existence of a temperature of maximum density for freshwater, and by the pressure dependence of that temperature. Birsal (1994) noted that construction of dams across rivers and the resultant man made lakes generates harsh ecological aspects. According to him the large-scale development of dams has produced sudden and dramatic changes within riverine habitats and ineffective management of watersheds result in premature siltation, which affects the capacity of such reservoir/lakes. The preponderant issues of environmental protection and the development of Lake *Kasumigaura* in Japan and its catchments areas were discussed and observed by researchers all over the world, because the Lake played a vital role in fisheries and shipping transport, along its basin since 1960. Investigation by Tomiyama (1995) revealed that the recent developments in its catchments basin made water quality deterioration with high levels of chemical oxygen demand (COD), algal blooms, eutrophication and decrease in fish wealth. In order to fully realize the benefits available from small water bodies, Sugunan (1997) made a comparative study of small reservoirs in seven different countries spread over in Africa, Asia and Latin America. According to him flood plane lakes, estuaries, ponds, brackish water and reservoirs are the important water systems in India, which support large amounts of fish. Nurnberg and Margo (1998) discussed many systems of lake classification and compilations during the last 40 years. Bhatt *et al.* (1999) investigated the physico-chemical characteristics and phytoplankton

dynamics in *Taudaha* Lake in the high altitudes of Nepal on the basis of its importance as a major drinking and irrigation water resource in the country and found out that the quality of water is deteriorating fast due to anthropogenic wastes.

Su and Jassby (2000) investigated Lake *Inle*, in southern Myanmar for analyzing several environmental problems affecting the Lake basin. They revealed a long-term decrease in Lake area over the last 30 years, due to the siltation and climate change. Optical and biological measurements were performed in Lake *Ulemiste*, the main drinking water reservoir of Tallinn, Estonia from 1997 to 1998 in order to understand the ecological state of the deteriorating Lake (Erm *et al.*, 2001). The authors are of the opinion that knowledge of the type and amount of optically active substances in the water, phytoplankton characteristics, under water light field, and temperature–oxygen situation in the lake are necessary when estimating the ecological state of the system. Sene *et al.* (2001) studied the impacts of climate change on flows of river *Nile* and found that a change in flows of a water body is extremely sensitive to the rainfall and evaporation at its surface.

Gulati and Donk (2002) identified fresh water deterioration as a challenging problem in industrialized Western Europe, especially in countries with intensive agricultural practices as well as animal husbandry. Two main criteria for good water quality which they identified were, a decrease in phytoplankton biomass and improvement in the under water light climate. Seasonal water quality of shallow and eutrophic Lake *Pamvotis* in Greece was studied for implications for restorations (Romero *et al.*, 2002). Rabalais (2002) after a detailed investigation of the nitrogen input in aquatic systems by human activities found that nitrogen in water has increased over the last one and a half centuries. The accumulation of it in reservoirs alters many ecological processes in them, which may differ with latitude, temperature and season and, the overall global dynamics are as yet unpredictable. Lind and Lind (2002) analyzed the Ecology of one of the largest tropical Lake, *Chapala* in Mexico and found out that high nutrient and turbidity in lakes result in a characteristic stable state of high phytoplankton biomass. They also noted that water quantity has a determining effect on the water quality and control of water quantity is a necessary step towards achieving a desirable water quality. Becht and Harper (2002) examined the water balance of Lake *Naivasha*, Kenya's second

Ramsar site, which supplies drinking water to Nakuru and irrigation water to the nationally important industries of horticulture and power generation. The authors found that the Lake is deteriorating in its water quality due to over exploitation. Gelda and Effler (2002) reported that day-to-day differences in the dissolved oxygen concentration of lake waters are mostly due to variations in wind.

According to Hakanson *et al.* (2003) there are close relationships between catchments area characteristics and lake characteristics. The other important factors influencing lake characteristics as per their observations are climate change, changes in epilimnetic temperatures and increased variations in lake temperature. They used Lake Web model to quantify such changes for key functional organisms and food web structures. Hakanson (2004) believes that every aquatic ecosystem is a unique natural feature, and the study of each system in detail is necessary for case-by-case assessment of ecological threats and health, and development of proposals for realistic remedial measures for these systems in particular. There is very little understanding and knowledge on the relative role of the different process in aquatic systems. Haggard *et al.* (2005) studied the phosphorus flux from bottom sediments in Lake/reservoir *Oklahoma*. The authors found that phosphorus input into the reservoir is from external sources as well as from the reservoir bottom sediments. Karagul *et al.* (2005) evaluated the seasonal changes of some water quality parameters of the *Buyuk Melen* River Basin in Turkey, and noticed that water resources are under pressure and in danger as a result of potential pollution and contamination risks due to over use and misuse of the resources all around the world.

2.3. Major themes in Ecology of freshwater

2.3.1. Hydrobiology

Hydrobiology deals with the details of various forms of aquatic life such as algae (Phytoplankton, Periphyton, Lithophytes and Benthos), zooplanktons, fishes and other groups of living organisms. Phytoplankton, Periphyton and Benthic algal communities represent the major producer components of aquatic systems. Since the study of autotrophic components of the *Periyar* Lake systems was integral to the present research, a comprehensive review of research works on such components in different parts of the world was essential.

Odum (1971) gives a good account of the producer components of aquatic systems and found that Diatoms are good indicators of water quality. Hunding (1971) observed the benthic algae as an important producer component of the littoral zone of eutrophic lake. Palmer (1980) noticed that plankton algae are much more important than the attached algae in deep water bodies such as reservoirs. The author has also emphasized that both the dissolved and suspended nutrients support the growth of algae and other aquatic life, and considered algae as good indicators of water quality. Moore (1980) analyzed all the epipelagic, epilithic, and planktonic forms of algae in three widely separated inshore areas of the *Great Bear Lake* and found similarities in species composition and standing crop between different groups, over seasons and across different sites due to similarity of water chemistry and temperature throughout the Lake. Osborne *et al.* (1987) reported that unlike temperate lakes, tropical lakes, particularly those that occur in areas where the climate is divided into distinct wet and dry seasons do not show stable water quality characteristics throughout the year.

Issa and Ismail (1995) analyzed the effect of detergents on river *Nile* water micro flora, and reported that algae are more sensitive to detergents than Bacteria and Fungi. Coesel (1997) provided more insight into the significance of planktonic Desmids species and their role in the aquatic food web in general. Wasielewska (1997) gave a good account of the smallest size group of phytoplankton, the pico-plankton, in 12 different fresh water lake ecosystems of Polish part of Pomerania. According to the author the relative importance of pico-plankton is highest in the oligotrophic lakes, decreasing in importance in the eutrophic, but the number of cells may be highest under eutrophic conditions.

Wani (1998) investigated the seasonal dynamics of phytoplankton in a shallow Himalayan lake as a part of its conservation and management. The seasonal dynamics and species composition of phytoplankton were recorded in the system and found to be indicators of eutrophic lakes. Stoyneva (1998) stated that the composition of phytoplankton is potentially a better indicator of trophic state in an aquatic ecosystem. They observed specific changes in algal community structure in accordance with changes in the nutrient status of the system. Vareethiah and Haniffa (1998) reported that conservative species of phytoplankton become the first casualties of disturbances in

habitats while other species are most favored and often become the biomass dominants. They also stated that high load of biological oxygen demand and hypoxic situations are uncondusive for phytoplankton community. According to Bormans and Condie (1998) a complex diurnal stratification behavior is encountered in natural fresh water systems. Phytoplankton distribution and overall concentrations depended critically on that. The authors are of opinion that the time scale associated with the change in stratification implies that the time of day is important in the vertical distribution of plankton and the growth rate of each algal species was assumed to be strictly light limited than nutrient limitation. The authors also noticed that, limited vertical mixing gave a growth advantage to the positively buoyant Diatoms, while negatively buoyant Diatoms shows a declining population as soon as the stratification built up. Wu (1999) reported that aquatic algae are sensitive to pollution or other events, and are therefore commonly used for monitoring environmental contamination.

An and Jones (2000) noticed that the flagellate algae are the dominants in summer in most water bodies. According to them the magnitude and frequency of blue green blooms and the taxonomic composition of them in Asian water bodies are regulated by intensity of monsoon due to variation in the physical and chemical features of water. The authors reported that Diatoms have a competent advantage during deep mixing of water. Anand (2000) studied the ecology of a Diatom species in relation to changes in water quality parameters at different regions of a stream in Jammu and explained its limnological significance. Coesel (2001) noted that, Desmids are ecologically highly sensitive microorganisms and are useful tool in aquatic conservation management especially in those cases where macro organisms fail.

Mahadev and Hosmani (2002) correlated Langliers index and phytoplankton in two lakes of Mysore city in India. They reported that the absence of Desmids is an indication of heavy pollution in water. Steinhart *et al.* (2002) studied phytoplankton as indicators of nutrient deficiency in the southern Chilean lakes and found that phosphorus should not be discounted as a limiting nutrient in aquatic system. They identified Desmids as indicators of good quality of water. According to Brunberg and Blomqvist (2002) *Microcystis* is a widely distributed organism, which dominates the phytoplankton community in nutrient rich lakes. Rodriguez and Tavera (2002) examined the

phytoplankton composition and biomass in a shallow monomictic lake in Mexican tropical zone and found that species restricted to temperate zones are found in that tropical water body. Lange and Tiffany (2002) noticed that when turbulence is high in a lake as during strong winds, Diatoms that are usually associated with benthic and epiphytic habitats gets mixed into plankton in such systems. Trick *et al.* (2002) explored spatial variation in Diatom communities within the Turkey lakes and found that the Diatom community is influenced by a nutrient gradient.

Coesel (2003) investigated the Desmid flora of Dutch fresh water wetlands as a tool for conservation and management. According to the author, among aquatic microorganisms, Desmids are particularly well for the assessment of water quality and nature conservation value, not only because of their specific ecological demands but also as their species regional distribution patterns than those of other groups of microorganisms. Mercado (2003) made a comparative analysis of the phytoplankton from 6 Pampean lotic systems of Argentina and found that the structure of phytoplankton community is related to the degree of anthropological pollution. Sedamkar and Angadi (2003) stated that algal growth in tropical inland water constitutes one of the principal causes of deteriorating the potable potentials of water. According to Fabricus *et al.* (2003) a combination of physical, chemical and biological factors determines the distribution of the Diatom communities in water bodies. Lindholm *et al.* (2003) analyzed the occurrence and harmful effects of a *Cyanobacterial* toxin microcystin in the Lake *Aland*, in Finland. The study revealed that microcystin occurs mainly in eutrophic lakes but also in some dystrophic and oligotrophic lakes. They also stated that increased detection of microcystin in water bodies' worldwide generates a complex challenge for water resource managers. They found *Microcystis aeruginosa* as the main microcystin producer of lakes. Murphy *et al.* (2003) investigated the harmful effects of microcystin in *Lower Great Lakes*. The authors noticed blooms of *Microcystis* species in the Lake in some seasons. They are of the opinion that this toxic *Cyanobacterium* constitutes a potential threat in many different types of lakes. They observed death of some aquatic organisms and birds in the study area due to the toxicity of microcystin.

Johnston and Jacoby (2003) investigated the *Cyanobacterial* toxicity and migration in a mesotrophic lake in western Washington and found out that thick surface

accumulation or blooms of *Cyanobacteria* in fresh water ecosystems are primarily attributed to nutrient, particularly phosphorus enrichment. Krupa and Czernas (2003) noticed mass appearance of *Cyanobacterium*, *Planktothrix rubescence* in Lake *Piaseczno*, Poland. Vilbaste and Truu (2003) studied the distribution of benthic Diatoms in relation to environmental variables in low land streams in Estonia and found that the trophic level of water plays an important role governing the structure of benthic Diatom assemblages. Moreover, they reported temporal variability in the structure and function of phytoplankton community is of fundamental importance to aquatic system metabolism. According to Rooney and Kalff (2003) the presence of extensive submerged macrophyte-beds has a negative effect on phytoplankton biomass, and submerged macrophytes influence bacterioplankton metabolism directly through the supply of dissolved organic carbon to the epilimnion and indirectly by suppressing phytoplankton biomass.

Izaguirre *et al.* (2004) analyzed the algal assemblages across a wetland in South America. The study revealed that phytoplankton of the Lake comprised of many small autotrophic green algae, accompanied by many flagellates of the classes *Cryptophyceae*, *Euglenophyceae* and *Dinophyceae*. The results indicated that the macrophytes cover was probably the stirring factor in the selection of algal species along the transitional zone comprising a floodplain shallow lake. Owen *et al.* (2004) made a detailed investigation of the wetlands in Kenya and observed that the Diatom flora shows clear differences between contrasting wetland types. Tewari and Srivastava (2004) investigated the distribution pattern of algal flora in a water body affected by the effluents from the nearby rubber factory in India. According to them algae play very important roles as pollution indicators, because they show high range of tolerance capacity against the polluted water releasing from rubber factory. Halvorsen (2004) studied some physical and chemical characteristics of waters of Lake *Atnjoen* in Norway and found *Chrysophytes* and *Cryptomonads* as the two main phytoplankton groups dominated in the Lake waters in all seasons through out the year. Kamenir *et al.* (2004) analyzed phytoplankton size structure stability in a meso-eutrophic subtropical lake and found that mainly large plankton cells produce high values of phytoplankton biomass during nutrient inflow periods. Brettum and Halvorsen (2004) investigated the phytoplankton of

lake Atnsjoen, Norway and found that the Lake is having fewer nutrients with oligotrophic characteristics. According to Menon (2004) wetlands are among the most productive ecosystems of the world and is essential life supporting systems providing a wide array of benefits to human kind. As per the author many species of wetland flora and fauna show extreme sensitivity to deterioration in the quality of their environment and one of the most valuable functions of wetlands is the cleansing and detoxification of polluted waters.

In the literature on hydrobiology of recent periods importance of the studies of phytoplankton and their seasonal dynamics were found useful to conservation of water bodies. Moreover, hydrobiology of water is found useful in understanding the ecological trend of a water body, which is subjected to anthropogenic impacts.

2.3.2. Primary production

Hunding (1971) studied production of benthic algae in the littoral zone of a eutrophic lake and found that sessile algae accounted for the bulk of primary production (70-90%) and most of them in the area studied by the author were pinnate Diatoms. Osborne *et al.* (1987) made a detailed study of Lake *Murray* of Papua New Guinea and found that wind induced disturbance of anaerobic sediments in the Lake enhances nutrient release from the sediment, which stimulates phytoplankton production. According to Kassim and Al-Saadi (1995) periphyton are important primary producers in the inland waters and they frequently contribute to the energy cycle in water systems. Nurnberg and Margo (1998) studied the productivity of clear and humic lakes, and the study revealed that primary productivity was higher in coloured lakes. According to the author, primary production of aquatic systems depends on mean annual temperature; mean annual variation in solar radiation, and climatic conditions. Ignacimuthu (1998) found that primary production in a standing water ecosystem depends on the chemical nature of the basin, the nature of import from streams or land and the depth. According to the author shallow lakes are usually more fertile than deep ones.

Aponasenکو *et al.* (2000) noticed that the surface area of phytoplankton plays an important role in metabolism and productivity. According to Hakanson and Boulion (2001) primary production is a process depending on the influence of many biotic and

abiotic mechanisms in aquatic systems. Moschini-Carlos *et al.* (2001) found out that the biomass and productivity of the plankton community are controlled by fluctuations of water level. They stated that the epiphytic algae are important autotrophic organisms for the aquatic ecosystem. According to them the rate of primary production of periphyton algae depends on the type and quality of substratum and area available on the substratum for phytoplankton colonization. Lind and Lind (2002) observed that phytoplankton production and biomass accumulation is mostly determined by the duration of photoperiod in the lake. According to them seasonal patterns of primary production show highest rates in the rainy season when the lake is at its seasonal maximum depth and turbidity is lowest. Downing and Leibold (2002) are of the opinion that productivity increases with respect to species richness within single trophic levels, and that richness influences trophic structure. Romero *et al.* (2002) stated that the knowledge of the limiting factors of phytoplankton productivity and algal adaptations to growth limitations are needed prior to the development of scientifically based restoration strategies for culturally eutrophic lakes. Joniak *et al.* (2003) observed the highest monthly average values of primary production in summer in some aquatic systems, when *Cyanobacteria* were dominated. According to them in new or completely restored reservoirs the main variable influencing plankton primary production is marked fluctuation of their trophic status. They noticed maximum values of specific primary production in such seasons, in which small sized phytoplankton dominated in the water. According to Hakanson and Boulion (2004) the production and biomass of benthic algae is of great importance in lake management. Review of researches on primary productivity revealed that it is an important parameter to assess the Ecology of freshwater bodies in general.

2.3.3. Physico-chemical parameters

In the understanding of ecology of freshwater systems, analyses of physico-chemical parameters are very essential. Kaul *et al.* (1980) stated that dissolved oxygen has been used as a most reliable parameter of lake eutrophication. According to them a change in the trophic status of a lake is associated with an increase in its nutrient status, so an increase in the conductivity values indicates a tendency towards higher level of trophication. Finlayson (1980) reported that phosphorus appeared to be a limiting factor for growth of the aquatic plants and the presence of chloride in water indicates pollution.

Sodium, potassium and calcium ions produce salty taste when the concentration is 100mgL^{-1} . Brown (1982) investigated the effect of pH and calcium on fish and fisheries. Ferris and Tayler (1985) studied total phosphorus relation in *Burraborang* Lake, New South Wales and some other southern hemisphere lake.

Burton *et al.* (1990) investigated the effects of stream odour and alkalinity on the composition of Diatom communities in two northern Michigan river systems. Adam *et al.* (1990) studied the physico-chemical characteristics and phytoplankton of two irrigation canals and a closed pond at Assiut area, Egypt. Adamus and Brandt (1990) surveyed the indicators, techniques and applications of community level bio-monitoring data to assess the impacts on quality of inland wetlands of the United States. Bircks *et al.* (1990) studied the Diatoms and pH reconstruction. Vincent (1992) found that nitrogen uptake in planktons is stimulated by light. Egge and Aksnes (1992) studied silicate as a regulating nutrient in phytoplankton competition. Hornstorm *et al.* (1993) investigated plankton and chemical, physical development in 6 Swedish west-coast lakes under acidic and limed conditions. Kitano *et al.* (1997) made a study of algae tolerant to pH values up to 10. Prins *et al.* (1999) reported that the level of spring phytoplankton bloom in some aquatic ecosystems is determined by phosphorus loading, whereas during summer the nitrogen loading determines phytoplankton biomass. According to them difference in nutrient loading did not result in shifts in phytoplankton biomass in all nutrient treatments. Chaturvedi *et al.* (1999) reported that water resources the world over is being polluted with a wide range of pollutants including heavy metals. According to them this is the reason for greater concern among water managers and scientist to develop economically viable strategies for the restoration of water bodies. Biodegradation and bio-absorption, accomplished by microbes, are now considered as the most effective and cheap methods to deal with the pollutants in water as per the authors observation.

Vestergaard and Sand-Jensen (2000) stated that alkalinity and trophic state regulate aquatic plant distribution in Danish lakes. Murugavel and Pandian (2000) recorded that a decrease in temperature enhances solubility of oxygen in water. Klug *et al.* (2000) investigated the compensatory dynamics in planktonic community responses to pH perturbations. Carvalho *et al.* (2002) investigated the physico-chemical conditions for supporting different levels of biological quality for fresh water. Adak *et al.* (2002)

reported that different physico-chemical parameters of water are very important for effective maintenance of water quality through appropriate control. Gulati and Donk (2002) explained that *Cyanobacteria* can withstand great variations in their phosphorus (P) content and thus in the C: P ratios. As per their report, for a unit weight of P the *Cyanobacteria* can yield relatively more biomass and cause greater turbidity than green alga which has relatively low C: P ratios. Romero *et al.* (2002) noticed that phosphorus limit algal growth and sometimes nitrogen also limits growth, however nitrogen-fixing species are not limited by nitrogen. Trick *et al.* (2002) reported that in interconnected water bodies, the lentic system have a regulatory effect on the nutrient regime of the lotic systems particularly on ammonium-N, nitrate-N, total-N and total-P.

According to Sedamkar and Angadi (2003) a low DO is a sign of organic pollution, and they noticed high percentage of *Chlorococcales* in waters having high dissolved oxygen. They also reported that *Chlorococcales* thrive well in water rich in nitrates than P. According to the report by Rooney and Kalff (2003) phosphorus, phytoplankton and heterotrophic bacteria interact in the epilimnion of lakes to determine the flow of energy and the biogeochemical pathways at the base of pelagic food webs, and macrophytes thrive well in lakes having low phytoplankton concentrations even at high phosphorus concentrations. There is an interaction between phytoplankton and phosphorus that is dependent on macrophytes cover. According to Vilbaste and Truu (2003) the phytoplankton *Eunotia bilunaris* is known to be common in streams with lower pH.

Owen *et al.* (2004) stated that pH, conductivity, temperature and nitrates appear to be closely related to Diatom development. Halvorsen (2004) investigated some physical and chemical characteristics of Lake *Atnsjoen*, Norway. According to Ojha and Mandloi (2004) pH increases in water bodies from morning onwards and decline during evening as temperature decreases. They also noticed that turbidity; suspended matters, clay, silt, colloidal organic particles, plankton and other microbes are an expression of light scattering and absorbing properties of water. Radhika *et al.* (2004) reported that water temperature is of enormous significance as it regulates various abiotic as well as biotic activities of an aquatic system. This perusal of literature on ecological investigations of water bodies showed that long-term monitoring and comprehensive analysis of the

physico-chemical parameters is crucial to a holistic approach in solving environmental problems of such systems.

2.4. Impact of tourism on aquatic systems

Hilton and Phillips (1982) stressed the problems of boat activity on deterioration of water quality of recreational waterways and found that the effect of boat activity is more on turbidity in shallow waters. Pandey and Soni (1993) found that regular visits of tourists and the consequent disposal of wastes from catchments areas enhanced the degradation of water quality of *Naukuchiyatal* Lake in Kamaun Himalaya. Maharana *et al.* (2000) studied the eco-tourism values in a sacred Lake of the southern Sikkim Himalaya, India and found that the Lake water is deteriorating due to the input of anthropogenic wastes as a part of tourism and pilgrimage. Evidences to relate tourism as an important reason for degradation of aquatic systems were thus plenty in the recent literature.

2.4.1. Motor boats and oil spill

In many of the tourist visited aquatic systems oil pollution was found a common pollutant. Baker (1971) studied the growth stimulation following oil pollution in the littoral communities. Bury (1972) studied the effects of diesel fuel on a stream fauna, California. Alexander *et al.* (1981) investigated the impacts of oil on marsh communities in the *St. Lawrence* River, and found out that mild amounts of oil favored the growth of *Cyanophycean* alga, but when concentration increases the growth decreased.

Eppley (1992) assessed the indirect effects of oil in the presence of natural variation. Eppley and Rubega (1996) investigated the indirect effects of an Oil Spill and the reproductive failure in a population of south Polar Skuas following the Bahia Pariaso, Oil Spill in Antarctica. Skvortsov (1997) found out that the oil pollution caused structural changes of plankton communities in some sub arctic lakes. Among them benthic *Cladocera* and *Chironomidae* are more vulnerable to the effect of oil pollution. Conides and Parpoura (1997) carried out oil pollution effects on the Ecology of a coastal Lake ecosystem and revealed that the oil scum prevented the dissolution of oxygen to the water and it ultimately affected the organisms there.

El-sheekh *et al.* (2000) investigated the effects of crude oil and its refinery products in the culture media of algae, and found that the same influenced very much in algal growth, proteins, and nucleic acid content. According to him the toxicity of oil was concentration dependant. The low concentration stimulated growth, protein content and nucleic acid; whereas high concentrations had an inhibitory effect on the growth of alga *Chlorella homosphaera*. Begak and Syroezhko (2001) developed a set of modern instrumental methods for the identification of oil pollution. The review of literature on the impact of oil spill in freshwater systems suggested the importance of this as a measure to assess the ecological status and sustainable management of tourism dominated fresh water bodies.

2.5. Major fresh water resources in India

Since literature on freshwater researches over the world has revealed its significance in sustainable development and progress of humans in general, review of similar research works in our country is also very relevant and significant before assessing the ecological status of *Periyar* Lake, Kerala, India.

India is a land of rich fresh water wealth. It is crucial to the sustainable development and progress of her agrarian economy. Limnological studies in India have a brief history starting form 1920's (Joseph, 1994). Sugunan (1997) found out that among the fresh water bodies, reservoirs are the prime resource regarding the fisheries and extensive aquaculture in India. He emphasized that the reservoirs and natural water bodies in the country are threatened by increasing environmental degradation and need conservation efforts. A large number of fresh water studies in the country were found in the literature since 1950.

Ganapati *et al.* (1953) investigated the hydro-biological conditions of *Gangadhareswar* temple tank in Madras. Ganapati (1956) investigated the hydrobiology of the *Hope* reservoir and of the *Thamparaparani* River at Papanasanam, TN. Zafar (1956) investigated the Limnology of *Hussainsagar* Lake, Hyderabad. Sreenivasan (1964) analyzed the hydrobiology of *Bhavanisagar* reservoir, Madras. Sreenivasan (1966) studied the Limnology of *Stanely* reservoir and *Mettur* dam. Unni (1967) examined the vegetation of ponds, swamps, and river banks in Raipur, M.P. Ganapati and

Sreenivasan (1968) investigated different aspects of Limnology, primary production and fisheries in the *Stanely* reservoir, Madras. Sreenivasan (1968) studied the Limnology and fish production in two ponds of *Chungalepet*, Madras. Sreenivasan (1970) compared the Limnology of two major reservoirs in Madras. Varkey (1971) studied the fresh water conservatories in Kerala with special reference to physiology of specific grounds. Nair (1971) investigated the water wealth of Kerala. Kaliyamoorthy (1973) studied the transparency of waters of the *Pulicat* Lake with reference to plankton productivity. Nasar and Munshi (1975) examined the primary production of a fresh water pond. Sreenivasan (1976) studied the fish production and fish population changes in some reservoirs in south India. Mathew (1978) investigated the Limnology of Lake *Govindgarh* and studied the correlation between plankton and physico-chemical parameters. Nair and Prabhoo (1980) investigated the primary productivity and limnological features of *Neyyar* reservoir in Kerala. Kannan and Job (1980) studied diurnal, seasonal, and vertical changes in the primary production in *Sathiar* reservoir. Kaul *et al.* (1980) investigated the physico-chemical characteristics of a high altitude forest lake *Nilnag* in Kashmir in comparison with the other valley lakes. Unni (1984) studied pollution in a major water tank in central India.

Shibu (1991) studied the Ecology of *Paravur* Lake, Kollam. Pandey and Soni (1993) investigated the water quality of *Naukuchiyatal* Lake in Kamaun Himalaya. Joseph (1994) conducted an ecological study of *Sasthamkottah* Lake. Iqbal and Katariya (1995) analyzed the physico-chemical characteristics of *Upper* Lake, Bhopal. Kataria *et al.* (1995) investigated the Limnology and water chemistry of *Tawa* reservoir. Chapman and Reiss (1995) compiled different studies on water and sustainable development in the *Ganges* valley in India. According to Kumra (1995) the holy river *Ganges* in India carry high amount of biological oxygen demand (BOD) per day, received from urban, domestic and industrial wastes. Jain *et al.* (1996) investigated the impacts of waste disposal on the water quality of river *Kali*, the drinking water source of Rookie city in Uttar Pradesh. Jeyasingh (1997) studied the hydrobiology of some reservoirs in *Kanyakumari* district of TN. Sreenivasan *et al.* (1997) investigated the Limnology of *Kolovoi* Lake in TN. Nambudiripad (1997) investigated the surface water resources of Kerala. Naganandini and Hosmani (1998) studied the Ecology of inland waters of Mysore district in Karnataka

State. Sareena (1998) investigated the Ecology of *Vellayani* Lake in southern Kerala. Gowd *et al.* (1998) made a study of the physico-chemical characteristics of water samples in the *Peddavanka* water shed of Andhra Pradesh. Chaturvedi *et al.* (1999) investigated the plankton community in different water tanks in *Jaipur* city. Sharma *et al.* (1999) made an ecological investigation of *Jalmahal* Lake, Jaipur. Tiwari (1999) investigated the physico-chemical characteristics of the *Upper* Lake Bhopal. Singh and Rai (1999) studied the physico-chemical characteristics of river *Ganga* at Varanasi. Jacob *et al.* (1999) investigated the impact of industrial effluents on river *Noyal*; Tirupur in TN. Bandela *et al.* (1999) studied the distribution of phosphate and nitrogen forms and their interrelationships in *Barul* dam water, Maharashtra.

Maharana *et al.* (2000) studied the Lake *Khecheopalri* of the Sikkim Himalaya, which is subjected to eco-tourism, and found that it remains stable due to careful monitoring and management. Analysis of the Limnology of *Tawa* reservoir (Bhade *et al.*, 2001), Madhya Pradesh showed that the nearby thermal power station effluents have marked impact on the nutrient status of the reservoir. Das and Kaur (2001) investigated the ion chemistry and weathering processes of *Renuka* Lake, Himachal Pradesh. Shukla and Gupta (2001) investigated the assemblage of ciliated protozoan community in polluted and non-polluted environment in a tropical central Himalayan Lake, *Naini Tal*. Rao and Pillala (2001) investigated the concentration of pesticides in sediments from *Kolleru* Lake, Andhra Pradesh. Sujatha *et al.* (2001) studied sewage and sludge treated Lake, *Dalavayi* near Mysore and its impact on the environment. Nagdali and Gupta (2002) found that the fish fauna and water quality parameters of Lake *Naini Tal* are closely related. Pandey and Pandey (2002) studied the relationship between *Cyanobacterial* flora and the physico-chemical environment of six tropical fresh water lakes of *Udaipur*, Rajasthan. Nachiappan *et al.* (2002) carried out water balance study of Lake *Naini Tal*. Lalraju *et al.* (2002) studied the chemical constituents of Kayamkulam estuary near the NTPC power plant, in Kerala. Amaraneni (2002) investigated the presence of pesticides in water, sediment and fish in *Kolleru* Lake and reported that the chemicals used in intensive aquaculture farms had major bad effects on the biodiversity of the Lake. Garg (2002) investigated the fluctuations on physico-chemical parameters of river *Mandakini* in Madhya Pradesh. Chauhya *et al.* (2002) investigated the ecology of a

large pond near *Jharia* coalfield in Jharkhand. Chandrashekhar *et al.* (2003) are of opinion that if the present state of pollution as a part of urbanization near *Bellandur* Lake, Bangalore city continues, the Lake might become inactive. Nagaraju *et al.* (2003) investigated a sewage treated Lake *Dalavayi* in Mysore, and are of opinion that developing countries in the world in general are facing pollution problems due to toxic elements in the environment. Sharma and Sarang (2004) studied the physico-chemical Limnology and productivity of *Jaisamand* Lake in Rajasthan. Scaria (2004) investigated the toxicity of industrial effluents on phytoplankton of *Cochin* estuary and is of opinion that the plankton community structures are affected with the effluents released into the water in that area. Kumar and Kurup (2005) investigated the biotic integrity in the lower reaches of *Periyar* River. James (2005) studied the management of river basins in relation to wetlands in the Indian subcontinent. He stressed the importance of an integrated development and management for the river basins and wetlands. Dwivedi *et al.* (2005) carried out an ecological study of the *Chlorophyceae* in the north Indian water bodies and their relationship with water quality.

This review of literature on ecological study of freshwater systems in India revealed that ignorance of the people and irresponsibility of the local, state and central Governments systems are the major causes of water pollution in India. Researches to understand the anthropogenic impacts on water bodies; especially the lakes and reservoirs are getting high momentum in the country today.

2.6. Freshwater ecosystems in the Western Ghats

Since majority of the lakes and reservoirs in India are located in the high altitudes of Western Ghats, a review of literature on fresh water studies related to the Western Ghats became imperative. The Western Ghats is a very important ecological zone as it is one of the major biodiversity 'hotspots' of the world. Rare and endemic species diversity of this region entirely depends on the water resources of the area. Therefore, the study of lakes and reservoirs in this region of the country has a significant role in evaluating the ecological conditions existing in such water bodies as well as evaluating the anthropogenic impacts on these ecosystems.

The reservoirs of Kerala located in the Western Ghats are oligotrophic as reported by (Khatri, 1987). He investigated the *Idukki* reservoir for different aspects. Nair (1985) investigated the wasting wealth of Western Ghats. According to him the Western Ghats form the major water shed in peninsular India and 58 major peninsular Indian rivers originate from them. The intensive utilization of the water resources of the Western Ghats through major dams has resulted in the extensive submission of valley forests in the river catchments. Chattopadhyay *et al.* (1986) studied the *Bhavalipuzha*, *Aralampuzha* drainage basin in the Western Ghats of Kerala as part of the integrated environment assessment for eco-development. The study is a base to develop more sophisticated methodology and it provides basic information for a part of the Western Ghats to practice eco-development. Prasad (1986) studied the Kerala Western Ghats in the five-year plans. The author pointed out the importance of implementation of immediate action on the eco-development of Western Ghats, as it is the vital hill area, which is so richly endowed with natural resources. The region supporting vast human and animal populations are forced to pay a severe price for the unplanned and unsustainable exploitation of its natural wealth. The main aftereffects of exploitation in this region are considerable shortening of the life span of high dams, siltation due to erosion, scarcity of drinking water and extinction of valuable medicinal herbs. Chavadi and Gokhale (1986) investigated the seasonal variation in the water quality of river *Kali*, originating in the Western Ghats of Karnataka. The physico-chemical parameters of this water showed pollution trends. They found out that the source of pollutants is factories at the *Dandeli* region. As per Kerala State Gazetteer (1986), and Mathew and Raghaviah (1988) the Western Ghats region of Kerala covering an area of nearly 56% of the total geographical area of the state, and 42.7% of the entire Western Ghats region is the water shed of all 44 rivers that sustain the agro economy of the state. Joseph (1986) investigated the insect life and eco-development of the Western Ghats and pointed out that unplanned and un regulated activities of civilized man in the region created serious problems like soil erosion in the Ghats, frequent floods in the plains, silting of rivers and reservoirs and navigable water ways, and even drastic changes in the climate itself. Khatri (1987) investigated the seasonal distribution of phytoplankton in *Idukki* reservoir of Kerala. CWRDM (1989) studied the management

and conservation of *Pookote* Lake ecosystem in Wayanad in the Western Ghats of Kerala. The exploitation of the Lake and the catchments has led to siltation, eutrophication, and ultimate loss of this water body. Harikrishnan and Aziz (1989) prepared a preliminary investigative report on the ecological characteristics of *Neyyar* reservoir in Kerala Western Ghats and recorded highest phosphate in the system at the end of monsoon. Sugunan (1995) stressed detailed investigations of the reservoirs in Kerala, located in unique environments surrounded by high hills. Tewari (1995) reported that the Western Ghats is rich in algal flora but no significant efforts have been made to systematically enumerate them. Thomas and Azis (1999) investigated the zooplankton community characteristics in the *Peppara* reservoir in the southern Western Ghats of Kerala. James *et al.* (2000) analyzed the hydrology of forest watersheds in the Western Ghats and found out that the degradation of watersheds through denudation of vegetation causing depletion of water resources is a major problem in the region.

Murugavel and Pandian (2000) studied hydrology and productivity in *Kodayar* reservoir system in the Western Ghats of TN. The study proved that the reservoir is productive and has rich algal flora. According to Chauhya *et al.* (2002) the programmes that are implemented so far in Kerala for the conservation and management of inland fisheries resources have been found to be inadequate. According to the authors, all anthropological disturbances, like habitat destruction, such as reclamation of inland waters for agricultural purposes, indiscriminate use of biocides and the discharge of industrial effluents and anthropogenic wastes created due to extensive tourism in to the rivers have caused irreparable damage to the water bodies and their fisheries. Varghese *et al.* (2003) investigated the fish fauna of *Bhoothathankettu* reservoir in the Western Ghats of Kerala and reported 85 species of endemic fresh water fishes. Of which 25 species have been reported, as endemic to Kerala. They said that it is very urgent to conserve the freshwater habitats, which are under severe threat due to a multitude of reasons. Sedimentation survey (James, 2005) in one of the reservoirs in the Western Ghats has shown that almost 20% of total capacity (121mm^3) of the reservoir has been lost mainly because of deforestation in the catchments and change in the cropping pattern.

Literature survey on the study of fresh water systems of Western Ghats revealed that thorough ecological monitoring investigations were not yet carried out in many of the very sensitive precious fresh water bodies in the area. The direct and indirect preliminary and short duration investigations on fresh water systems of the region revealed the increasing anthropogenic impact on them. So the present ecological investigation on the *Periyar* Lake is most significant to reveal the limnological and ecological aspects of freshwater reservoirs in the Western Ghats in general.

2.7. The Periyar Lake

Chacko (1948) made the first scientific report on the fish fauna of the *Periyar* Lake and reported that the commonest fish in the Lake was '*Masheer*'. It was also mentioned in the report that two exotic species, *Catla catla* (C. & V.) – the carp, and *Chanos chanos* (Forsk.) the milkfish, were introduced in the Lake in October 1946 and April 1947 respectively as a part of the enriching of fisheries of the several irrigation tanks in the *Madurai* district of TN, which were fed by the *Periyar* system.

Zacharia and Bharadwaj (1995) reported the presence of freshwater Medusa *Limnonida indica anandale* in *Periyar* Lake. According to them very little study has been done on the Limnology of the Lake. They stressed the importance of limnological study with special reference to the biodiversity of the Lake. Arun *et al.* (1996) recorded new species of fishes from the inlets to the Lake and found that the Lake and the associated streams support a diverse fish fauna. Zacharias *et al.* (1996) made a detailed study of fishes of the Lake and recorded a total of 16 species, of which 10 were found to be endemic to the Western Ghats. They emphasized the conservation problems and management measures needed in the Lake. '*Mannan*' and '*Paliyan*' tribes were identified as the main fishermen in the Lake. Jafer *et al.* (1997) studied aquatic birds seen in PTR and recorded a total of 23 species, of which 17 were found residents and the other 6 were migratory.

Arun (1998) studied the status and distribution of fishes in *Periyar* Lake and its inlets. According to this study the streams drain into the Lake form a length of about 74 km. The fish densities in the streams are more than that of the Lake. A total of 27 species of fishes were encountered in this survey. Among them 14 were found endemic to Western Ghats, 4 were threatened, 9 threatened and endemic. Arun (1999) analyzed the patterns and process of fish assemblages in *Periyar* Lake valley system and identified five niche types for fishes there, which are the surface dwellers, pelagic, benthic, substratum attached and individualistic. As per his report the water quality parameters showed a pristine nature and production was relatively low in the Lake. Zacharias and Minimol (1999) reported a new species of fish *Noemacheilus menoni* from *Malappara* in PTR.

CED (2000) revealed that the main fish catch from the Lake belong to exotic species such as *Tilapia* and European Carp. The native fishes like ‘*Masheer*’ and ‘*Kooral*’ are under endemism now. The study pointed out that the Forest Department granted extensive fishing rights to the tribes considering the importance of fisheries in the livelihood of tribal people. Lal (2000) analyzed the conservation of fish fauna of *Periyar* Lake and stressed the need for immediate conservation efforts for the native fishes of the Lake, *Gonoproktopterus micropogon periyarensis* and *Lepidopygopsis typus*. According to the author these two fishes are reported only from this Lake in the Indian subcontinent. Thomas *et al.* (2002) surveyed the fishes of *Periyar* Lake and prepared notes on the distribution of endemic and endangered species.

Kurup (2003) investigated the threats to the biodiversity of *Periyar* Lake with special reference to management options for sustainable utilization of aquatic living resources. According to the author various threats imposed on this aquatic system have eventually resulted in the loss of biodiversity as manifested by the disappearance of various aquatic species, which were recorded earlier from the Lake. Radhakrishnan and Kurup (2003) studied the biodiversity status of fishes of the Lake with special reference

to endemic and endangered fishes. According to the authors different types of threats are faced by the unique germplasm there and the major problems of the Lake include pollution due to the discharge of sewages and increased human intervention due to the tourist influx in the Lake. They advised the prohibition of plastic goods in the Lake, prevention of oil spillage from tourist boats. Kumar and Kurup (2003) analyzed the significance of the fish microhabitats of the Lake as the major measures of conservation of endemic and endangered fishes. They observed that habitat alteration due to illegal fishing activities, human intervention, and riparian encroachment activities should be controlled in the microhabitats, which were very essential for the conservation of the dynamic fish diversity of the Lake.

Minimol (2003) examined the fish diversity of the Lake, and recorded 41 species of fishes belonging to 5 different Orders and 11 Families. The author emphasized the need of periodical observation and monitoring of Limnology, particularly fish fauna in the *Periyar* Lake and also stated that illegal fishing should be strictly banned. Kurup (2003) analyzed threats to biodiversity of *Periyar* Lake with special reference to management options for sustainable development and utilization of aquatic living resources. He emphasized the degradation of the Lake and its living resources. Krishnan *et al.* (2003) made a report on *Periyar* Lake. Ray *et al.* (2004) in a preliminary study on the water quality parameters of the Lake emphasized a dangerous problem of accumulation of oil on the surface water and disposal of solid wastes near the Lake.

This review of research work on *Periyar* Lake shows that the present problem is original and useful to a better understanding of the Ecology of the Lake system as a whole. It revealed that only very few studies have been conducted for investigating the pollution status of the Lake. No detailed investigation was carried out regarding the phytoplankton of the Lake. Hence the present three-year study on the hydrobiology in relation to physico-chemical parameters in the Lake was very significant and timely.

Chapter-III

MATERIALS AND METHODS

3.1. The Periyar Lake

The *Periyar* Lake at the centre of PTR lies between 09°16' and 09°40'N latitude, and 76°55' and 77°26'E longitude, and at an altitude of 1525m above mean sea level. The reserve has 90km interstate boundary with the three districts of *Thirunelveli*, *Kamarajar*, and *Madurai* in the TN. The *Ranni* forest division of *Pathanamthitta* district of Kerala borders on the southern part of the reserve. The western boundary of the reserve is the eastern side of *Kottayam* forest division. The northern boundary of the reserve is *Kumily* town and *Peermade* taluk of *Idukky* (Manoharan, 2000). Presently, an area of 777km² forms the Periyar Wildlife Sanctuary, which is the major watershed of the *Periyar* Lake.

Construction of the *Mullaperiyar* Dam across *Periyar* River near *Thekkady*, *Kumily* formed the Lake in 1895. The water body has a total surface area of 26 km². The Full Reservoir Limit (FRL) is 152 ft and the Central Water Commission in 1979 limited it to 136 ft. The Lake represents a unique tropical high altitude fresh water ecosystem. The Lake serves as the major base for the survival of precious wildlife in the Sanctuary. Though Kerala is the custodian of the PTR, the dam is managed by TN as per the contract established at the time of its construction. Water from the Lake is taken to eastern side in the TN through an open watershed cut of 6100 ft long and then through a tunnel of 5704 ft long. On the way to the east, the water is used for power generation and then stored and distributed for agricultural purposes in three districts in TN. Thus irrigation and power generation are the two major uses of the waters of *Periyar* Lake in the TN. Tourism is the other major business in Kerala based on the same waters.

3.2. Field stations

For convenient monitoring, systematic field study and regular sampling of waters, six permanent sampling stations were fixed in the Lake (**Figure-3**). These stations were

fixed according to differences in degrees of human interactions within different parts of the Lake system, and also as zones of special ecological interests. The stations were fixed after a detailed survey of the Lake system. These stations were designated as Periyar Lake Station (PLS) - PLS-1 (**Plate-1**), PLS-2, PLS-3, PLS-4A, PLS-4B, and PLS-5 respectively (**Plate-3**).

3.2.1. PLS-1

This is the boat jetty, the station where maximum human interaction takes place (**Plate-2**). Tourists start their cruise from this site, and a crowd of tourists can be observed from morning to evening in this site. The water in the Lake at this station was always turbid due to the continuous boat plying. Around 8 boats of different sizes owned by the KFD, KTDC, PDS and TN-PWD carry out 4 to 5 trips daily in the Lake. The boat cruise starts at 7.30 am in the morning and stops at 5.30 pm in the evening. Two streams join the Lake at this site. The smaller one flows from the south east of the Jetty and joins the Lake near the landing site and the larger one flows from the north of the landing site, and joins the Lake in the eastern side of the jetty. The Kerala Forest information center, a KTDC hotel - the 'Periyar House', staff quarters, cafeteria and common toilets for tourists are located near the boat jetty. From the Jetty the water tunnel to TN begins, it is located towards the northwest side of the jetty. The boat jetty is an area with lesser forest cover and open sky, clearly exposed to sunlight throughout the day. The maximum water level in the Lake was shown in the jetty on a graduated iron scale.

3.2.2. PLS-2

This is the station near a star hotel run by the KTDC in the forest, the 'Lake Palace', which is around 3 kms away from the jetty towards the south of the Lake. This was the summer house of the erstwhile *Travancore* King. The area around this hotel is commonly called as 'Deer Island', where tourists are able to watch the frequent grazing of *Sambar* deer population. The vegetation here is deciduous forest and grasslands. This is a very attractive place for national and international tourists who are rich enough to afford the charges of the hotel. Hence this place is considered as a station with medium anthropogenic impact.

3.2.3. PLS-3

This is the *Mullaperiyar* Dam site, which is around 15 kms away from the boat jetty, towards the south of the Lake. In this site the natural flow of the *Mullaperiyar* is blocked by the Dam of length 1200 ft and height of 176 ft. The capacity of the reservoir is 15662 m³. To the southeast of the *Mullaperiyar* dam there is a Eucalyptus plantation and in the eastern direction of the Dam, thick evergreen forest can be seen. In the western portion lie grasslands. Approximate depth of this region of the Lake ranges between 40-43 mts. This is considered as the deepest and broadest portion of the Lake. On the right side of the major dam there is a spillway having 16 shutters, open always. Whenever the dam water level reaches above 139 ft, the water overflows through these shutters to the *Idukki* reservoir. This happens very rarely, because the TN-PWD is vigilant to increase the outflow through the water tunnel whenever water level increases in the dam. Only once during our investigation trips (in August 2005), the Dam was found over flowed because of the heavy rain in the watershed region of the Lake. PLS-3 represents a general confluent zone of all the anthropogenic impacts in the Lake.

3.2.4. PLS-4A

This station is located at a place called the '*Mullakkudi*', the site at which '*Mullayar*' (a tributary of *Periyar* River) merges with the Lake. It is around 30kms away from the boat jetty in the eastern direction. The '*Mullakkudi*' represents the core area of the PTR. It is a site where a Forest Inspection Bungalow is situated. The forest type found in this region is mixed deciduous. PLS-4A represents the zone of the impact of the confluence of *Mullayar* with the Lake.

3.2.5. PLS-4B

This is near the *Thannikkudy* forest station. It is the site at which *Periyar* merges with the Lake. It is around 35 kms away from the boat jetty in the southeast direction of the Lake. This site is nearer to the '*Sabarimala Poonkavanam*' range of forests but there is no direct access to that region from here. Two rivers *Pampa* and *Azutha* originate nearer to this station from the opposite slope of the hills here. *Thannikkudy* region also represents the core area of the reserve where tiger is available evidenced by its pugmarks

on the riverbanks. There are a number of different sized springs and streams join the *Periyar* River along its upper reaches and the flow of water in the River is comparatively faster towards these upper catchments. The River is very shallow at this region and water was always found mixed with partially decayed litter and logs and full of organic sediments. The riverbanks are rocky, and along the shores of the river rich growth of Bamboo is seen. The forest here is deciduous with rich growth of grasses. PLS-4B represents the impact of confluence of *Periyar* River with the Lake.

3.2.6. PLS-5

This site is the water tunnel way to TN, where the sewage channel from *Kumily* township enters the Lake and is considered as the most contaminated station. It is 1km away from the main Lake towards west direction from the boat landing site. The flow of wastewater from the sewage channel to the tunnel varies according to the season. During the monsoon season hydrophytes like *Eichornia crassipes* flourished in the sewage channel and during the end of the monsoon another group of plants like *Asclepias curessavica* (*Kakathundi*) were found in the channel. During dry seasons *Ipomea fistulosa* flourished in the same place. However, such macrophytes were not found in the tunnel water. At the end of the tunnel three shutters are present, under the control of TN-PWD. Two of them were always open and TN- PWD draws in water throughout the day, through this tunnel. However, all the shutters were found closed during certain days during our investigation period and it was due to some reasons of repair somewhere in the system. In such periods we found the sewage water reaching the tunnel flowing back into the Lake.

3.3. Climate and environmental characteristics of the Lake

Air temperature, monthly precipitation (average of daily precipitation), and average monthly water level of the Lake and the rate of monthly inflow and outflow (average of the daily inflow and out flow) were the general environmental characteristics studied in the Lake. Averages of monthly characteristics were then grouped into seasonal characteristics. Precipitation rate was collected from two climate stations—one situated at

the dam site and the other situated at *Thekkady*. The averages of the values of both stations were then calculated as the representative monthly rainfall at the Lake.

3.4. Field visit and sample collections

Water samples were collected from the Lake between 15th and 20th of every month from April 2002 to April 2005. We usually started our journey to *Thekkady* in a taxi at 5 AM from *Changanacherry* and reached *Kumily* at 8.30 AM. We usually started our sampling from PLS-5 at 9AM and continued in the order PLS-1 to PLS-4B. We usually collected the last samples from the PLS-4B at 2.30PM. All the water samples for different laboratory analysis were packed appropriately in well-insulated boxes filled with ice cubes. After reaching the laboratory at about 10 PM, the samples for BOD measurements were immediately incubated and others were kept in the fridge for next day's analysis.

3.5. Water sample collections

The sampling for surface and bottom waters at PLS-5 and PLS-1 were done from the shores, but surface and depth sampling at the PLS-2 to PLS-4B were carried out from the motor boat. During the boat trips in the official forest boats along with the staff, the forest officials usually gave us a halt at the centre of the water body in each station for 20-35mts times for field measurements and collection of water samples in designated bottles. For the collection and preservation of water samples for different laboratory analysis we always carried with us separate pre-labeled bottles and preservatives and all other requirements for this study.

3.5.1. Collection of water samples for physico-chemical analysis

Samples for physicochemical analysis were collected manually from two different depths. Samples were collected from surface (1-2cm) and bottom (maximum of 10mtrs) regions of the Lake. Variations occurred in depth sampling according to the variations in water level of the Lake and depth of the sites. Samples were collected directly from the surface of water with the help of 2Ltr acid cleaned polythene bottles. The depth samples were collected using a Meyer's water sampler (Trivedy and Goel, 1986) and samples were transferred to the acid cleaned 2-Ltr polythene bottles using a plastic tube. These

water samples were kept in darkness in iceboxes at 4 °C till the samples reached the laboratory for analysis.

3.5.2 Collection of water samples for BOD

The samples for BOD analysis were collected from surface (1-2cm) as well as bottom (maximum of 10mts) of the Lake in separate BOD bottles. Two such bottles were used for each sample. One was fixed on the spot immediately after the collection following Winkler method (Trivedy and Goel, 1986), and the second bottle containing water was kept in darkness at 4 °C (in iceboxes) till it reached the laboratory.

3.5.3. Collection of water samples for Phytoplankton analysis

The samples for phytoplankton study were collected from all the 6 stations in separate clean plastic bottles. Water samples were collected separately for the study of all the general phytoplankton and Benthos.

3.5.4. Collection of Phytoplankton

For the study of phytoplankton 1Ltr samples were collected from the surface water at all the stations in clean plastic jars and were fixed immediately using Lugol's iodine solution (1ml: 10ml) (Trivedy and Goel, 1986).

3.5.5. Collection of Periphyton

For the study of Periphyton, the phytoplankton colonized on some plants seen along the shore lines of the Lake, were collected every season on the basis of their availability on the shores of the Lake. Representations of these plants were collected on the basis of their presence, and dipped in 100ml-distilled water taken in 150ml clean plastic bottles. The samples were fixed immediately after collection, using Lugol's iodine solutions (1ml: 10ml). Periphyton algae colonized on plants near the periphery of the Lake were collected from PLS-1 and PLS-4A respectively. The entire 100ml samples of each station were mixed thoroughly after preservation (Trivedy and Goel, 1986).

3.5.6. Collection of Benthos

Algae of the sediments were collected from the mud using a 50ml (2cm wide) syringe from the shores. Two representative samples were collected from each location

(50mlx50ml=100ml) and fixed in Lugol's iodine solution immediately after the collection (1ml: 10ml). Benthic algal forms were collected only from PLS-1,4A and 4B. Those three stations were the three representations of the Lake, having minimum as well as maximum anthropogenic influence (Trivedy and Goel, 1986).

3.5.7. Collection of water samples for Bacteriology

Samples for MPN and fecal *Coli form* analysis were collected from surface water of each station separately in 100ml pre-sterilized dark bottles, and kept in darkness at 4 °C during sampling, and were transported to the laboratory, these had been kept in ice boxes of 4 °C (Trivedy and Goel, 1986) .

3.5.8. Study of primary productivity

Primary productivity of surface water samples only were measured by light and dark bottle method (incubated on the spot for 3hrs) (Trivedy and Goel, 1986).

3.6. Field measurements

Air temperature, water temperature (of both the surface and bottom) were measured using a glass thermometer; pH, dissolved oxygen (DO), electric conductivity(EC), total dissolved solids (TDS) and salinity of both surface and bottom water samples were measured on the spot using a portable water and soil analysis kit(EI-microprocessor no.1160E). EC and pH were also measured using separate pocket testers (Eutechscan-3). All the data were recorded in separate field books. The samples for DO were fixed on the spot using Winkler iodometric method (Trivedy and Goel, 1986). Total depth and transparency (Measured with the help of a secchi disc-20cm diameter black and white iron plate) were measured for each station.

3.7. Laboratory water analysis

3.7.1. Physico-chemical parameters

DO, Carbon dioxide (CO₂), Total alkalinity, Total hardness, Calcium (Ca), Magnesium (Mg), Chloride (Cl), bicarbonates, were measured titrimetrically following the method of APHA (1995), and Trivedy and Goel (1986).

Total Nitrogen was determined by Micro-kjeldal method. Nitrate nitrogen, inorganic phosphorus and silica were measured using a U.V visible spectrophotometer. Sodium (Na) and Potassium (K) were measured using a flame photometer. Total solids (TS), TDS, Total suspended solids (TSS), oil and grease in the water were measured in the laboratory. Chemical Oxygen Demand (COD) was measured following standard methods.

3.7.2. Analysis of biological parameters

3.7.2.1. BOD

Having once they reached the lab, the samples kept for BOD were transferred to BOD incubator at 20⁰C, and further incubated for 5 days, and the BOD was measured according to the standard methods followed by APHA (1995).

3.7.2. 2. Phytoplankton

Each of the 1Ltr samples collected was centrifuged to concentrate the plankton organisms. Every one of these samples was made up to 100 ml after removing the surface water in the centrifuge tube. General phytoplanktons were studied for quantitative and qualitative details. Counting was made using a stereomicroscope with 40x magnification using Lacky's drop method (Trivedy and Goel, 1986), and thus the phytoplankton of the concentrate was calculated. The actual count/ L were calculated from this by dividing it with the concentration factor 10. Colonial and filamentous forms were counted as single units. The phytoplanktons were identified using the standard keys provided by Palmer (1980), and Reynolds (1980). The micro-photographs of each representative sample were taken using a digital camera. Periphyton and Benthos were identified using the same methods adopted for the general phytoplankton.

3.7.2. 3. Bacteria

Samples for bacterial analysis kept in the fridge were carried out immediately in the next morning. The MPN count was detected with the help of the chart provided by Trivedy and Goel (1986). The bacteriological studies for *E.coli* were carried out in the Laboratory of Microbiology of the RRI, Kottayam, according to the standard procedures of APHA (1995).

3.8. Other data collected and Statistical analysis done

The details of tourism and Lake morphometry were collected from the Forest Department. The rainfall data was provided by the TN- PWD office.

Results of the descriptive measures (average and variance) for all the climatic, water quality and hydro biological parameters were calculated station wise, season wise and year wise. The data used for these analyses were the averages of the four measurements made in each season for the three years of study. The variations of each particular parameter across stations and that over seasons or years were calculated using the ANOVA. Correlation studies were conducted between three-year average phytoplankton densities of different seasons with all the corresponding physico-chemical parameters including nutrients and pollutants such as oil and grease, at all stations. Correlation analyses were done between the densities of major groups of plankton in the Lake (*Cyanophyta*, *Euglenophyta*, *Bacillariophyta*, and *Chlorophyta*) with seasonal fluctuations of physico-chemical parameters. This was to identify the seasonal dynamics of different groups of algae in relation to fluctuations in water quality parameters. All these were done using the Microsoft Excel.

Chapter-IV

RESULTS

4.1. Introduction

Precipitation, temperature, inflow and outflow, and standing water level are the important environmental factors of marked seasonal variations that affect all the other environmental characteristics of freshwater ecosystems. These are the factors which usually fluctuate according to seasons within a year. In tropical systems, environmental fluctuations which could be accounted are limited to summer and rainy seasons alone. Since monthly changes are quite gradual and wide fluctuations in monthly characteristics exist between successive years, calculation of seasonal trends from the regular monthly observations is much more useful to explain ecological status of tropical ecosystems.

Two definite periods of rainfall—the southwest and the northeast monsoon—with a gradual short break in between followed by a summer period are usually felt within a year in Kerala. In order to account all the major seasonal environmental fluctuations of the study area the monthly measurements done were accordingly grouped into averages of three seasons such as the pre-monsoon (January, February, March and April), southwest monsoon (May, June, July and August) and the northeast monsoon (September, October, November and December). Since human activities in and around the Lake also differ according to these periods, this season wise analysis and comparative description of the data explain the degree of human impact on the Lake ecosystem in the different seasons of a year. Station wise analysis and comparison of different data explain the difference in the degree of anthropogenic impact on different parts of the Lake system. Comparison of identical stations in similar seasons between the different years of study explains the degree of fluctuation of the impacts between years as well as the tendency of human impact as we advance in future. The variations between stations, seasons and years of each particular parameter are clear from the given ANOVA tables. The correlation analysis done using the same programme explains the relationship

between all the different parameters accounted during this study in all the stations, seasons and years.

4.2. Climate and water dynamics of the Lake system

Air temperature, precipitation, water level, total inflow and outflow and the stored water content of the Lake were the important general environmental characteristics of climate and water dynamics of the Lake, recorded monthly.

4.2.1. Air temperature ($^{\circ}\text{C}$)

The seasonal average air temperatures recorded during three different seasons over three-years are given in **Tables-1 to 3** and average for the three-year period during the different seasons are given in **Table-4**. It is clear from these ANOVA tables that there were no significant variations in air temperature across the stations and over the years during the pre-monsoon and northeast monsoon in the Lake area where as the differences in air temperature across the stations and over the years were significant during the southwest monsoon. The variations in air temperature over the three different seasons and across the stations were very significant in the Lake. The variation in the average seasonal air temperature noticed between different stations during the study period was 1-6 $^{\circ}\text{C}$. The lowest average air temperature was 24 $^{\circ}\text{C}$ from 9.30 AM to 2.30 PM (recorded during the northeast monsoon at stations 1, 2, 3 and 4B); and the highest average air temperature was 30 $^{\circ}\text{C}$ from 12.30 to 1.30 PM, (recorded during the pre-monsoon, at stations 3 and 4A).

Table-1. Average seasonal air temperature - pre-monsoon

Air temperature ($^{\circ}\text{C}$)	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon 1	28	28	28	28	29	27
Pre-monsoon 2	27	28	30	30	29	25
Pre-monsoon 3	27	29	27	26	26	28
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	3.44444	2	1.722222	0.81152	0.471413	4.10282
Columns	6.44444	5	1.288889	0.60733	0.696823	3.32584
Error	21.2222	10	2.122222			
Total	31.1111	17				

Table-2. Average seasonal air temperature - southwest monsoon

Air temperature ($^{\circ}\text{C}$)	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	25	27	26	26	27	26
Southwest monsoon-2	25	28	27	27	29	26
Southwest monsoon-3	25	27	25	27	27	25
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	3.4444444	2	1.7222222	5.344828	0.026378	4.102816
Columns	15.611111	5	3.122222	9.689655	0.001366	3.325837
Error	3.2222222	10	0.322222			
Total	22.277778	17				

Table-3. Average seasonal air temperature- northeast monsoon

Air temperature ($^{\circ}\text{C}$)	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	24	26	25	25	26	25
Northeast monsoon-2	25	25	25	28	27	25
Northeast monsoon-3	24	24	24	26	24	25
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	5.333333	2	2.666667	3.636364	0.065042	4.10282
Columns	7.833333	5	1.566667	2.136364	0.143708	3.32584
Error	7.333333	10	0.733333			
Total	20.5	17				

Table-4. Seasonal air temperature- average of three-year period

Air temperature ($^{\circ}\text{C}$)	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre monsoon	27.3	28.3	28.3	28	28	26.7
Southwest monsoon	25	27.3	26	26.6	27.6	25.6
Northeast monsoon	24.3	25	24.6	26.3	25.6	25
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	20.843333	2	10.42167	32.2652	4.35E-05	4.102816
Columns	6.4316667	5	1.286333	3.98246	0.030062	3.325837
Error	3.23	10	0.323			
Total	30.505	17				

4.2.2. Precipitation in the Periyar watersheds

All the details of the precipitation of the Lake area are given in **Table-5**. During the three-year study, a visible increase in precipitation in the Lake area was noted (average of precipitation measured at two different climate-stations situated in the Lake area) from 2002 to 2005. In the year 2002 the annual precipitation was 1275mm, which increased to 1450 mm in 2003 and 1853 mm in the year 2004. Season wise analysis of precipitation showed that the watershed of the Lake received most of the rain in the southwest monsoon. However, there occurred more rain during the northeast monsoon than in the southwest monsoon in 2003. There was a higher fluctuation in the rainfall during the southwest monsoon than during the northeast monsoon over the years. The highest monthly fall was recorded in June 2004 (511mm) during the three-year study. The highest and the lowest rain fall season recorded during this study were southwest monsoon and pre-monsoon 2004 respectively. In all the three-years of investigations, the highest number of days of rainfall was recorded during the southwest monsoon. The month of the lowest rainfall in the pre-monsoon season for all the three years was January and the month of the lowest fall in the northeast monsoon was always December. In the southwest monsoon, the month of the lowest fall was most often May. However in the southwest monsoon period of 2004, it was July, which recorded the lowest rainfall.

Table: 5. Seasonal details of precipitation in the Lake Area (pre-monsoon 2002 to pm-2005) PM-pre monsoon, SWM-southwest monsoon, and NEM-northeast monsoon

Year & Season	Total rainfall of the season (mm)	No. of days of rainfall	Average daily rainfall (mm)	Highest daily rainfall (mm)	Lowest daily rainfall (mm)	Month of the highest rainfall	Highest monthly rainfall (mm)	Lowest monthly rainfall (mm)	Month of the lowest rainfall	Total annual rainfall (mm)
PM SWM NEM 2002	158 695 422	13 74 43	1.3 5.6 3.5	60 79 52	0 0 0	Mar Aug Oct	99 263 249	0 134 41	Jan May Dec	1275
PM SWM NEM 2003	193 609 648	20 68 46	1.6 5.0 5.3	50 51 104	0 0 0	Apr Jul Oct	144 203 488	1 41 14	Jan May Dec	1450
PM SWM NEM 2004	126 1190 537	14 89 57	1.0 5.0 9.7	53 94 63	0 0 0	Apr Jun Oct	102 511 269	2 145 1	Jan Jul Dec	1853

4.2.3. Hydrology of the Periyar Lake

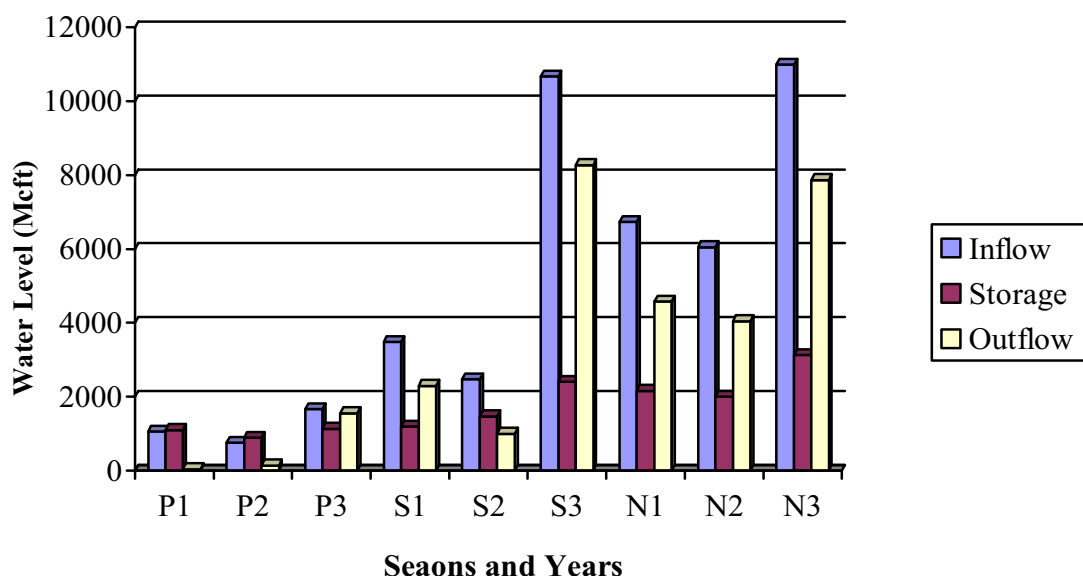
The fluctuations in water quantity related parameters examined included average seasonal and total annual precipitation, seasonal water level of the Lake, total seasonal storage in million cubic feet (mcft), and seasonal as well as annual inflow and outflow in mcft, which are given in **Table-6**. It is clear from **chart-1** that the inflow as well as outflow is proportional to each other in different seasons of all the three years of study. The average seasonal water level of the Lake during the entire three year period was more or less steady. The highest average storage noticed in the Lake during the study period was 3124 mcft during the northeast monsoon of 2004 and the lowest storage noticed was 888 mcft during the pre-monsoon of 2004.

Comparison of annual precipitation and inflow showed that they were not always proportional. The precipitation in 2002 was 1275 mm whereas it was 1450 mm in 2003. But the inflow in these years was recorded as 10224mcft and 9585mcft respectively. This fact clearly shows that the rainfall-data collected at the two climate stations (presently situated in the PTR) are different from the actual average precipitation in the entire watershed of the Lake.

Table: 6- Year wise and season wise comparison of hydrology of the Lake

Hydrology of the Lake (mcft)						
season	year	Precipitation (mm)	Storage (mcft)	Inflow (mcft)	Outflow (mcft)	Waterlevel (ft)
PM	P1	193	1101	1060	40	111
	P2	126	888	751	137	110
	P3	237	1130	1662	1552	111
SWM	S1	695	1195	3487	2292	112
	S2	610	1473	2474	1001	113
	S3	1190	2404	10677	8273	118
NEM	N1	422	2157	6737	4580	117
	N2	647	2000	6051	4050	115
	N3	537	3124	10997	7872	122

Chart: 1. Hydrology of the Lake during different seasons



4.3. General physico-chemical water quality parameters

Temperature, transparency, electric conductivity, total solids (TS), total dissolved solids (TDS), salinity, hardness, pH, total alkalinity, total nitrogen, nitrate nitrogen, dissolved CO₂ and DO, total Cl, Ca, Mg, Na, K, total phosphorus (P), silica were the general physico-chemical parameters studied.

4.3.1. Water Temperature (°C) - surface and bottom waters

The average seasonal surface-water temperatures for three different seasons are given separately in **Tables 7 to 9**. Three-year average water temperature for different seasons are given in **Table-10**. As in the measurement of air temperature, the measurement of water temperature of different stations were also not done at the same time. But both the air temperature and water temperature of a station was measured at the same time. However, the variation in the surface water temperature noticed between different stations in a particular season of a particular year was usually 1-2 °C and the variation noticed between years was also just 1-2 °C in a season at all the stations. Temperature varied from 2 to 5 °C at all the stations between different seasons. In general, the maximum annual variation in average seasonal surface water temperature at the *Periyar* Lake during the three-year period of observations was from just 24 °C once in station-3 in the northeast monsoon to 29 °C once in station-4B in the pre-monsoon.

The average seasonal bottom water temperatures for three different seasons are given separately in **Tables 11 to13**. The three-year average temperature of bottom water of different seasons is given in **Table-14**. The depth from which the bottom water sample collected was not uniform at all stations. Between seasons the depth varied from 1-3 meters at stations 1 and 4B, 2-6 meters at station 5; it varied from 6-10 m at station-2 but it was almost uniformly 10 meters at station-3 and 4A. The average seasonal bottom water temperature variation was just 1-2 °C in all seasons in stations 1 and 5; the variation was 1-3 °C at all seasons in station 2 and 3; the variation was 1-4 °C at stations 4A and 4B. The lowest seasonal average temperature noticed during the study period was 22 °C in stations 3, during south west monsoon, station 3 and 4A during north east and southwest monsoon period; and the highest bottom water temperature noticed during the study period was 27 °C, at pre-monsoon period in station 4B.

Table: 7- Average surface water temperature – pre-monsoon

Water temp- S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon 1	26	27	27	27	28	26
Pre-monsoon 2	28	28	27	28	27	26
Pre-monsoon 3	27	28	28	26	29	27
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	1.44444	2	0.72222	1.101695	0.369486	4.10282
Columns	5.11111	5	1.02222	1.559322	0.256857	3.32584
Error	6.55556	10	0.65556			
Total	13.1111	17				

Table: 8- Average surface water temperature – southwest monsoon

Water temp- S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	26	27	25	27	25	25
Southwest monsoon-2	27	26	26	28	26	26
Southwest monsoon-3	25	25	25	26	25	24
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	6.777777778	2	3.388889	13.26087	0.001539	4.102816
Columns	7.777777778	5	1.555556	6.086957	0.007683	3.325837
Error	2.555555556	10	0.255556			
Total	17.11111111	17				

Table: 9- Average surface water temperature – northeast monsoon

Water temp- S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	25	26	24	26	24	26
Northeast monsoon-2	25	25	25	25	27	25
Northeast monsoon-3	25	28	24	25	24	25
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.111111111	2	0.055556	0.044248	0.956903	4.102816
Columns	6.444444444	5	1.288889	1.026549	0.452139	3.325837
Error	12.55555556	10	1.255556			
Total	19.11111111	17				

Table: 10- Three-year average surface water temperature

Water temp- S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	27	27.6	27.3	27	28	26.3
Southwest monsoon	26	26	25.3	27	25.3	25
Northeast monsoon	25	26.3	24.3	25.3	25	25.3
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	12.75111111	2	6.375556	17.34583	0.000561	4.102816
Columns	2.797777778	5	0.559556	1.52237	0.26696	3.325837
Error	3.675555556	10	0.367556			
Total	19.22444444	17				

Table: 11 – Bottom water temperature – pre-monsoon

Water temp- B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon-1	25	26	24	25	25	26
Pre-monsoon-2	26	26	24	24	26	25
Pre-monsoon-3	26	26	24	24	27	25
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.111111111	2	0.055556	0.142857	0.868616	4.102816
Columns	11.11111111	5	2.222222	5.714286	0.009545	3.325837
Error	3.888888889	10	0.388889			
Total	15.11111111	17				

Table: 12 – Bottom water temperature – southwest monsoon

Water temp- B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	25	26	24	26	24	24
Southwest monsoon-2	26	25	25	25	26	26
Southwest monsoon-3	25	24	22	24	25	24
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	6.777777778	2	3.388889	4.692308	0.036535	4.102816
Columns	5.111111111	5	1.022222	1.415385	0.298734	3.325837
Error	7.222222222	10	0.722222			
Total	19.11111111	17				

Table: 13 – Bottom water temperature – northeast monsoon

Water temp- B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	24	25	23	25	24	25
Northeast monsoon-2	25	23	24	24	25	25
Northeast monsoon-3	24	24	22	22	23	24
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	5.444444444	2	2.722222	4.152542	0.048657	4.102816
Columns	4.944444444	5	0.988889	1.508475	0.270871	3.325837
Error	6.555555556	10	0.655556			
Total	16.94444444	17				

Table: 14 – Average bottom water temperature over three-years

Water temp- B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre monsoon	25.6	26	24	24.3	26	25.3
Southwest monsoon	25.3	25	23.7	25	25	24.7
Northeast monsoon	24.3	24	23	23.7	24	24.7
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	4.861111111	2	2.430556	14.47717	0.001115	4.102816
Columns	5.264444444	5	1.052889	6.271343	0.006923	3.325837
Error	1.678888889	10	0.167889			
Total	11.80444444	17				

4.3.2. Water Transparency (Secchi depth - Meters)

Water transparency is an important measure of light penetration, which is crucial to the hydrobiology of all aquatic systems. The different seasonal values of secchi depth at different stations during the three-year period of observations are separately given in **Tables-15-18**. In general, the lowest secchi depth was found during the pre-monsoon in all stations and the highest during the northeast monsoon. Among different stations highest secchi depth was noticed at station-3 and the lowest was noticed at the station-5. Moderate secchi depth was noticed at the other stations. The highest secchi depth noticed during the study period was 2.2 m at station-3 during the northeast monsoon of 2004 and the lowest measure was 0.85m at station-5 during the pre-monsoon, 2003.

Table: 15- Secchi depth or Transparency –pre-monsoon

Secchi depth (m)	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon -1	1	1.7	1.6	1.2	1.2	0.7
Pre-monsoon -2	1	1.2	2.1	1.6	1	0.8
Pre-monsoon -3	1	1.2	2.4	1.7	1.3	0.9
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.107777778	2	0.053889	0.909944	0.433444	4.102816
Columns	2.817777778	5	0.563556	9.515947	0.001466	3.325837
Error	0.592222222	10	0.059222			
Total	3.517777778	17				

Table: 16- Secchi depth or Transparency –southwest monsoon

Secchi depth	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	1	1.5	1.6	1.4	1.4	1
Southwest monsoon-2	1.1	1.5	1.7	1.5	1.7	1.3
Southwest monsoon-3	1.4	1.5	1.7	1.7	1.3	1.3
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.101111111	2	0.050556	2.724551	0.113628	4.102816
Columns	0.584444444	5	0.116889	6.299401	0.006815	3.325837
Error	0.185555556	10	0.018556			
Total	0.871111111	17				

Table: 17- Secchi depth or Transparency –northeast monsoon

Secchi depth	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	1.2	1.6	1.9	1.7	1.6	1.2
Northeast monsoon-2	1.2	1.6	2.2	1.6	1.6	1.2
Northeast monsoon-3	1.5	1.9	2.5	1.9	1.4	1.2
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.137778	2	0.0689	2.924528	0.09996	4.102816
Columns	1.924444	5	0.3849	16.33962	0.00016	3.325837
Error	0.235556	10	0.0236			
Total	2.297778	17				

Table: 18-Three- year average secchi depth

Secchi depth (m)	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	1	1.4	2	1.5	1.2	0.85
Southwest monsoon	1.2	1.5	1.7	1.5	1.5	1.2
Northeast monsoon	1.3	1.7	2.2	1.7	1.5	1.2
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.230277778	2	0.115139	7.28471	0.011169	4.102816
Columns	1.514027778	5	0.302806	19.15817	7.83E-05	3.325837
Error	0.158055556	10	0.015806			
Total	1.902361111	17				

4.3.3. pH variations in the surface and bottom waters

The pH of surface water in *Periyar* Lake in general showed a neutral or slightly alkaline tendency during all the seasons (**Table-19 to 21**). The three-year average pH of surface waters during different seasons is given in **Table-22**. The maximum pH noticed in the study period was 8.2 at station-3 during the pre-monsoon-1 and the minimum pH noticed was 6.5 at station 2 during pre-monsoon-3. The pH of bottom waters in all the different seasons is given in **Tables 23 to 25**. Three-year average pH of bottom water during different seasons is given in **Table-26**. The maximum pH noticed was 7.9 (at most stations during the pre-monsoon-1 and southwest monsoon-2 and the northeast monsoon-3) and the minimum pH noticed was 6.9 (only once during the study period, at station 4B during southwest monsoon of 2004).

Table: 19- pH of surface water during pre-monsoon

P H - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon - 1	7.8	8	8.2	8	7.7	7.9
Pre-monsoon - 2	7.4	7.4	7.7	7.7	7.6	7.6
Pre-monsoon - 3	7.2	6.5	6.7	6.9	7.1	7.5
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	2.754444	2	1.377222	20.28642	0.000302	4.102816
Columns	0.216111	5	0.043222	0.636661	0.677249	3.325837
Error	0.678889	10	0.067889			
Total	3.649444	17				

Table: 20- pH of surface water during southwest monsoon

P H - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	7.7	7.8	7.9	7.6	7.3	7.8
Southwest monsoon-2	7.8	7.7	7.7	7.7	7.7	7.5
Southwest monsoon-3	7.5	7.3	7.3	7.4	7.3	7.3
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.444444	2	0.222222	10.6383	0.003341	4.102816
Columns	0.102778	5	0.020556	0.984043	0.473089	3.325837
Error	0.208889	10	0.020889			
Total	0.756111	17				

Table: 21- pH of surface water during northeast monsoon

P H - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	7.8	7.7	7.8	7.7	7.5	7.8
Northeast monsoon-2	7.9	7.7	7.7	7.7	7.6	7.9
Northeast monsoon-3	8	7.7	7.5	7.5	7.7	7.7
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.01333	2	0.006667	0.555556	0.59049	4.102816
Columns	0.19167	5	0.038333	3.194444	0.055685	3.325837
Error	0.12	10	0.012			
Total	0.325	17				

Table: 22- Three-year average pH of surface water

P H - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	7.5	7.3	7.5	7.5	7.5	7.7
S.West monsoon	7.7	7.6	7.6	7.6	7.4	7.5
Northeast monsoon	7.9	7.7	7.7	7.6	7.6	7.8
ANOVA						

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.1478	2	0.073889	6.584158	0.014981	4.102816
Columns	0.0894	5	0.017889	1.594059	0.247742	3.325837
Error	0.1122	10	0.011222			
Total	0.3494	17				

Table: 23- pH of bottom water during pre-monsoon

P H - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	7.9	7.9	7.9	7.5	7.7	7.9
Pre-monsoon- 2	7.1	7.6	7.2	7.6	7.6	7.6
Pre-monsoon- 3	7.2	6.7	7	7	7.1	7.5
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	1.541111	2	0.770556	13.62475	0.001394	4.102816
Columns	0.197778	5	0.039556	0.699411	0.636355	3.325837
Error	0.565556	10	0.056556			
Total	2.304444	17				

Table: 24- pH of bottom water during southwest monsoon

P H - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	7.9	7.8	7.9	7.4	7.3	7.9
Southwest monsoon-2	7.8	7.6	7.6	7.6	7.7	7.8
Southwest monsoon-3	7.4	7.1	7	7.2	6.9	7.4
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	1.10333	2	0.55167	21.494	0.00024	4.10282
Columns	0.385	5	0.077	3	0.0656	3.32584
Error	0.2567	10	0.0257			
Total	1.745	17				

Table: 25- pH of bottom water during northeast monsoon

P H - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	7.8	7.4	7.7	7.5	7.5	7.7
Northeast monsoon-2	7.9	7.5	7.6	7.6	7.9	7.9
Northeast monsoon-3	7.8	7.5	7.5	7.7	7.7	7.5
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.06333	2	0.03167	2.111111	0.171855	4.10282
Columns	0.23167	5	0.04633	3.088889	0.060809	3.32584
Error	0.15	10	0.015			
Total	0.445	17				

Table: 26- Three-year average pH of bottom water during different seasons

P H - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	7.4	7.4	7.4	7.4	7.4	7.7
Southwest monsoon	7.7	7.5	7.5	7.4	7.3	7.7
Northeast monsoon	7.8	7.5	7.6	7.6	7.7	7.7
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.124444	2	0.062222	6.086957	0.018655	4.102816
Columns	0.156111	5	0.031222	3.054348	0.062604	3.325837
Error	0.102222	10	0.010222			
Total	0.382778	17				

4.3.4. Electric Conductivity (EC) of surface and bottom waters (μS)

EC is an important physical quality parameter, which explains the ionic status of all waters and its measurement during the study period is given in **Tables-27 to 29**. A comparison of the three year EC of surface water is given in **Table-30**. EC value at station-5 was much higher (almost double or more) than the other stations during all seasons throughout the study period. Station-2 showed the second highest EC during all seasons whereas station-4B in general showed the lowest EC values during most of the seasons during the entire period of study. The highest average seasonal EC reported during this study was 80 μS at station-5 during the pre-monsoon-2, and the lowest EC reported was just 15.2 at station-4B during the northeast monsoon-3. The difference in EC over seasons was very significant whereas that across different stations was insignificant. Seasonal average EC of bottom water at different stations during the study period are given in **Tables-31 to 33** and a comparison of the three-year average of different seasons is given in **Table-34**. As in the case of surface water, the bottom water also showed a wide fluctuation in EC between seasons as well as between the different years in a particular season. The highest average seasonal conductivity of bottom water reported during this study was 86.7 μS at station 5 during the southwest monsoon of 2004 and the lowest conductivity reported was just 15.6 μS at station-4B during the northeast monsoon 2004. Water at station-5 showed the highest EC values as in the case of surface water. All the other five stations showed more or less the same values.

Table: 27- Electric conductivity of surface water – pre-monsoon

Conductivity - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon-1	17.3	17.8	17	17.6	15.5	79.1
Pre-monsoon-2	40	32.3	23.2	31.8	23	80
Pre-monsoon-3	30.7	31.5	40	40.5	26.7	29.8
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	363.4011111	2	181.7006	0.791395	0.479661	4.102816
Columns	3361.484444	5	672.2969	2.928183	0.069715	3.325837
Error	2295.952222	10	229.5952			
Total	6020.837778	17				

Table: 28- Electric conductivity of surface water – southwest monsoon

Conductivity - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	19	24	21	16	18	70
Southwest monsoon-2	20.2	26.6	25.6	17.9	16.6	69.7
Southwest monsoon-3	29.3	34.3	23.7	20.6	23.7	43
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	6.751111111	2	3.375556	0.052383	0.949224	4.102816
Columns	3887.557778	5	777.5116	12.06575	0.000564	3.325837
Error	644.3955556	10	64.43956			
Total	4538.704444	17				

Table: 29- Electric conductivity of surface water – northeast monsoon

Conductivity - μ S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	24	33	22	19	22	63
Northeast monsoon-2	35.7	35.7	26.4	20.9	28.3	57.2
Northeast monsoon-3	28.2	26.1	24	25.6	15.2	38.3
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	183.0577778	2	91.52889	2.355902	0.145101	4.102816
Columns	2075.477778	5	415.0956	10.68433	0.000926	3.325837
Error	388.5088889	10	38.85089			
Total	2647.044444	17				

Table: 30- Three-year average EC of surface water of different seasons

EC- μ S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	29.3	27.2	26.7	30	21.7	63
SWM	22.8	28.3	23.4	18.2	19.4	60.9
NEM	29.3	31.6	24.1	21.8	21.8	52.8
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit

Rows	53.49	2	26.745	2.121553	0.170599	4.102816
Columns	2986.031667	5	597.2063	47.37352	1.22E-06	3.325837
Error	126.0633333	10	12.60633			
Total	3165.585	17				

Table: 31- Electric conductivity of bottom water –pre-monsoon

Conductivity – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon-1	17.7	17.1	18.1	18.5	17.9	51.3
Pre-monsoon- 2	40	32.3	36.7	26.4	23	80.2
Pre-monsoon- 3	30.7	30.7	34.5	26.7	26.7	29.8
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	812.5833333	2	406.2917	3.545457	0.068576	4.102816
Columns	1989.751667	5	397.9503	3.472668	0.044438	3.325837
Error	1145.95	10	114.595			
Total	3948.285	17				

Table: 32- Electric conductivity of bottom water – southwest monsoon

Conductivity – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	22	27	22	20	20	55
Southwest monsoon-2	25.8	29.5	25.9	26.8	22.9	50.8
Southwest monsoon-3	37.1	19.7	31.5	22.3	23.7	86.7
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	267.5544444	2	133.7772	1.771308	0.219527	4.102816
Columns	3894.049444	5	778.8099	10.31201	0.001067	3.325837
Error	755.2455556	10	75.52456			
Total	4916.849444	17				

Table: 33- Electric conductivity of bottom water – northeast monsoon

Conductivity – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	23	33	32	21	25	45
Northeast monsoon-2	30.9	34.4	34.3	29.5	27	25.1
Northeast monsoon-3	32.8	21.4	30	17.3	15.6	28.5
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	132.6533333	2	66.32667	1.612062	0.247267	4.102816
Columns	308.5466667	5	61.70933	1.499838	0.273333	3.325837
Error	411.44	10	41.144			
Total	852.64	17				

Table: 34- Three-year average of EC of bottom water

Conductivity – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	29.5	26.7	29.8	23.9	22.5	53.8
Southwest monsoon	28.3	25.4	26.5	23	22.2	64.2
Northeast monsoon	28.9	29.6	32.1	22.6	22.5	32.9
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	42.35111111	2	21.17556	0.429848	0.662082	4.102816
Columns	1576.004444	5	315.2009	6.398344	0.006452	3.325837
Error	492.6288889	10	49.26289			
Total	2110.984444	17				

4.3.5. Salinity of surface and bottom waters (ppm)

Salinity is a quantitative measure of the dissolved mineral ions in waters. The average seasonal salinity of both the surface waters of *Periyar* Lake is given in **Table- 35 to 37**, and a comparison of the three-year average of salinity of surface waters during different seasons are given in **Table-38**. The lowest recorded average seasonal salinity of surface waters during the period of this investigation was 11.4 ppm at station-4B during northeast monsoon of 2003 and the highest recorded salinity was 24ppm at station-5 during the southwest monsoon in 2002. In general, the surface water at station-5 showed a higher salinity range (16-24 ppm) and the lowest salinity range noticed was 11-17 ppm at station 4B. The 2nd highest salinity of surface water was observed at station-2. There were no significant differences in salinity between the surface and bottom waters at all stations. Salinity of bottom water of different seasons during three different years of investigations is given in **Tables 39-41**. **Table-42** gives a comparison of the average salinity of bottom-water for the three- year period of investigation.

Table: 35- Salinity of surface water during pre-monsoon

Salinity – S	PLS-1	PLS-2	PLS-3	PLS-4A	PLS-4B	PLS-5
Pre-monsoon-1	11.9	13.3	13	13.5	14.6	16
Pre-monsoon-2	17.9	14.7	18.1	19.5	16.8	15.4
Pre-monsoon-3	19	12	15	18	17	22
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	46.27	2	23.135	4.675942	0.036845	4.10282
Columns	35.5183	5	7.103667	1.435761	0.29238	3.32584
Error	49.4766	10	4.947667			
Total	131.265	17				

Table: 36- Salinity of surface water during southwest monsoon

Salinity – S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	13	12	12	12	13	24
Southwest monsoon-2	15.1	13.7	13	13.1	12.3	22.6
Southwest monsoon-3	18.5	15.5	14.5	12.8	13.2	18.8
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	4.44333333	2	2.221667	0.620058	0.557373	4.102816
Columns	185.311667	5	37.06233	10.34394	0.001054	3.325837
Error	35.83	10	3.583			
Total	225.585	17				

Table: 37- Salinity of surface water during northeast monsoon

Salinity – S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	14	12	11.5	11.5	12	18
Northeast monsoon-2	16.5	13.3	13.4	12.2	11.4	16.2
Northeast monsoon-3	19.1	12.6	14.9	13.9	11.9	17.3
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	9.74333333	2	4.871667	3.287964	0.079912	4.102816
Columns	77.965	5	15.593	10.52396	0.000984	3.325837
Error	14.8166667	10	1.481667			
Total	102.525	17				

Table: 38-Three-year average salinity of surface water during different seasons

Salinity – S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	16.3	13.3	15.4	17	16.1	17.8
Southwest monsoon	15.5	13.7	13.2	12.6	12.8	21.8
Northeast monsoon	16.5	12.6	13.3	12.5	11.8	17.2
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	12.01	2	6.005	2.137264	0.16873	4.102816
Columns	71.913333	5	14.3827	5.118994	0.013774	3.32584
Error	28.096667	10	2.80967			
Total	112.02	17				

Table: 39- Salinity of bottom water during pre- monsoon

Salinity – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon-1	13.7	12.8	13.8	13.4	13.4	23.3
Pre-monsoon-2	17.9	18.6	21	16.8	16.8	15.4
Pre-monsoon-3	19.3	19.1	13.3	17	17	22
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	31.1077778	2	15.55389	1.558627	0.257505	4.102816
Columns	43.7711111	5	8.754222	0.877245	0.529707	3.325837

Error	99.7922222	10	9.979222			
Total	174.671111	17				

Table: 40- Salinity of bottom water during southwest monsoon

Salinity – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	13.5	11.5	12.5	14	14	22
Southwest monsoon-2	14.2	12.4	13.5	16.6	16.6	30.3
Southwest monsoon-3	17.5	13.5	14.8	13.2	13.2	15.8
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	27.9344444	2	13.96722	1.338384	0.305462	4.102816
Columns	199.376111	5	39.87522	3.82097	0.033922	3.325837
Error	104.358889	10	10.43589			
Total	331.669444	17				

Table: 41- Salinity of bottom water during northeast monsoon

Salinity – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	14	13	12	13	13	14
Northeast monsoon-2	13.9	16.7	13.5	12	12	13.8
Northeast monsoon-3	17	18	14.2	11.9	11.9	17.3
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	11.4811111	2	5.740556	2.881966	0.102725	4.102816
Columns	35.9044444	5	7.180889	3.605065	0.04004	3.325837
Error	19.9188889	10	1.991889			
Total	67.3044444	17				

Table: 42- Three year average salinity of bottom water during different seasons

Salinity – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	17	16.9	16	15.7	15.7	20.2
Southwest monsoon	15	12.5	13.6	14.6	14.6	22.7
Northeast monsoon	15	15.9	13.2	12.3	12.3	15
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	26.4211111	2	13.21056	3.843381	0.057777	4.102816
Columns	58.5511111	5	11.71022	3.406885	0.046834	3.325837
Error	34.3722222	10	3.437222			
Total	119.344444	17				

4.3.6. Total Solids (TS) - surface water (mgL⁻¹)

TS were found out for the surface waters only. TS of surface waters of the three different seasons are given in **Tables 43 to 45** and a comparison of the three-year average of TS of different seasons are available in **Table-46**. In general the highest TS content was

observed at station-5 followed by station-1 during the entire period of study. The TS of surface water varied from 110 mgL⁻¹ (at station-4B during northeast monsoon of 2004) to 530 mgL⁻¹(at station-5 during southwest monsoon of 2002).

Table: 43- Total Solids of surface water during pre-monsoon

Total solid-S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon-1	400	200	300	300	200	420
Pre-monsoon-2	310	230	260	240	150	340
Pre-monsoon-3	220	130	160	90	120	180
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	73744.44444	2	36872.22222	25.15921	0.000125	4.102816
Columns	62627.77778	5	12525.55556	8.546626	0.002223	3.325837
Error	14655.55556	10	1465.555556			
Total	151027.7778	17				

Table: 44- Total Solids of surface water during southwest monsoon

Total solid-S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	420	220	320	250	190	530
Southwest monsoon-2	230	190	200	220	190	340
Southwest monsoon-3	240	210	240	200	130	230
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	43911.111	2	21955.55556	5.995146	0.019447	4.102816
Columns	74227.777	5	14845.55556	4.053701	0.028527	3.325837
Error	36622.222	10	3662.222222			
Total	154761.11	17				

Table: 45- Total Solids of surface water during northeast monsoon

Total solid-S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	230	130	230	230	130	330
Northeast monsoon-2	230	150	160	180	130	250
Northeast monsoon-3	180	120	180	140	110	180
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	11411.11111	2	5705.555556	6.39477	0.016268	4.102816
Columns	35827.77778	5	7165.555556	8.031133	0.002815	3.325837
Error	8922.222222	10	892.2222222			
Total	56161.11111	17				

Table: 46- Three-year average of TS of surface water during different seasons

Total solid-S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	310	186.7	240	210	156.7	313.3
Southwest monsoon	296.7	206.7	253.3	223.3	170	355.7

Northeast monsoon	213.3	133.3	190	183.3	123.3	253.3
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	15438.53778	2	7719.268889	31.5619	4.78E-05	4.102816
Columns	52706.14278	5	10541.22856	43.10009	1.9E-06	3.325837
Error	2445.755556	10	244.5755556			
Total	70590.43611	17				

4.3.7. Total Dissolved Solids (TDS) - surface and bottom waters (mgL⁻¹)

Details of TDS of surface waters at different stations during different seasons are given in **Table-47 to 49** and a comparison of the three-year average of total dissolved solids of surface-water of different seasons are available in **Table-50**. TDS of bottom-water at different stations during different seasons are given in **Tables-51 to 53** and a comparison of the three-year average of TDS of bottom-water of different seasons is available in **Table-54**. The TDS at station-5 was found high during all the seasons in surface as well as bottom-water. And the second highest TDS of surface-water observed was at station-1.

Table: 47- T D S of surface water during pre-monsoon

T D S – S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon-1	25.5	20.5	20	22.5	21.5	35.5
Pre-monsoon-2	25	19	23.2	23.8	20.7	34.9
Pre-monsoon-3	28.2	26.5	22	21.5	20.3	29.8
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.663333	2	0.331666667	0.051012561	0.950512	4.102816
Columns	339.5	5	67.9	10.44347603	0.001014	3.325837
Error	65.01667	10	6.501666667			
Total	405.18	17				

Table: 48- TDS of surface water during southwest monsoon

T D S - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	21.1	21.1	21.6	22.4	21.7	34.2
Southwest monsoon-2	22.2	20.1	20.6	20.4	20.7	44.2
Southwest monsoon-3	26.3	24.3	23.7	22.6	23.8	37.3
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	21.44778	2	10.72388889	1.563730335	0.256505	4.102816
Columns	675.9428	5	135.1885556	19.712853	6.9E-05	3.325837
Error	68.57889	10	6.857888889			
Total	765.9694	17				

Table: 49- TDS of surface water during northeast monsoon

T D S – S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	20	22.3	21.5	20.8	22.9	32.7
Northeast monsoon-2	22	23.3	19.8	21.8	20.9	36.7
Northeast monsoon-3	25	20.5	23	22.5	24.4	35.5
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	9.663333	2	4.831666667	1.712749616	0.22927	4.102816
Columns	420.4667	5	84.09333333	29.80976013	1.06E-05	3.325837
Error	28.21	10	2.821			
Total	458.34	17				

Table: 50- Three-year average TDS of surface water

T D S – S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	26.2	22	21.7	22.6	20.8	33.4
Southwest monsoon	23.2	21.8	22	21.8	22.1	38.6
Northeast monsoon	22.3	22	21.4	21.7	22.7	35
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	1.653333	2	0.826666667	0.352472996	0.711341	4.102816
Columns	457.4983	5	91.49966667	39.01350199	3.04E-06	3.325837
Error	23.45333	10	2.345333333			
Total	482.605	17				

Table: 51- Total Dissolved Solids of bottom water during pre-monsoon

T D S – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon-1	20.5	19.5	19	18.5	22	35.1
Pre-monsoon-2	20	22.3	22.7	25.2	24.7	34.9
Pre-monsoon-3	28.2	22.7	21.5	22.7	22.3	29.8
Station 5	3	99.8	33.26666667	9.023333333		
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	22.03111	2	11.01555556	1.398110281	0.291468	4.102816
Columns	319.2511	5	63.85022222	8.10396277	0.002721	3.325837
Error	78.78889	10	7.878888889			
Total	420.0711	17				

Table: 52- Total Dissolved Solids of bottom water during southwest monsoon

T D S – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	18.5	19.3	21.5	23.2	23.6	33.9
Southwest monsoon-2	19.5	18.3	21.5	22.2	25.6	36.9
Southwest monsoon-3	27.5	19.7	21.5	22.3	23.8	37
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	12.0044	2	6.00222222	1.27864041	0.32027	4.102816

Columns	537.771	5	107.554222	22.9120432	3.53E-05	3.325837
Error	46.9422	10	4.69422222			
Total	596.718	17				

Table: 53- Total Dissolved Solids of bottom water during northeast monsoon

T D S – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	22.5	18.8	20.4	22.2	21.1	32.2
Northeast monsoon-2	25.5	28.8	21.2	23.2	21	47.2
Northeast monsoon-3	22.9	21.4	22.4	27	22.4	35.5
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	73.53	2	36.765	2.919015482	0.100345	4.102816
Columns	625.805	5	125.161	9.937356094	0.001236	3.325837
Error	125.95	10	12.595			
Total	825.285	17				

Table: 54- Three-year average TDS of bottom water

T D S – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	22.9	21.5	21.1	22.1	23.0	33.3
Southwest monsoon	21.8	19.1	21.5	22.6	24.3	35.9
Northeast monsoon	23.6	23	21.3	24.1	21.5	38.3
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	5.981111	2	2.990555556	1.354077577	0.301708	4.102816
Columns	472.4628	5	94.49255556	42.78477637	1.97E-06	3.325837
Error	22.08556	10	2.208555556			
Total	500.5294	17				

4.3. 8. Total Alkalinity of surface and bottom waters (mgL⁻¹)

Details of total alkalinity of surface water at different stations in the Lake are given in **Tables 55 to 57** and that of bottom waters are given in **Tables-59 to 61**. Comparison of three-year average total alkalinity of surface water during different seasons is given in **Table-58** whereas that of bottom waters is given in **Table-62**. Total Alkalinity of bottom waters in general was slightly lesser than that of surface waters. The highest reported value in the bottom water was 23.8 mg L⁻¹ (at station-4A during pre-monsoon of 2004) and lowest recorded was 10 mg L⁻¹ (at station-5 during southwest monsoon of 2004). However in station-3, 4A and 4B the bottom alkalinity was found slightly higher than that of surface alkalinity during most of the seasons in the entire period of study.

Table: 55- Total Alkalinity of surface water during pre-monsoon

Total Alkalinity - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon 1	14.5	14.3	13.3	14.3	17.5	16.7
Pre-monsoon 2	16.3	15	16.3	16.3	21.3	20
Pre-monsoon 3	22.5	18	17.6	20	17.5	22.5
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	63.10111111	2	31.55056	9.601833	0.004708	4.102816
Columns	39.50277778	5	7.900556	2.404389	0.111425	3.325837
Error	32.85888889	10	3.285889			
Total	135.4627778	17				

Table: 56- Total Alkalinity of surface water during southwest monsoon

Total Alkalinity – S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	16	15	17	16	17	19
Southwest monsoon-2	17.5	16.3	17.5	16.3	17.8	18.8
Southwest monsoon-3	15	15	15.6	13.1	13.1	15
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	27.48	2	13.74	17.60034	0.00053	4.102816
Columns	11.95333333	5	2.390667	3.06234	0.062183	3.325837
Error	7.806666667	10	0.780667			
Total	47.24	17				

Table: 57- Total Alkalinity of surface water during northeast monsoon

Total Alkalinity – S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	15.5	16	16	14	15	16
Northeast monsoon-2	15	15	15	15	15	15
Northeast monsoon-3	16.3	16.3	16.3	16.3	13.8	21.7
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	10.44333333	2	5.221667	2.371688	0.143554	4.102816
Columns	15.2	5	3.04	1.380772	0.30987	3.325837
Error	22.01666667	10	2.201667			
Total	47.66	17				

Table: 58- Three-year average total Alkalinity of surface water

Total Alkalinity – S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	17.8	15.8	15.7	16.9	18.8	19.7
Southwest monsoon	16.2	15.4	16.7	15.1	16	17.6
Northeast monsoon	15.6	15.8	15.8	15.1	14.6	17.6
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>

Rows	9.421111	2	4.710556	5.79721	0.021296	4.102816
Columns	14.25777	5	2.851556	3.509367	0.043164	3.325837
Error	8.125555	10	0.812556			
Total	31.80444	17				

Table: 59- Total Alkalinity of bottom water during pre-monsoon

Total Alkalinity - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon1	12.5	15.3	21.7	15	17.5	18.3
Pre-monsoon2	15	16.3	21.3	23.8	20	20
Pre-monsoon3	22	20	15	20	17	22
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	28.10333333	2	14.05167	1.255847	0.326152	4.102816
Columns	30.79166667	5	6.158333	0.550392	0.735441	3.325837
Error	111.89	10	11.189			
Total	170.785	17				

Table: 60- Total Alkalinity of bottom water during southwest monsoon

Total Alkalinity- B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	16	16	17	16	17	18
Southwest monsoon-2	17.5	15.5	16.8	15.5	17.8	18.8
Southwest monsoon-3	13.3	16.3	15	12.5	15	10
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	39.78111111	2	19.89056	6.475024	0.015707	4.102816
Columns	6.711111111	5	1.342222	0.436937	0.813239	3.325837
Error	30.71888889	10	3.071889			
Total	77.21111111	17				

Table: 61- Total Alkalinity of bottom water during northeast monsoon

Total Alkalinity – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	15.5	16	17	14	15	16
Northeast monsoon-2	15	16.7	18.3	16.7	15	15
Northeast monsoon-3	16.3	16.3	16.3	16.9	14	20
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	3.307777778	2	1.653889	0.836471	0.461422	4.102816
Columns	13.29777778	5	2.659556	1.345097	0.321814	3.325837
Error	19.77222222	10	1.977222			
Total	36.37777778	17				

Table: 62- Three-year average total Alkalinity of bottom water

Total Alkalinity - B	Station 1	Station 2	Station 3	Station A	Station 4B	Station 5
Pre-monsoon	16.5	17.2	19.3	19.6	18.2	20.1
Southwest monsoon	15.6	15.2	16.2	14.6	16.6	15.6
Northeast monsoon	15.6	16.3	17.2	15.9	14.7	17

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	27.91444444	2	13.95722	14.17617	0.001205	4.102816
Columns	7.164444444	5	1.432889	1.455366	0.286404	3.325837
Error	9.845555556	10	0.984556			
Total	44.92444444	17				

4. 3. 9. Total Hardness of surface and bottom waters (mgL⁻¹)

Hardness is the property of water which prevents lather formation with soap and increases the boiling point of water. Principal cations imparting hardness are calcium and magnesium. However, other cations such as strontium, iron and manganese also contribute to hardness. The anions responsible for hardness are mainly bicarbonate, carbonate, sulphate, chloride, nitrate and silicates, etc. The details of the hardness of surface and bottom waters recorded during the period of study in this Lake are given in **Table-63 to 65** (surface-water) and **Table-67 to 69** (bottom-water). Comparison of the three-year average of total hardness of surface and bottom waters during different seasons is given in **Table 66** and **70** respectively. In general, the hardness recorded (both surface and bottom waters) in *Periyar* Lake varied from 5 to 12.5 mg L⁻¹ among the different seasons. The highest hardness recorded was 12.5 mg L⁻¹ at station 5 (both on the surface and in the bottom) in 2003 during pre-monsoon and the lowest hardness recorded was 5 mg L⁻¹ in the surface-water of stations-3 and 5 during northeast monsoon 2004. A gradual decrease in the hardness of both surface and bottom waters were visible in *Periyar* Lake from pre-monsoon to northeast monsoon at all stations.

Table: 63- Total Hardness of surface water during pre-monsoon

Total hard - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	10	10	10	10.7	10	12.5
Pre-monsoon- 2	9	9	9	9	10.5	9.5
Pre-monsoon- 3	7	6	5.3	8	7	7
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	45.707777	2	22.85389	38.43861	2.02E-05	4.10282
Columns	5.3294444	5	1.065889	1.792749	0.202032	3.32584
Error	5.9455556	10	0.594556			
Total	56.982778	17				

Table: 64- Total Hardness of surface water during southwest monsoon

Total hard – S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	7	8	8	8	7	9.5
Southwest monsoon-2	8	8	9.3	9.5	8.5	9
Southwest monsoon-3	7.5	7.5	7.5	7	6.5	9
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	4.587778	2	2.293889	6.939496	0.01288	4.103
Columns	6.511111	5	1.302222	3.939496	0.031036	3.337
Error	3.305556	10	0.330556			
Total	14.40444	17				

Table: 65- Total Hardness of surface water during northeast monsoon

Total hard – S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	7	6	7	7	6	8
Northeast monsoon-2	6	6	6	6	6	6.7
Northeast monsoon-3	6.5	6	5	6	5.5	5
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	4.15444	2	2.077222	5.605697	0.023289	4.103
Columns	1.3694444	5	0.273889	0.73913	0.611273	3.33
Error	3.7055556	10	0.370556			
Total	9.229444	17				

Table: 66- Three-year average Hardness of surface water

Total hard – S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	8.7	8.3	8.1	9.2	9.1	9.6
Southwest monsoon	7.5	7.8	8.3	8.2	7.3	9.2
Northeast monsoon	6.5	6	6	6.3	5.8	6.5
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	22.24111	2	11.12056	60.25587	2.64E-06	4.1028
Columns	2.551111	5	0.510222	2.7646	0.080394	3.3258
Error	1.845555	10	0.184556			
Total	26.63778	17				

Table: 67- Total Hardness of bottom water during pre-monsoon

Total hard – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	10	10	10	10.7	10	12.5
Pre-monsoon- 2	9	9.5	10.5	11	10.5	9.5
Pre-monsoon- 3	7	6	6	8	7	7
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	48.004444	2	24.00222	39.20508	1.85E-05	4.102816
Columns	4.7444444	5	0.948889	1.549909	0.25939	3.325837
Error	6.1222222	10	0.612222			
Total	58.871111	17				

Table: 68- Total Hardness of bottom water during southwest monsoon

Total hard – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	7	7	8	9	7	9
Southwest monsoon-2	8	8	9.3	9.5	8.5	9
Southwest monsoon-3	7.5	8	8	7	6.5	9
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	3.821111	2	1.9106	4.616107	0.038006	4.102816
Columns	6.636111	5	1.3272	3.206711	0.055123	3.325837
Error	4.138889	10	0.4139			
Total	14.59611	17				

Table: 69- Total Hardness of bottom water during northeast monsoon

Total hard – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
N.East monsoon-1	6	6	6	7	6	7.5
N.East monsoon-2	6	6	6	6	6	6.7
N.East monsoon-3	6.5	6.5	6	7	5.5	5
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.4044444	2	0.202222	0.502762	0.619364	4.102816
Columns	1.3027778	5	0.260556	0.64779	0.669893	3.325837
Error	4.0222222	10	0.402222			
Total	5.7294444	17				

Table: 70- Three-year average Hardness of bottom water

Total hard – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	8.7	8.5	8.8	9.9	9.2	9.7
Southwest monsoon	7.5	7.7	8.4	8.5	7.3	9
Northeast monsoon	6.2	6.2	6	6.7	5.8	6.4
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	26.13444444	2	13.06722	100.0894	2.44E-07	4.102816
Columns	3.009444444	5	0.601889	4.610213	0.01926	3.325837
Error	1.305555556	10	0.130556			
Total	30.44944444	17				

4. 3.10. Total dissolved Carbon dioxide (CO₂) - surface and bottom waters (mgL⁻¹)

During the period of study, the lowest seasonal average surface water content of dissolved CO₂ noticed in the Lake was 1.6 mgL⁻¹ in the southwest monsoon of 2004 at station-3 and the highest noticed was 3.4 mgL⁻¹ in the same season at station-5. **Tables 71 to 73** describe the CO₂ regime of surface waters of different seasons during the entire

period of study. Comparison of the three year average of CO₂ during different seasons is given in **Table-74**. Station-5 showed a comparatively higher CO₂ content than that at other stations during the entire period of study. During the southwest monsoon of 2004 there was a high fluctuation in the CO₂ content in the surface waters of different stations. In this season, the CO₂ content sharply increased at stations-5 and 1 whereas it sharply decreased at stations 4A, 4 B and 3. In the same season, it remained more or less steady at station 2. Another significant trend observed was a slight increase of CO₂ content in the surface-water at station 4 A during the northeast monsoon. In the other stations during the entire period of study the CO₂ content of surface waters did not show much fluctuation. Seasonal values of dissolved CO₂ content of bottom water are given in **Table-75 to 77**. **Table 78** explains the three-year average of CO₂ content of bottom water during different seasons.

Table: 71- Total dissolved CO₂ of surface water during pre monsoon

Dissolved CO ₂ -S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	2.6	2.3	2.3	2.2	2.1	2.5
Pre-monsoon- 2	2.5	2.5	2.5	2.5	2.5	2.4
Pre-monsoon- 3	2.3	2.3	2.4	2.5	2.1	2.6
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.074444444	2	0.037222	1.810811	0.213234	4.102816
Columns	0.129444444	5	0.025889	1.259459	0.352518	3.325837
Error	0.205555556	10	0.020556			
Total	0.409444444	17				

Table: 72- Total dissolved CO₂ of surface water during southwest monsoon

Dissolved CO ₂ -S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
S.west monsoon-1	2.2	2.1	2.2	2.3	2.1	2.5
S.west monsoon-2	2.3	2.3	2.3	2.3	2.3	2.5
S.west monsoon-3	2.8	2.1	1.6	1.8	1.9	3.4
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.0311	2	0.015556	0.121951	0.886488	4.102816
Columns	1.2644	5	0.252889	1.982578	0.167045	3.325837
Error	1.2755	10	0.127556			
Total	2.5711	17				

Table-73: Total dissolved CO₂ of surface water during northeast monsoon

Dissolved CO ₂ -S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	2.1	2.5	2.8	2.6	2.4	2.6
Northeast monsoon-2	2.4	2.7	2.9	2.7	2.7	2.7
Northeast monsoon-3	3.1	2.9	2.6	2.8	2.3	3.2
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.303333333	2	0.152	2.286432	0.152151	4.102816
Columns	0.293333333	5	0.059	0.884422	0.525723	3.325837
Error	0.663333333	10	0.066			
Total	1.26	17				

Table-74: Three year average total dissolved CO₂ of surface water

Dissolved CO ₂ -S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	2.5	2.4	2.4	2.4	2.2	2.5
Southwest monsoon	2.4	2.2	2	2.1	2.1	2.8
Northeast monsoon	2.5	2.7	2.8	2.7	2.5	2.8
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.4977778	2	0.248889	8.818898	0.006201	4.102816
Columns	0.3044444	5	0.060889	2.15748	0.140805	3.325837
Error	0.2822222	10	0.028222			
Total	1.0844444	17				

Table-75: Total dissolved CO₂ of bottom water during pre-monsoon

Dissolved CO ₂ - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon-1	1.3	2.4	2.3	1.6	1.3	1.9
Pre-monsoon- 2	1.2	1.1	1.1	1.1	1	1.6
Pre-monsoon- 3	1.4	1.5	1.9	1.7	1.5	1.8
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	1.221111111	2	0.610556	7.5171	0.01017	4.102816
Columns	0.769444444	5	0.153889	1.89466	0.182315	3.325837
Error	0.812222222	10	0.081222			
Total	2.802777778	17				

Table-76: Total dissolved CO₂ of bottom water during southwest monsoon

Dissolved CO ₂ - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	2.1	2.3	2.5	3.1	2.4	2.4
Southwest monsoon-2	2.3	2.5	2.5	2.6	2.5	2.5
Southwest monsoon-3	2.3	2.9	2.9	3	1.7	3.4
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.203333333	2	0.101667	0.817694	0.468916	4.1028

						16
Columns	1.198333333	5	0.239667	1.927614	0.176414	3.325837
Error	1.243333333	10	0.124333			
Total	2.645	17				

Table-77: Total dissolved CO₂ of bottom water during northeast monsoon

Dissolved CO ₂ - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	2.2	2.9	2.8	2.9	2.6	2.8
Northeast monsoon-2	2.4	3	3.1	3.4	2.7	2.7
Northeast monsoon-2	3.2	4	3.3	3.6	2.1	3.2
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.881111111	2	0.440556	3.823529	0.05843	4.1028
Columns	1.849444444	5	0.369889	3.210222	0.05496	3.3258
Error	1.152222222	10	0.115222			
Total	3.882777778	17				

Table-78: Three-year average total dissolved CO₂ of bottom water

Dissolved CO ₂ - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	1.3	1.7	1.8	1.5	1.3	1.8
Southwest monsoon	2.2	2.6	2.6	2.9	2.2	2.8
Northeast monsoon	2.6	3.3	3.1	3.3	2.5	2.9
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	6.081111111	2	3.040556	117.4464	1.14E-07	4.102816
Columns	1.044444444	5	0.208889	8.06867	0.002766	3.325837
Error	0.258888889	10	0.025889			
Total	7.384444444	17				

4. 3.11. Dissolved Oxygen (DO) - surface and bottom waters (mgL⁻¹)

The seasonal averages DO in the surface-water of all the stations are given in **Tables 79 to 81**. **Table 82** explains the three-year average DO of surface water during different seasons. During the pre-monsoon of 2004, there was a sharp reduction in the DO content at all stations. In general station-4B showed the maximum DO content in the surface waters whereas station-5 showed the lowest DO content. The amounts of DO in bottom waters during different seasons are given in **Tables 83 to 85**. Three-year average of DO in bottom-water during different seasons is given in **Table 86**. The bottom water at station-4B showed the highest amount of DO during the entire period of study followed by station-1 and 5, all

these stations were less than 3 meters deep, during the entire period of study. The DO content of bottom water at station 2, 3 and 4A, which were around 10 meters deep showed the lowest DO content over the entire period of study.

Table-79: Total DO of surface water during pre-monsoon

Dissolved O ₂ -S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	6.5	6.6	6.8	6.8	7.5	6.6
Pre-monsoon- 2	4.6	4.6	5.1	5.2	5.5	4.7
Pre-monsoon- 3	7.6	7.1	7.5	7.9	8.3	7.1
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	21.941111111	2	10.97056	413.1172	2.45E-10	4.102816
Columns	2.177777778	5	0.435556	16.40167	0.000154	3.325837
Error	0.265555556	10	0.026556			
Total	24.38444444	17				

Table-80: Total DO of surface water during southwest monsoon

Dissolved O ₂ -S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	6.8	6.6	6.7	7.7	7.8	6.9
Southwest monsoon-2	6.7	6.8	6.8	7.8	7.5	7
Southwest monsoon-3	6.5	7.2	7.3	8.2	8.1	6.2
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.101111111	2	0.050556	0.486631	0.628523	4.102816
Columns	4.644444444	5	0.928889	8.941176	0.001869	3.325837
Error	1.038888889	10	0.103889			
Total	5.784444444	17				

Table-81: Total DO of surface water during northeast monsoon

Dissolved O ₂ -S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	6.5	6.8	6.9	7.2	7.6	6.1
Northeast monsoon-2	6.1	6.7	7.1	7	7.6	5.9
Northeast monsoon-3	7.1	7.4	7.6	7.7	7.9	6.3
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	1.214444444	2	0.607222	25.4186	0.00012	4.102816
Columns	4.842777778	5	0.968556	40.54419	2.54E-06	3.325837
Error	0.238888889	10	0.023889			
Total	6.296111111	17				

Table-82: Three-year average total DO of surface water during different seasons

Dissolved O ₂ -S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	6.2	6.1	6.5	6.6	7.1	6.1
Southwest monsoon	6.7	6.9	6.9	7.9	7.8	6.7
Northeast monsoon	6.6	7	7.2	7.3	7.7	6.1
ANOVA						

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	1.6877777	2	0.84388	15.0994	0.000953	4.102816
Columns	3.2977777	5	0.65955	11.80119	0.000618	3.325837
Error	0.5588888	10	0.05588			
Total	5.5444444	17				

Table-83: Total DO of bottom water during pre-monsoon

Dissolved O ₂ - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon-1	6.4	6.2	5	5.1	6.7	5.9
Pre-monsoon-2	4.6	4.6	2.1	2	5.5	4.7
Pre-monsoon-3	7.2	6	3.8	3.1	7.8	6.2
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	14.05777778	2	7.028889	17.13434	0.000588	4.102816
Columns	26.72277778	5	5.344556	13.02844	0.000411	3.325837
Error	4.102222222	10	0.410222			
Total	44.88277778	17				

Table-84: Total DO of bottom water during southwest monsoon

Dissolved O ₂ - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	6.5	6	4.8	4.9	7.7	5.4
Southwest monsoon-2	6.7	5.9	4.7	5.6	7.3	6.9
Southwest monsoon-3	6.5	4.6	4.6	7.2	7.9	6.2
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.3411111111	2	0.170556	0.339827	0.719804	4.102816
Columns	14.79111111	5	2.958222	5.894178	0.008586	3.325837
Error	5.018888889	10	0.501889			
Total	20.15111111	17				

Table-85: Total DO of bottom water during northeast monsoon

Dissolved O ₂ - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	6.1	5.8	4	5.1	7.4	4.9
Northeast monsoon-2	6.1	4.9	4	4.4	7.6	5.9
Northeast monsoon-3	7	6.5	4.8	6.9	7.2	6.3
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	3.497777778	2	1.748889	5.461485	0.024939	4.102816
Columns	16.17611111	5	3.235222	10.10305	0.001158	3.325837
Error	3.202222222	10	0.320222			
Total	22.87611111	17				

Table-86: Three-year averages of total DO of bottom water

Dissolved O ₂ - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	6.1	5.6	3.6	3.4	6.7	5.6
Southwest monsoon	6.6	5.5	4.7	5.9	7.6	6.2
Northeast monsoon	6.4	5.7	4.3	5.5	7.4	5.7

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	2.694444444	2	1.347222	5.77656	0.021501	4.1028
Columns	16.98277778	5	3.396556	14.5636	0.000257	3.3258
Error	2.332222222	10	0.233222			
Total	22.00944444	17				

4. 4. Organic waste in the Lake

4. 4. 1. BOD of surface and bottom waters (MgL⁻¹)

BOD is the measure of degradable organic matter present in a water sample and is defined as the amount of oxygen required by microorganisms in stabilizing biologically degradable organic matter under aerobic conditions. BOD of both surface and bottom waters of *Periyar* Lake are given in **Tables 87 to 94** respectively. BOD of the surface water in the Lake varied from 0.4 to 3.1 mg L⁻¹ and that of bottom water varied from 0.7 to 3.1 mg L⁻¹. In the years 2003 and 2005 BOD was found comparatively high during the pre-monsoon.

Table- 87: BOD of surface water during pre-monsoon

BOD -S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon-1	2	1	1.9	0.9	1.5	3.1
Pre-monsoon-2	1.4	1.1	1.3	1.4	1.9	1.7
Pre-monsoon-3	2.6	1.3	1.7	1.5	2	3.1
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.964444	2	0.482222	2.936401	0.09925	4.102816
Columns	4.417778	5	0.883556	5.380244	0.011689	3.325837
Error	1.642222	10	0.164222			
Total	7.024444	17				

Table- 88: BOD of surface water during southwest monsoon

BOD -S	PLS-1	PLS-2	PLS-3	PLS-4A	PLS-4B	PLS-5
Southwest monsoon-1	1.1	0.9	0.6	0.6	0.5	1.6
Southwest monsoon-2	0.4	0.6	0.4	1.1	0.6	0.8
Southwest monsoon-3	1.5	1.8	0.9	1.3	0.7	1.8
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	1.447778	2	0.723889	7.877872	0.008823	4.102816
Columns	1.357778	5	0.271556	2.95526	0.068112	3.325837
Error	0.918889	10	0.091889			
Total	3.724444	17				

Table- 89: BOD of surface water during northeast monsoon

BOD -S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	1.6	1.2	1.2	1.5	0.9	2.1
Northeast monsoon-2	1.8	1.3	1.3	1.8	1.2	1.7
Northeast monsoon-3	1.4	1.4	1	1.3	1.3	1.7
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.084444	2	0.042222	1.104651	0.368592	4.102816
Columns	1.129444	5	0.225889	5.909884	0.008507	3.325837
Error	0.382222	10	0.038222			
Total	1.596111	17				

Table- 90: Three-year average BOD of surface water

BOD -S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	2	1.1	1.6	1.3	1.8	2.6
Southwest monsoon	1	1.1	0.6	1	0.6	1.4
Northeast monsoon	1.6	1.3	1.2	1.5	1.1	1.8
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	1.863333	2	0.931667	11.99571	0.002204	4.102816
Columns	1.48	5	0.296	3.811159	0.034175	3.325837
Error	0.776667	10	0.077667			
Total	4.12	17				

Table- 91: BOD of bottom water during pre-monsoon

BOD-B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon-1	1.4	1	2.3	2	1.4	2.8
Pre-monsoon-2	1.4	0.7	1.5	0.5	1.9	1.7
Pre-monsoon-3	2.6	2.6	1.6	0.9	1.3	3.1
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	1.724444	2	0.862222	2.051824	0.179202	4.102816
Columns	3.402778	5	0.680556	1.619513	0.241289	3.325837
Error	4.202222	10	0.420222			
Total	9.329444	17				

Table- 92: BOD of bottom water during southwest monsoon

BOD-B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	1	1	0.9	1.1	0.9	2.2
Southwest monsoon-2	0.9	0.4	1.2	2.2	1.1	1
Southwest monsoon-3	1.3	2.6	1.2	1.8	0.8	1.8
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.73	2	0.365	1.068293	0.379767	4.102816
Columns	1.573333	5	0.314667	0.920976	0.505832	3.325837
Error	3.416667	10	0.341667			
Total	5.72	17				

Table-93: BOD of bottom water during northeast monsoon

BOD-B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	1.7	2	2	1.2	1.1	2.6
Northeast monsoon-2	1.8	2.5	2.2	2.8	1.3	1.8
Northeast monsoon-3	1.2	1.4	1.1	0.9	1.3	1.7
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	1.96	2	0.98	4.579439	0.038739	4.102816
Columns	1.28	5	0.256	1.196262	0.377126	3.325837
Error	2.14	10	0.214			
Total	5.38	17				

Table- 94: Three-year average BOD of bottom water

BOD-B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	1.8	1.4	1.8	1.1	1.5	2.5
Southwest monsoon	1.1	1.3	1.1	1.7	0.93	1.7
Northeast monsoon	1.6	2	1.8	1.6	1.2	2
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.598878	2	0.299439	3.085762	0.090416	4.102816
Columns	1.174694	5	0.234939	2.42108	0.10971	3.325837
Error	0.970389	10	0.097039			
Total	2.743961	17				

4. 4. 2. COD of surface water (MgL⁻¹)

Chemical Oxygen Demand (COD) is the measure of oxygen consumed during the oxidation of oxidizable organic matter by a strong oxidizing agent. Therefore, unlike the BOD, COD gives an idea of not only the biodegradable organic material, but also all kinds of organic material including the oil and grease in the water. COD of the *Periyar* Lake water is given in **Table-95 to 98**. COD of the surface water at stations-1 and 5 were found quite different from that of the other stations. During the pre-monsoon seasons of the entire period of study, the COD at station-1 and 5 were quite similar and COD at station-5 was only slightly higher than that at station-1, but during the southwest and northeast monsoons the COD at station-5 was found higher from that at station-1.

Table- 95: COD of surface water during pre-monsoon

C O D	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	3.4	2.1	1.5	1.4	1	3.7
Pre-monsoon- 2	3.5	2	1.4	1.5	0.9	3.8
Pre-monsoon- 3	3.7	1.1	1.6	1.7	1.1	3.2
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.054444	2	0.027222	0.305106	0.743669	4.102816
Columns	18.65778	5	3.731556	41.82316	2.19E-06	3.325837
Error	0.892222	10	0.089222			
Total	19.60444	17				

Table- 96: COD of surface-water during southwest monsoon

C O D	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	3.2	2.2	1.7	1.3	1	3.5
Southwest monsoon-2	2.9	1.8	1.4	1.2	0.6	3.1
Southwest monsoon-3	2.4	1.9	1.5	1	0.8	3.6
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.363333	2	0.181667	5	0.03125	4.102816
Columns	14.97833	5	2.995667	82.44954	8.48E-08	3.325837
Error	0.363333	10	0.036333			
Total	15.705	17				

Table-97: COD of surface-water during northeast monsoon

C O D	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	2.5	2	1.3	1.1	0.7	3.2
Northeast monsoon-2	2.7	1.9	1.3	0.9	0.7	3.5
Northeast monsoon-3	2.6	2	1.6	0.9	0.9	3.7
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.074444	2	0.037222	1.936416	0.194614	4.102816
Columns	16.03611	5	3.207222	166.8497	2.69E-09	3.325837
Error	0.192222	10	0.019222			
Total	16.30278	17				

Table- 98: Three-year average COD of surface water

C O D	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	3.5	1.7	1.5	1.5	1	3.6
Southwest monsoon	2.8	2	1.5	1.2	0.8	3.4
Northeast monsoon	2.6	2	1.4	1	0.9	3.5
ANOVA						

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.181111	2	0.090556	1.815145	0.212557	4.102816
Columns	15.82944	5	3.165889	63.4588	3E-07	3.325837
Error	0.498889	10	0.049889			
Total	16.50944	17				

4.5. Major inorganic ions in the water

4.5.1. Total Calcium (Ca) - surface and bottom waters (MgL⁻¹)

Calcium is one of the most abundant substances in natural water. The quantity of Ca in natural water generally varies from 10-100 mgL⁻¹ depending on the type of rocks (Trivedy and Goel, 1986). Ca content of *Periyar* Lake of both surface and bottom waters are given in **Table 99 to 106** respectively. It is clear from the tables that Ca content of surface water in *Periyar* Lake varies from 2 to 3.5 mgL⁻¹. The highest Ca content was at station-5 and the lowest was at station-3.

Table-99: Total dissolved Ca of surface-water during pre-monsoon

Total Ca ++ - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	2.4	2.5	2.2	2.6	2.8	3.5
Pre-monsoon- 2	2.8	2.4	2.4	2.4	3	2.8
Pre-monsoon- 3	2.6	2.1	2.1	2.4	2.9	2.6
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.1633333333	2	0.081667	1.503067	0.268694	4.102816
Columns	1.3383333333	5	0.267667	4.92638	0.015598	3.325837
Error	0.5433333333	10	0.054333			
Total	2.045	17				

Table- 100: Total dissolved Ca of surface water during southwest monsoon

Total Ca ++ - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	2.4	2.6	2.1	2.6	2.9	2.9
Southwest monsoon-2	2.4	2.4	2.4	2.8	2.8	2.6
Southwest monsoon-3	3	2.4	2.7	2.6	2	3
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.007777778	2	0.003889	0.037433	0.963393	4.102816
Columns	0.3511111111	5	0.070222	0.675936	0.651482	3.325837
Error	1.038888889	10	0.103889			
Total	1.397777778	17				

Table- 101: Total dissolved Ca of surface-water during northeast monsoon

Total Ca ++ - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	2.6	2.4	2	2.7	2.8	2.8
Northeast monsoon-2	2.4	2.4	2.1	2.1	2.1	2.7
Northeast monsoon-3	2	2.2	2.2	2	2.2	2.9

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.31	2	0.155	3	0.095367	4.102816
Columns	0.813333333	5	0.162667	3.148387	0.057855	3.325837
Error	0.516666667	10	0.051667			
Total	1.64	17				

Table-102: Three-year average total dissolved Ca of surface-water

Total Ca ++ - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	2.6	2.3	2.2	2.5	2.9	3
Southwest monsoon	2.6	2.5	2.4	2.7	2.6	2.8
Northeast monsoon	2.3	2.3	2.1	2.7	2.4	2.8

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.101111111	2	0.050556	2.382199	0.142535	4.102816
Columns	0.749444444	5	0.149889	7.062827	0.004529	3.325837
Error	0.212222222	10	0.021222			
Total	1.062777778	17				

Table- 103: Total dissolved Ca of bottom-water during pre-monsoon

Total Ca ++ - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	2.4	2.7	3.5	2.7	2.8	3.6
Pre-monsoon- 1	2.8	2.6	3	3	3	2.8
Pre-monsoon- 1	2.6	2	2.1	2.9	2.4	2.6

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.923333333	2	0.461667	3.713137	0.062227	4.102816
Columns	0.638333333	5	0.127667	1.02681	0.452013	3.325837
Error	1.243333333	10	0.124333			
Total	2.805	17				

Table-104: Total dissolved Ca of bottom water during southwest monsoon

Total Ca ++ - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	2.4	2.6	2.1	2.9	2.9	3
Southwest monsoon-2	2.4	2.7	3.5	2.7	2.8	3.6
Southwest monsoon-3	3	2.6	2.8	2.7	2	3

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.324444444	2	0.162222	0.979866	0.408689	4.102816
Columns	0.822777778	5	0.164556	0.99396	0.468121	3.325837
Error	1.655555556	10	0.165556			
Total	2.802777778	17				

Table- 105: Total dissolved Ca of bottom-water during northeast monsoon

Total Ca ++ - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	2.6	2.4	2	2.6	2.8	2.9
Northeast monsoon-2	2.4	2.7	2.7	2.4	2.1	2.7
Northeast monsoon-3	2.1	2.2	2.2	2.4	2.2	2.9
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.154444444	2	0.077222	1.104928	0.368508	4.102816
Columns	0.549444444	5	0.109889	1.572337	0.253399	3.325837
Error	0.698888889	10	0.069889			
Total	1.402777778	17				

Table- 106: Three-year average total dissolved Ca of bottom-water

Total Ca ++ - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	2.6	2.4	2.9	2.9	2.7	3
Southwest monsoon	2.6	2.6	2.8	2.8	2.6	3.2
Northeast monsoon	2.4	2.4	2.3	2.5	2.4	2.8
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.341111111	2	0.170556	12.89916	0.001701	4.102816
Columns	0.549444444	5	0.109889	8.310924	0.002473	3.325837
Error	0.132222222	10	0.013222			
Total	1.022777778	17				

4. 5. 2. Total Magnesium (Mg) - surface and bottom waters (MgL⁻¹)

Magnesium occurs in all kinds of natural water with calcium, but the concentration remains generally lower than that of calcium. However, in the *Periyar* Lake waters, Mg content was found slightly more than the amount of Ca. Mg content of *Periyar* Lake of both surface and bottom waters are given in **Table 107 to 114** respectively. The highest quantity observed was 6.6 mg L⁻¹ at station-5 during the southwest monsoon 2004 and the lowest quantity observed was 3.1 mg L⁻¹ at station-3 during the northeast monsoon 2003. In general, station-5 showed higher Mg content than other stations throughout the study period and station-3 showed lower Mg content than other stations during the same period.

Table- 107: Total dissolved Mg of surface-water during pre-monsoon

Total Mg++ - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	5.3	5.2	5.9	5.8	5.3	6.2
Pre-monsoon- 2	5.4	5.6	5.6	5.6	5.3	6
Pre-monsoon- 3	5.4	4.7	4	5.8	4.9	5.4
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit

Rows	1.287777778	2	0.643889	3.80499	0.059048	4.102816
Columns	1.477777778	5	0.295556	1.746553	0.211752	3.325837
Error	1.692222222	10	0.169222			
Total	4.457777778	17				

Table- 108: Total dissolved Mg of surface-water during southwest monsoon

Total Mg++ - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	4.2	4.1	4.1	5.1	5.1	5.8
Southwest monsoon-2	4.3	4.3	4.3	5.6	5.6	5.2
Southwest monsoon-3	5.7	5.9	5.9	5.4	5.2	6.6
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	3.87	2	1.935	7.21118	0.01151	4.102816
Columns	3.146666667	5	0.629333	2.345342	0.117748	3.325837
Error	2.683333333	10	0.268333			
Total	9.7	17				

Table- 109: Total dissolved Mg of surface-water during northeast monsoon

Total Mg++ - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	4.3	4.2	4.2	4.4	4.3	5.1
Northeast monsoon-2	4.5	4.4	3.1	3.2	3.2	5.1
Northeast monsoon-3	4.8	4.2	3.7	4.8	4.2	4.4
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.884444444	2	0.442222	1.898855	0.19997	4.102816
Columns	2.802777778	5	0.560556	2.406966	0.111158	3.325837
Error	2.328888889	10	0.232889			
Total	6.016111111	17				

Table- 110: Three-year average total dissolved Mg of surface-water

Total Mg++ - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	5.4	5.2	5.2	5.7	5.2	5.9
Southwest monsoon	4.7	4.8	4.8	5.4	5.3	5.9
Northeast monsoon	4.5	4.3	3.7	4.1	3.9	4.9
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	4.721111111	2	2.360556	35.1157	3.01E-05	4.102816
Columns	1.809444444	5	0.361889	5.383471	0.011665	3.325837
Error	0.672222222	10	0.067222			
Total	7.202777778	17				

Table- 111: Total dissolved Mg of bottom-water during pre-monsoon

Total Mg++ - S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	5.3	3.1	4	4.7	5.3	7.3
Pre-monsoon- 1	5.4	5.6	6.4	6.6	6.4	6.1
Pre-monsoon- 1	5.4	4.6	4.7	5.5	4.5	5.4

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	4.853333333	2	2.426667	3.540856	0.068761	4.102816
Columns	5.538333333	5	1.107667	1.616245	0.242107	3.325837
Error	6.853333333	10	0.685333			
Total	17.245	17				

Table- 112: Total dissolved Mg of bottom-water during southwest monsoon

Total Mg++ - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	4.2	4.2	4.1	5.5	5.2	4.8
Southwest monsoon-2	4.3	4.3	4.2	5.6	5.6	5.2
Southwest monsoon-3	5.7	6.4	6.4	5	3.6	6.6
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	3.01	2	1.505	1.654452	0.239491	4.102816
Columns	1.578333333	5	0.315667	0.347014	0.872853	3.325837
Error	9.096666667	10	0.909667			
Total	13.685	17				

Table- 113: Total dissolved Mg of bottom-water during northeast monsoon

Total Mg++ - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	4.2	4.2	4.1	5.5	5.2	4.8
Northeast monsoon-2	4.3	4.3	4.2	5.6	5.6	5.2
Northeast monsoon-3	5.7	6.4	6.4	5	3.6	6.6
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	3.01	2	1.505	1.654452	0.239491	4.102816
Columns	1.578333333	5	0.315667	0.347014	0.872853	3.325837
Error	9.096666667	10	0.909667			
Total	13.685	17				

Table- 114: Three-year average total dissolved Mg of bottom-water

Total Mg++ - B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	5.4	4.4	5	5.6	5.4	6.3
Southwest monsoon	4.7	5	4.9	5.4	4.8	5.3
Northeast monsoon	4.6	4.5	4.4	4.8	3.8	4.9
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	2.201111111	2	1.100556	8.560933	0.006814	4.102816
Columns	1.857777778	5	0.371556	2.890233	0.072036	3.325837
Error	1.285555556	10	0.128556			
Total	5.344444444	17				

4. 5.3. Total Potassium (K) - surface and bottom waters (ppm)

Potassium is a naturally occurring element in water; however, its concentration remains quite lower than that of sodium, Ca and Mg. K content of *Periyar* Lake of both surface and bottom

waters are given in **Tables 115 to 122**. In the Lake water (both surface and bottom) the K content varies from 0.9 ppm to 2.1 ppm. K content in the Lake waters does not show much variation across different sampling stations or across different seasons.

Table- 115: Total dissolved K of surface-water during pre-monsoon

K- S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	1.6	1.4	1.3	1.7	2	1.6
Pre-monsoon- 1	1.2	1.2	1.2	1.3	1.3	1.3
Pre-monsoon- 1	1.5	1.2	1.2	1.2	1.4	1.5
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.401111	2	0.200556	10.43353	0.003569	4.102816
Columns	0.236111	5	0.047222	2.456647	0.106155	3.325837
Error	0.192222	10	0.019222			
Total	0.829444	17				

Table- 116: Total dissolved K of surface-water during southwest monsoon

K- S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	1.9	2.1	1.6	1.3	1.3	1.9
Southwest monsoon-2	2	1.4	1.5	1.6	1.4	1.6
Southwest monsoon-3	1.1	1.1	1.1	1.1	1	1.2
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	1.167778	2	0.583889	13.10474	0.001607	4.102816
Columns	0.391111	5	0.078222	1.755611	0.209806	3.325837
Error	0.445556	10	0.044556			
Total	2.004444	17				

Table- 117: Total dissolved K of surface-water during northeast monsoon

K- S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	1.5	1.5	1.2	1	1.1	1.5
Northeast monsoon-2	1.2	1.2	1.2	1	0.9	1.2
Northeast monsoon-3	1.5	1.2	1.2	1.2	1.4	1.5
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.163333	2	0.081667	4.803922	0.034503	4.102816
Columns	0.291667	5	0.058333	3.431373	0.045925	3.325837
Error	0.17	10	0.017			
Total	0.625	17				

Table- 118: Three-year average total dissolved K of surface-water

K- S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	1.4	1.3	1.2	1.4	1.6	1.5
Southwest monsoon	1.7	1.5	1.4	1.3	1.2	1.6
Northeast monsoon	1.4	1.3	1.2	1.1	1.1	1.4
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.13	2	0.065	3.421053	0.073794	4.102816
Columns	0.18	5	0.036	1.894737	0.182302	3.325837
Error	0.19	10	0.019			
Total	0.5	17				

Table- 119: Total dissolved K of bottom-water during pre-monsoon

K- B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	1	1	1	2	1.5	1.9
Pre-monsoon- 2	1.2	1.2	1.3	1.3	1.3	1.3
Pre-monsoon- 3	1.5	1.1	1.1	1.1	1.4	1.5
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.063333	2	0.031667	0.404255	0.677908	4.102816
Columns	0.538333	5	0.107667	1.374468	0.311946	3.325837
Error	0.783333	10	0.078333			
Total	1.385	17				

Table- 120: Total dissolved K of bottom-water during southwest monsoon

K- B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	2	2	1.4	1.4	1.3	1.8
Southwest monsoon-2	2	1.6	1.6	1.7	1.4	1.6
Southwest monsoon-3	1.1	1.1	1.1	0.9	1.2	1.2
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	1.21	2	0.605	15.2521	0.000917	4.102816
Columns	0.373333	5	0.074667	1.882353	0.184578	3.325837
Error	0.396667	10	0.039667			
Total	1.98	17				

Table- 121: Total dissolved K of bottom-water during northeast monsoon

K- B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	1.8	1.8	1.1	1	0.8	1.3
Northeast monsoon-2	1.2	1.4	1.2	1.1	0.9	1.3
Northeast monsoon-3	1	1	1	1	0.9	1.2
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.243333	2	0.121667	2.625899	0.12117	4.102816
Columns	0.613333	5	0.122667	2.647482	0.089224	3.325837
Error	0.463333	10	0.046333			
Total	1.32	17				

Table- 122: Three-year average total dissolved K of bottom-water

K- B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	1.2	1.1	1.1	1.5	1.4	1.6
Southwest monsoon	1.7	1.6	1.4	1.3	1.3	1.5
Northeast monsoon	1.3	1.4	1.1	1	0.9	1.3
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.27	2	0.135	3.648649	0.064582	4.102816
Columns	0.185	5	0.037	1	0.465119	3.325837
Error	0.37	10	0.037			
Total	0.825	17				

4. 5. 4. Total Sodium (Na) - surface and bottom waters (ppm)

Sodium is one of the important cations occurring naturally. The concentration of Na in natural freshwater is generally lower than that of Ca and Mg (Trivedi and Goel, 1986) Na content of *Periyar* Lake of both surface and bottom waters are given in **Table 123 to 130**. Na content of both surface and bottom water of the Lake varied from 1.9 ppm to 6.5 ppm. Among different stations, water at station-5 showed a comparatively higher amount of Na than other stations across seasons.

Table- 123: Total dissolved Na of surface-water during pre-monsoon

Na – S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	4.8	2.8	4	5.5	2.7	6.5
Pre-monsoon- 2	3.1	3	3	3.1	3.2	3.3
Pre-monsoon- 3	3.1	3	3.1	3.1	3	3.1
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	6.681111	2	3.340556	4.688133	0.036614	4.102816
Columns	4.344444	5	0.868889	1.219398	0.367918	3.325837
Error	7.125556	10	0.712556			
Total	18.15111	17				

Table- 124: Total dissolved Na of surface-water during southwest monsoon

Na – S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	2.3	2.2	2.2	2.1	2	3.2
Southwest monsoon-2	2.5	2.4	2.4	2.4	2.5	3.1
Southwest monsoon-3	2.8	2.7	2.6	2.7	2.2	3.1
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.374444	2	0.187222	6.877551	0.01322	4.102816
Columns	1.484444	5	0.296889	10.90612	0.000852	3.325837
Error	0.272222	10	0.027222			
Total	2.131111	17				

Table- 125: Total dissolved Na of surface-water during northeast monsoon

Na – S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	2.1	2	2	2	1.9	2.9
Northeast monsoon-2	2.2	2.2	2.2	2.3	2.1	2.5
Northeast monsoon-3	2.5	2.5	2.4	2.7	2.5	2.8
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.567778	2	0.283889	11.56109	0.002508	4.102816
Columns	0.657778	5	0.131556	5.357466	0.011855	3.325837
Error	0.245556	10	0.024556			
Total	1.471111	17				

Table- 126: Three-year average total dissolved Na of surface-water

Na – S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	3.7	2.9	3.4	3.9	3	4.3
Southwest monsoon	2.5	2.4	2.4	2.4	2.3	3.1
Northeast monsoon	2.3	2.2	2.2	2.3	2.2	2.7
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	5.107778	2	2.553889	51.19154	5.58E-06	4.102816
Columns	1.571111	5	0.314222	6.298441	0.006819	3.325837
Error	0.498889	10	0.049889			
Total	7.177778	17				

Table- 127: Total dissolved Na of bottom-water during pre-monsoon

Na – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	4.8	3	2.6	2.8	2.1	6.1
Pre-monsoon- 2	3.1	3	3	3	3.2	3.3
Pre-monsoon- 3	3.1	3	3.1	3.1	3	3.1
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.937778	2	0.468889	0.626113	0.55438	4.102816
Columns	4.537778	5	0.907556	1.211869	0.370888	3.325837
Error	7.488889	10	0.748889			
Total	12.96444	17				

Table- 128: Total dissolved Na of bottom-water during southwest monsoon

Na – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	2.3	2.2	2.2	2.1	2.1	3.1
Southwest monsoon-2	2.5	2.4	2.4	2.5	2.2	3.2
Southwest monsoon-3	2.8	2.6	2.6	2.4	1.9	3.1
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.191111	2	0.095556	4.056604	0.051289	4.102816
Columns	1.904444	5	0.380889	16.16981	0.000164	3.325837

Error	0.235556	10	0.023556			
Total	2.331111	17				

Table- 129: Total dissolved Na of bottom-water during northeast monsoon

Na – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	2.1	2	2	2	2	2.5
Northeast monsoon-2	2.2	2.3	2.2	2.2	2.1	2.5
Northeast monsoon-3	2.5	2.4	2.4	2.8	2.5	2.4
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.49	2	0.245	9.545455	0.0048	4.102816
Columns	0.158333	5	0.031667	1.233766	0.362316	3.325837
Error	0.256667	10	0.025667			
Total	0.905	17				

Table- 130: Three-year average total dissolved Na of bottom-water

Na – B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	3.7	3	2.9	3	2.8	4.2
Southwest monsoon	2.5	2.4	2.4	2.3	2.1	3.1
Northeast monsoon	2.3	2.2	2.2	2.3	2.2	2.5
(ANOVA)						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	3.281111	2	1.640556	28.6699	7.22E-05	4.102816
Columns	1.622778	5	0.324556	5.671845	0.00979	3.325837
Error	0.572222	10	0.057222			
Total	5.476111	17				

4.5.5. Total Chloride (Cl) - surface and bottom waters (MgL⁻¹)

Chloride occurs naturally in all types of water. In natural freshwater, however, its concentration remains quite low and is generally less than that of sulphates and bicarbonates. The most important source of Cl in water is the discharge of domestic sewage. Man and other animals excrete very high quantities of Cl together with nitrogenous compounds. Cl status of the surface and bottom waters of *Periyar* Lake is given in **Table 131 to 138**. The Cl ionic content in the Lake water ranged from 5 to 9.9 mgL⁻¹.

Table- 131: Total dissolved Cl of surface-water during pre-monsoon

Total chloride –S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon-1	6.6	5.8	5.5	5.8	5.7	8.3
Pre-monsoon-2	6.4	6.4	5.7	5.7	5.4	6.8
Pre-monsoon-3	9.9	7.6	5.7	6.4	5.7	9.9
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	7.521111111	2	3.760556	5.322378	0.026666	4.102816
Columns	19.20944444	5	3.841889	5.43749	0.011283	3.325837

Error	7.06555556	10	0.706556			
Total	33.79611111	17				

Table- 132: Total dissolved Cl of surface-water during southwest monsoon

Total chloride –S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	7.4	6.1	5.7	5.4	5.2	6.3
Southwest monsoon-2	7.5	5.7	5.7	5.4	5	6.4
Southwest monsoon-3	6.8	6.1	6.1	5.7	5.4	6.8
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.124444444	2	0.062222	0.949153	0.419348	4.102816
Columns	8.042777778	5	1.608556	24.53729	2.59E-05	3.325837
Error	0.655555556	10	0.065556			
Total	8.822777778	17				

Table- 133: Total dissolved Cl of surface-water during northeast monsoon

Total chloride –S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	6.5	6.3	5.6	5.8	5.1	7.2
Northeast monsoon-2	6.2	6.2	5.7	5.7	5.2	7.1
Northeast monsoon-3	6.4	6.4	6.4	6.1	6.1	7.1
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.551111111	2	0.275556	4.626866	0.037794	4.102816
Columns	4.929444444	5	0.985889	16.5541	0.000148	3.325837
Error	0.595555556	10	0.059556			
Total	6.076111111	17				

Table- 134: Three-year average total dissolved Cl of surface-water

Total chloride –S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	7.6	6.6	5.6	6	5.6	8.3
Southwest monsoon	7.2	6	5.8	5.5	5.2	6.5
Northeast monsoon	6.4	6.3	5.9	5.9	5.5	7.1
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	1.101111111	2	0.550556	3.094941	0.089905	4.102816
Columns	8.611111111	5	1.722222	9.681449	0.00137	3.325837
Error	1.778888889	10	0.177889			
Total	11.49111111	17				

Table- 135: Total dissolved Cl of bottom-water during pre-monsoon

Total chloride –S	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon-1	5.9	5	5.4	5	5.7	7.5
Pre-monsoon-2	6.4	6.4	6.4	5.4	5.2	6.8
Pre-monsoon-3	9.9	6.6	5.7	6.4	5.7	9.9
ANOVA						

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	8.681111111	2	4.340556	4.637896	0.037578	4.102816
Columns	16.94944444	5	3.389889	3.622106	0.039512	3.325837
Error	9.358888889	10	0.935889			
Total	34.98944444	17				

Table- 136: Total dissolved Cl of bottom-water during southwest monsoon

Total chloride –B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	7.3	5.6	5.6	5.3	4.9	6.3
Southwest monsoon-2	7.5	5.7	5.7	5.4	5	6.4
Southwest monsoon-3	6.8	6.1	5.7	6.2	5.7	7.1
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.603333333	2	0.301667	2.873016	0.10331	4.102816
Columns	8.17166667	5	1.634333	15.56508	0.000193	3.325837
Error	1.05	10	0.105			
Total	9.825	17				

Table- 137: Total dissolved Cl of bottom-water during northeast monsoon

Total chloride –B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	6.5	5.4	5.6	5.6	5.1	6.9
Northeast monsoon-2	6.2	5.7	5.7	5.7	5.2	7.1
Northeast monsoon-3	6.4	6.4	6.1	6.1	6.1	7.1
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.923333333	2	0.461667	8.195266	0.007812	4.102816
Columns	4.738333333	5	0.947667	16.82249	0.000138	3.325837
Error	0.563333333	10	0.056333			
Total	6.225	17				

Table-138: Three-year average of total dissolved Cl of bottom-water

Total chloride –B	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	7.4	6	5.8	5.6	5.5	8.1
Southwest monsoon	7.2	5.8	5.7	5.6	5.2	6.6
Northeast monsoon	6.4	5.8	5.8	5.8	5.5	7
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.541111111	2	0.270556	2.010735	0.184515	4.102816
Columns	8.757777778	5	1.751556	13.01734	0.000412	3.325837
Error	1.345555556	10	0.134556			
Total	10.64444444	17				

4. 6. Nutrient status of the Lake

4. 6.1. Nitrate Nitrogen - surface water (MgL⁻¹)

The Nitrate status of the surface water of *Periyar* Lake is given in **Tables 139 to 142**. In all the seasons and throughout the period of study, station-5 showed comparatively higher concentration of Nitrate than the other stations. Throughout the period of study the lowest Nitrate content was noticed at station 4B. Nitrate nitrogen in surface water ranged from 0.1 to 0.6 mgL⁻¹.

Table- 139: Total Nitrate Nitrogen of surface-water during pre-monsoon

Nitrate Nitrogen	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon-1	0.2	0.2	0.2	0.1	0.1	0.6
Pre-monsoon-2	0.3	0.3	0.3	0.2	0.1	0.4
Pre-monsoon-3	0.3	0.2	0.1	0.1	0.1	0.3
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.021111111	2	0.010556	1.610169	0.247621	4.102816
Columns	0.209444444	5	0.041889	6.389831	0.006482	3.325837
Error	0.065555556	10	0.006556			
Total	0.296111111	17				

Table- 140: Total Nitrate Nitrogen of surface-water during southwest monsoon

Nitrate Nitrogen	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	0.3	0.2	0.1	0.1	0.1	0.4
Southwest monsoon-2	0.2	0.2	0.1	0.2	0.1	0.4
Southwest monsoon-3	0.4	0.4	0.4	0.3	0.2	0.5
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.111111111	2	0.055556	19.23077	0.0003	4.102816
Columns	0.164444444	5	0.032889	11.38462	0.0007	3.325837
Error	0.028888889	10	0.002889			
Total	0.304444444	17				

Table- 141: Total Nitrate Nitrogen of surface-water during northeast monsoon

Nitrate Nitrogen	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	0.3	0.1	0.1	0.1	0.1	0.3
Northeast monsoon-2	0.2	0.3	0.1	0.1	0.1	0.5
Northeast monsoon-3	0.3	0.3	0.1	0.1	0.1	0.5
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit

Rows	0.014444444	2	0.007222	1.585366	0.252319	4.102816
Columns	0.269444444	5	0.053889	11.82927	0.000612	3.325837
Error	0.045555556	10	0.004556			
Total	0.329444444	17				

Table- 142: Three-year average Nitrate Nitrogen of surface-water

Nitrate Nitrogen	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	0.3	0.2	0.2	0.1	0.1	0.4
Southwest monsoon	0.3	0.3	0.2	0.2	0.1	0.4
Northeast monsoon	0.3	0.2	0.1	0.1	0.1	0.4
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.007777778	2	0.003889	3.181818	0.085232	4.102816
Columns	0.191111111	5	0.038222	31.27273	8.52E-06	3.325837
Error	0.012222222	10	0.001222			
Total	0.211111111	17				

4. 6.2. Total Kjeldal Nitrogen - surface water (MgL⁻¹)

Total Kjeldal Nitrogen content of *Periyar* Lake at different sampling stations are given in **Table 143 to 146**. Only in the pre-monsoon of 2003, the total Nitrogen content at station-5 showed a significant increase than that of the other stations. During all the other years and seasons total Kjeldal Nitrogen content at all stations remained more or less the same. The Kjeldal nitrogen content of *Periyar* Lake varied from 1 to 3.9mgL⁻¹. Station-5 showed more amounts of nitrate nitrogen and Kjeldal nitrogen than other stations.

Table- 143: Total Kjeldal Nitrogen of surface-water during pre-monsoon

Total Kjeldal –N	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon-1	2.4	2.1	1.9	2.2	2.1	3.5
Pre-monsoon-2	2.4	2.3	2.1	2.3	2.2	2.5
Pre-monsoon-3	2.9	2.7	3.1	2.9	1.4	3
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.457778	2	0.228889	1.211765	0.33789	4.102816
Columns	1.897778	5	0.379556	2.009412	0.162678	3.325837
Error	1.888889	10	0.188889			
Total	4.244444	17				

Table- 144: Total Kjeldal Nitrogen of surface-water during southwest monsoon

Total Kjeldal –N	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	1.3	1.2	1.3	1.1	1.1	1.9
Southwest monsoon-2	1.4	1.4	1.4	1	1	1.7
Southwest monsoon-3	2.6	2.5	2.3	2.3	2.6	2.7
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	5.601111	2	2.800556	114.0498	1.31E-07	4.102816

Columns	0.711111	5	0.142222	5.791855	0.009116	3.325837
Error	0.245556	10	0.024556			
Total	6.557778	17				

Table- 145: Total Kjeldal Nitrogen of surface-water during northeast monsoon

Total Kjeldal-N	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	1.5	1.3	1.4	1.6	1.3	1.8
Northeast monsoon-2	1.9	1.4	1.4	1.9	1.4	1.9
Northeast monsoon-3	3.1	3.9	3.7	3.7	1.8	3.5
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	11.87111	2	5.935556	30.87861	5.26E-05	4.102816
Columns	1.649444	5	0.329889	1.716185	0.218427	3.325837
Error	1.922222	10	0.192222			
Total	15.44278	17				

Table-146: Three-year average total Kjeldal Nitrogen of surface-water

Total Kjeldal-N	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	2.6	2.4	2.4	2.5	1.9	3
Southwest monsoon	1.8	1.7	1.7	1.5	1.6	2.1
Northeast monsoon	2.2	2.2	2.2	2.4	1.5	2.4
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	1.623333	2	0.811667	24.59596	0.000138	4.102816
Columns	1.071667	5	0.214333	6.494949	0.006119	3.325837
Error	0.33	10	0.033			
Total	3.025	17				

4.6.3. Total Inorganic Phosphorus (P) - surface water (MgL⁻¹)

Total inorganic phosphorus content of the Lake at all the stations is given in **Table-147 to 150**. The P content in the Lake varied from 0.01 to 0.1mgL⁻¹. Throughout the study period, in all the seasons, the inorganic P content at station-5 remained higher than all other stations. Water in the station-1 ranked the 2nd in P content. All the other stations were more or less similar in the P content throughout the study period.

Table- 147: Total inorganic P of surface-water during pre-monsoon

Total P	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon-1	0.05	0.02	0.02	0.01	0.01	0.07
Pre-monsoon-2	0.06	0.01	0.02	0.02	0.02	0.08
Pre-monsoon-3	0.07	0.08	0.07	0.06	0.05	0.1
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.006211	2	0.003106	24.73451	0.000134	4.102816
Columns	0.007178	5	0.001436	11.43363	0.000704	3.325837

Error	0.001256	10	0.000126			
Total	0.014644	17				

Table- 148: Total inorganic P of surface-water during southwest monsoon

TOTAL-P	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	0.05	0.04	0.04	0.05	0.05	0.08
Southwest monsoon-2	0.06	0.06	0.05	0.03	0.03	0.06
Southwest monsoon-3	0.04	0.02	0.02	0.02	0.02	0.05
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.001911	2	0.000956	10	0.004115	4.102816
Columns	0.002094	5	0.000419	4.383721	0.02252	3.325837
Error	0.000956	10	9.56E-05			
Total	0.004961	17				

Table- 149: Total inorganic P of surface-water during northeast monsoon

TOTAL-P	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	0.03	0.01	0.02	0.02	0.02	0.07
Northeast monsoon-2	0.03	0.01	0.01	0.01	0.01	0.06
Northeast monsoon-3	0.04	0.03	0.01	0.02	0.02	0.05
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.000178	2	8.89E-05	1.6	0.249534	4.102816
Columns	0.004894	5	0.000979	17.62	0.000113	3.325837
Error	0.000556	10	5.56E-05			
Total	0.005628	17				

Table- 150: Three-year average total inorganic P of surface-water

TOTAL-P	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	0.08	0.04	0.04	0.03	0.03	0.08
Southwest monsoon	0.05	0.04	0.04	0.03	0.03	0.06
Northeast monsoon	0.03	0.02	0.01	0.02	0.02	0.06
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.001678	2	0.000839	9.805195	0.004393	4.102816
Columns	0.004161	5	0.000832	9.727273	0.001345	3.325837
Error	0.000856	10	8.56E-05			
Total	0.006694	17				

4.6.4. Total Silica (Si) - surface water (MgL⁻¹)

Total Silica in waters during different seasons is given in **Tables 151-154**. The lowest amount of silica noticed in the Lake was 0.01 mgL⁻¹ during northeast monsoon and the highest amount was 0.41 mgL⁻¹ during the southwest monsoon at station-4B.

Table- 151: Total Silica of surface-water during pre-monsoon

Silica	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	0.11	0.08	0.09	0.11	0.11	0.11
Pre-monsoon- 2	0.12	0.1	0.11	0.14	0.21	0.11
Pre-monsoon- 3	0.11	0.09	0.21	0.25	0.25	0.11
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.014078	2	0.007039	4.477032	0.040878	4.102816
Columns	0.021444	5	0.004289	2.727915	0.083045	3.325837
Error	0.015722	10	0.001572			
Total	0.051244	17				

Table- 152: Total Silica of surface-water during southwest monsoon

Silica	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	0.15	0.11	0.21	0.21	0.31	0.21
Southwest monsoon-2	0.24	0.21	0.31	0.31	0.41	0.31
Southwest monsoon-3	0.22	0.21	0.25	0.21	0.31	0.21
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.029811	2	0.014906	23.33043	0.000171	4.102816
Columns	0.048644	5	0.009729	15.22783	0.000212	3.325837
Error	0.006389	10	0.000639			
Total	0.084844	17				

Table- 153: Total Silica of surface-water during northeast monsoon

Silica	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	0.01	0.01	0.02	0.02	0.04	0.09
Northeast monsoon-2	0.02	0.02	0.03	0.01	0.01	0.07
Northeast monsoon-3	0.01	0.01	0.01	0.01	0.01	0.06
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.000544	2	0.000272	2.951807	0.098293	4.102816
Columns	0.008378	5	0.001676	18.16867	9.88E-05	3.325837
Error	0.000922	10	9.22E-05			
Total	0.009844	17				

Table- 154: Three-year average total Silica of surface-water

Silica	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	0.1	0.09	0.14	0.17	0.19	0.11
Southwest monsoon	0.2	0.18	0.26	0.24	0.34	0.24
Northeast monsoon	0.01	0.01	0.02	0.01	0.02	0.07
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.1452	2	0.0726	66	1.73E-06	4.102816
Columns	0.0154	5	0.00308	2.8	0.077929	3.325837

Error	0.011	10	0.0011			
Total	0.1716	17				

4.7. Oil and Grease in surface water (mgL⁻¹)

Oil and grease in the *Periyar* Lake waters recorded during different seasons of the entire period of study are given in **Table-155 to 158**. The amount of oil and grease varied from 110 to 2282 mg L⁻¹. Oil and grease at station-1 and 5 were found much higher than that at other stations in all seasons during the entire period of study. It was also interesting to note that the amount of oil and grease at station-2 at certain season during certain years was almost equal to that at stations-1 and 5.

Table- 155: Oil and Grease of surface-water during pre-monsoon

Oil Grease	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	1695	890	840	430	240	1600
Pre-monsoon- 2	1875	792	1313	563	355	1846
Pre-monsoon- 3	2045	1600	946	420	328	1752
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	176090.33	2	88045.17	1.965085	0.190642	4.102816
Columns	6067034	5	1213407	27.08209	1.65E-05	3.325837
Error	448047.67	10	44804.77			
Total	6691172	17				

Table- 156: Oil and Grease of surface-water during southwest monsoon

Oil Grease	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	1220	650	720	387	180	1330
Southwest monsoon-2	1481	426	334	284	202	1430
Southwest monsoon-3	1590	1537	756	610	650	2282
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	1078920.4	2	539460.2	10.04773	0.00405	4.102816
Columns	4536279.6	5	907255.9	16.89812	0.000136	3.325837
Error	536897.56	10	53689.76			
Total	6152097.6	17				

Table- 157: Oil and Grease of surface-water during northeast monsoon

Oil Grease	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	940	330	265	220	89	930
Northeast monsoon-2	995	767	630	417	110	1029
Northeast monsoon-3	952	892	480	294	265	1283
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>

Rows	186859.11	2	93429.56	5.807759	0.021192	4.102816
Columns	2005348.4	5	401069.7	24.93126	2.41E-05	3.325837
Error	160870.22	10	16087.02			

Table- 158: Three-year average Oil and Grease of surface-water

Oil Grease	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	1871.7	1094	1033	471	307.7	1732
Southwest monsoon	1430.3	871	603.3	427	344	1680.7
Northeast monsoon	962.3	663	458.3	310.3	154.7	1080.7
ANOVA						
Source of Variation	SS	Df	MS	F	P-value	F crit
Rows	700396.92	2	350198.5	12.4605	0.001926	4.102816
Columns	3921021.2	5	784204.2	27.90297	1.44E-05	3.325837
Error	281046.89	10	28104.69			
Total	4902465	17				

4. 8. Primary Productivity of surface water in the Lake

Primary productivity is the rate at which the sun's radiant energy is stored by photosynthetic activity of producer organisms. Macrophytes and algae are the usual producers in aquatic systems. Macrophytes vegetation belongs to the categories such as surface or submerged free-floating and rooted with floating leaves were not found in the *Periyar* Lake system throughout the period of study. Rooted submerged plants were found in the shallow periphery alone. They were mostly grasses submerged by fluctuating water levels in the Lake. In the summer, when shallow regions of the Lake were exposed, hygrophyte communities were noted which were quite temporary. Therefore, the various kinds of algae are the major primary producers of the Lake. All the materials synthesized by the producers, however, are not available for the consumers (fauna – zooplanktons and fishes). Producers utilize part of it themselves for their maintenance (respiration). Some part of it is wasted and the decomposers (non-photosynthetic bacteria and detritivorous organisms) utilize this. In the present study only algal productivity was directly assessed. The accumulation of biomass in all the different kinds of fauna is referred to as the secondary production. In a Lake surrounded by forests such as the *Periyar* Lake, secondary production depends on the significant input such as flowers, fruits, litter, and dead or live faunal material including terrestrial insects, animal excreta and partly decayed dead matter and humus containing surface soil.

4. 8.1. Gross Primary Productivity (GPP) (mg L⁻¹)

The average seasonal values of GPP of surface water are given in **Table 159 to 162**. The GPP at station-5 was found slightly higher than that of other stations in all seasons. GPP varied from 0.17 to 0.36 mg L⁻¹ of Oxygen/hr (63.75 to 135 mg C/m³/hr). In general GPP at stations 2, 3 and 4A were observed slightly higher in the northeast monsoon than that of other seasons.

Table- 159: GPP of surface-water during pre-monsoon

Gross Pro	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	0.27	0.26	0.21	0.24	0.22	0.32
Pre-monsoon- 2	0.24	0.24	0.28	0.3	0.25	0.31
Pre-monsoon- 3	0.23	0.22	0.27	0.29	0.26	0.35
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.001111	2	0.000556	0.769231	0.488946	4.102816
Columns	0.016511	5	0.003302	4.572308	0.019764	3.325837
Error	0.007222	10	0.000722			
Total	0.024844	17				

Table- 160: GPP of surface-water during southwest monsoon

Gross Pro	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	0.22	0.23	0.26	0.24	0.21	0.31
Southwest monsoon-2	0.24	0.25	0.27	0.24	0.2	0.33
Southwest monsoon-3	0.25	0.27	0.28	0.26	0.17	0.31
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.000478	2	0.000239	1	0.401878	4.102816
Columns	0.024644	5	0.004929	20.63256	5.64E-05	3.325837
Error	0.002389	10	0.000239			
Total	0.027511	17				

Table- 161: GPP of surface-water during northeast monsoon

Gross Pro	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	0.29	0.31	0.32	0.3	0.26	0.29
Northeast monsoon-2	0.32	0.33	0.36	0.28	0.24	0.31
Northeast monsoon-3	0.31	0.3	0.31	0.31	0.3	0.29
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.000433	2	0.000217	0.481481	0.631481	4.102816
Columns	0.006717	5	0.001343	2.985185	0.066391	3.325837
Error	0.0045	10	0.00045			
Total	0.01165	17				

Table- 162: Three-year average GPP of surface-water during different seasons

Gross Pro	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	0.25	0.24	0.25	0.28	0.24	0.33
Southwest monsoon	0.24	0.25	0.27	0.25	0.19	0.32
Northeast monsoon	0.31	0.31	0.33	0.3	0.27	0.3
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.008211	2	0.004106	6.855288	0.013344	4.102816
Columns	0.011028	5	0.002206	3.682746	0.037699	3.325837
Error	0.005989	10	0.000599			
Total	0.025228	17				

4. 8.2. Net Primary Productivity (NPP) (mg L⁻¹)

The average seasonal values of NPP of the surface water are given in **Tables 163 to 166**.

In general, the NPP of surface-water in the Lake was very low at all stations, which varied from 0.03 to 0.19 mg L⁻¹ of Oxygen/hr. No definite trend was noticed in NPP among sampling stations and between seasons in the Lake throughout the entire period of study.

Table- 163: NPP of surface-water during pre-monsoon

Net Primary Pro	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	0.17	0.16	0.11	0.14	0.12	0.12
Pre-monsoon- 2	0.1	0.09	0.08	0.08	0.14	0.12
Pre-monsoon- 3	0.13	0.12	0.14	0.11	0.13	0.15
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.004144	2	0.002072	3.993576	0.053111	4.102816
Columns	0.001628	5	0.000326	0.627409	0.683395	3.325837
Error	0.005189	10	0.000519			
Total	0.010961	17				

Table- 164: NPP of surface-water during southwest monsoon

Net Pri Pro	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	0.12	0.13	0.16	0.14	0.11	0.19
Southwest monsoon-2	0.14	0.15	0.17	0.14	0.12	0.13
Southwest monsoon-3	0.16	0.19	0.09	0.05	0.03	0.15
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.0036	2	0.0018	1.2	0.341108	4.102816
Columns	0.01165	5	0.00233	1.553333	0.258465	3.325837
Error	0.015	10	0.0015			
Total	0.03025	17				

Table- 165: NPP of surface-water during northeast monsoon

Net Primary Pro	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	0.19	0.11	0.12	0.13	0.16	0.17
Northeast monsoon-2	0.12	0.13	0.16	0.13	0.14	0.11
Northeast monsoon-3	0.09	0.16	0.13	0.07	0.14	0.09
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.003344	2	0.001672	1.641221	0.241886	4.102816
Columns	0.002361	5	0.000472	0.463468	0.795117	3.325837
Error	0.010189	10	0.001019			
Total	0.015894	17				

Table- 166: Three-year average of NPP of surface-water during different seasons

Net Pri Pro	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	0.13	0.12	0.11	0.11	0.13	0.13
Southwest monsoon	0.14	0.16	0.14	0.11	0.09	0.15
Northeast monsoon	0.13	0.13	0.14	0.11	0.15	0.12
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.000344	2	0.000172	0.488959	0.627191	4.102816
Columns	0.001444	5	0.000289	0.820189	0.56229	3.325837
Error	0.003522	10	0.000352			
Total	0.005311	17				

4. 8.3. Community Respiration (CR) (mg L⁻¹)

The average seasonal values of respiration (R) in surface-water are given in **Table- 167 to 170**. The rate of respiration ranged from 0.08 to 0.24 mg L⁻¹ of Oxygen/hr. As in the case of NPP, the rate of respiration showed no definite trend across sampling stations or seasons in the Lake throughout the entire period of study.

Table- 167: Community Respiration of surface-water during pre-monsoon

Com Res	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	0.1	0.1	0.1	0.1	0.1	0.2
Pre-monsoon- 2	0.14	0.15	0.2	0.22	0.11	0.9
Pre-monsoon- 3	0.1	0.1	0.13	0.18	0.13	0.2
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.101911	2	0.050956	2.117071	0.171137	4.102816
Columns	0.235778	5	0.047156	1.959191	0.17096	3.325837
Error	0.240689	10	0.024069			
Total	0.578378	17				

Table- 168: Community Respiration of surface-water during southwest monsoon

Com. Res.	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Southwest monsoon-1	0.1	0.1	0.13	0.18	0.13	0.2
Southwest monsoon-2	0.1	0.1	0.1	0.1	0.1	0.12
Southwest monsoon-3	0.1	0.1	0.1	0.1	0.08	0.2
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.004311	2	0.002156	3.540146	0.06879	4.102816
Columns	0.012178	5	0.002436	4	0.029675	3.325837
Error	0.006089	10	0.000609			
Total	0.022578	17				

Table- 169: Community Respiration of surface-water during northeast monsoon

Com Res	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	0.1	0.2	0.2	0.17	0.1	0.12
Northeast monsoon-2	0.2	0.2	0.2	0.15	0.1	0.2
Northeast monsoon-3	0.22	0.14	0.18	0.24	0.16	0.09
(ANOVA)						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.002533	2	0.001267	0.582822	0.57621	4.102816
Columns	0.013183	5	0.002637	1.21319	0.370365	3.325837
Error	0.021733	10	0.002173			
Total	0.03745	17				

Table-170: Three-year average Community Respiration of surface-water – 3 seasons

Com Res	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	0.11	0.12	0.14	0.17	0.11	0.43
Southwest monsoon	1	0.09	0.13	0.14	0.11	0.16
Northeast monsoon	0.17	0.18	0.19	0.19	0.12	0.14
<i>Source of Variation (ANOVA)</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	0.040011	2	0.020006	0.388516	0.687866	4.102816
Columns	0.206311	5	0.041262	0.801329	0.573411	3.325837
Error	0.514922	10	0.051492			
Total	0.761244	17				

4. 9. Microbiology of water

The microbiological examination of water is significant, as it is a direct measure of the deleterious effects of pollution on human health. Among the different microbes in natural water, the measurement of *Coli form* bacteria (intestinal bacteria of animals) gives an idea about the extent of fecal contamination. *Escherichia coli* of this group are entirely

of human origin and their exclusive estimation gives us the degree of contamination of fresh water from human fecal matter. The bacteria measurements, both the MPN of *Coli forms* and the count of *E. coli* were determined monthly during 2004 and the pre-monsoon of 2005. The seasonal average of this data is given in **Table-171**. The MPN recorded at all the stations during the entire seasons were very high. It was highly embarrassing to note that *E. coli* count was above drinking water standards in all the stations except at station-4B. The count was extremely high at stations-1 and 5.

Table- 171: *Coli form* Bacteria and MPN (count/100ml) *A=absent

Year/ season	Station-1		Station-2		Station-3		Station-4A		Station-4B		Station-5	
	<i>E. coli</i>	MPN	<i>E. coli</i>	MPN	<i>E. coli</i>	MPN	<i>E. coli</i>	MPN	<i>E. coli</i>	MPN	<i>E. coli</i>	MPN
2004												
PM	146	940+	60	189	34	1900+	43	1910+	A	A	467	2487+
SWM	152	2400+	38	133	76	1800+	70	2400+	A	1900+	434	2400+
NEM	132	2400+	46	167	18	2400+	78	2400+	A	2400+	280	2400+
2005												
PM	422	1100+	84	210	57	244	571	655	80	655	254	1100+

4. 10. Hydrobiology

Algae are simple plants inhabiting diverse kinds of habitats, but are prominently and almost invariably present in all natural freshwater bodies. Natural freshwater, which is deficient in nutrients, possess low population of algae but addition of any kind of nutrients triggers their growth. Algae, which are unattached, dispersed, and occurring individually or as colonies in water is designated as *Phytoplankton*. The Algae growing at the bottom of the shallow regions of water bodies are known as *benthic* algae and the algal growth on rocks, barks, stems and leaves of plants in water plants are together called as *Periphyton*. Inventory of the algal flora and seasonal variations in the population density of the different species of them belonging to the different categories such as *phytoplankton*, *Benthon* and *Periphyton*, were carried out in the present study.

4. 10.1. Phytoplankton

4.10.1-a: Seasonal changes in the density of phytoplankton in the Lake

Monthly variations in population density (count/L) of phytoplankton in the surface water of the *Periyar* Lake at different sampling stations were observed for three-years. Seasonal variations spanning the entire period of study were calculated from this data. The details of this analysis for the three-year period are given in **Tables 172-175**. At all stations variations in density over different years were visible during all the 3 seasons. Pre-monsoon variations over the years at stations 1 and 5 were less pronounced than those at other stations. The density fluctuation during the pre-monsoon period over different years at station 1 was 370-550 cells/L, at station 5 it was 400-570/L. Such fluctuations at station 2 were 180-470, station 3 were 200-470; at station 4A the fluctuations were 260-470, and at station-4B the fluctuations were 120-450/L. Plankton density during the southwest monsoon at station-1 and 5 were much more pronounced than that at other stations during the pre-monsoon. The density fluctuation during the southwest monsoon period over different years at station-1 was 270-610, at station-2, 220-420, at station 3, 260-350, at station-4A 280-380, at station-4B ,220-300, and at station-5 ,250-530. During the northeast monsoon the density fluctuations over the years at all stations except at stations 2, 4A, and 5 were narrow. The seasonal density fluctuation over the years at station 1 was 410-450, at station-2 it was 260-410, station-3 it was 280-340, at station 4A it was 340-490, at station 4B it was 230-270 and at station-5 it was 260-380.

In order to assess the species diversity and the seasonal dynamics of different species of phytoplankton in the Lake, all the different genera were identified and they were counted individually every month. Study of species diversity was made during the year 2004 only. Phytoplankton identified in the Lake belongs to four classes—the *Cyanophyceae*, the *Euglenophyceae*, the *Bacillariophyceae* and the *Chlorophyceae*. The annual average and three-year average density of phytoplankton during different seasons from 2002-05 are given in **Table-176**.

Table: 172- Phytoplankton density of surface waters during pre-monsoon

Plank Den	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon- 1	370.0	180.0	200.0	260.0	120.0	400.0
Pre-monsoon- 2	550.0	470.0	470.0	470.0	450.0	570.0
Pre-monsoon- 3	490.0	400.0	330.0	470.0	340.0	500.0
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	183611.1	2	91805.56	57.65876	3.24E-06	4.102816
Columns	86444.44	5	17288.89	10.85834	0.000867	3.325837
Error	15922.22	10	1592.222			
Total	285977.8	17				

Table: 173-Phytoplankton density- surface waters-southwest monsoon

Plank Den	Station-1	Station-2	Station-3	Station-4A	Station-4B	Station-5
Southwest monsoon-1	300	310	280	280	250	320
Southwest monsoon-2	270	220	260	280	220	250
Southwest monsoon-3	610	420	350	380	300	530
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	109344.4	2	54672.22	17.05546	0.000599	4.102816
Columns	31027.78	5	6205.556	1.935875	0.174968	3.325837
Error	32055.56	10	3205.556			
Total	172427.8	17				

Table: 174- Phytoplankton density-surface waters-northeast monsoon

Plank Den	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Northeast monsoon-1	430.0	350.0	300.0	370.0	260.0	260.0
Northeast monsoon-2	450.0	260.0	340.0	490.0	270.0	370.0
Northeast monsoon-3	410.0	410.0	280.0	340.0	230.0	380.0
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	3744.444	2	1872.222	0.573324	0.581137	4.102816
Columns	60644.44	5	12128.89	3.714188	0.036798	3.325837
Error	32655.56	10	3265.556			
Total	97044.44	17				

Table: 175 -Three year average Phytoplankton density of surface water - 3 seasons

Plank Den	Station 1	Station 2	Station 3	Station 4A	Station 4B	Station 5
Pre-monsoon	470	350	333.3	400	303.3	490
Southwest monsoon	393.3	306.6	296.6	313.3	266.6	366.6
Northeast monsoon	430	340	306.7	400	253.3	336.7

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	12926	2	6463.001	6.232354	0.017478	4.102816
Columns	51471.26	5	10294.25	9.92688	0.001241	3.325837
Error	10370.08	10	1037.008			
Total	74767.34	17				

Table: 176- Year average and three-year average of phytoplankton density

Sl.No	Year	Year Average of the Lake (No. cells/L)	Average of Pre-monsoon (No. cells/L)	Average of SW. monsoon (No. cells/L)	Average of NE. monsoon (No. cells/L)
1	2002	-	-	290	328
2	2003	289	255	250	363
3	2004	423	496	432	340
4	2005	-	421	-	-
5	3Yr Average	356	391	324	344

Study of average of phytoplankton density in the Lake, shows that the fluctuations in algal density across seasons in the Lake is quite narrow (324-391/L). In general highest density (391/L) was found during the pre-monsoon followed by the northeast monsoon (344/L), and the lowest density (324/L) was found during the southwest monsoon. In the year average and three year average of density also this trend is visible.

4.10.1-b: Density and diversity of phytoplankton during pre-monsoon

Species diversity of phytoplankton during the pre-monsoon of 2004 at all stations is given in **Table 177**. During the pre-monsoon, altogether 49 species of phytoplankton were recorded from different stations of the Lake, of which 24 were identified up to the species level and the rest up to the genus level only. The phytoplankton recorded belongs to 4 major groups (*Cyanophyta*, *Euglenophyta*, *Bacillariophyta*, and *Chlorophyta*) and the station-wise percentage distribution of each group is clear from the table. The *Cyanophyceae* group was found at 13, 11, 15 and 13 % of the total count at stations-1, 2, 3 and 5 respectively, but its percentage was just 6 at station-4A and only 2 at station-4B. Six percentages of total phytoplankton at stations-4A and 5, 2% at station-2 and 4B, 5% at

station-1 were *Euglenophyta*, but *Euglenophyta* were totally absent at station-3. *Euglenophyta* were the least occurring group of phytoplankton in the *Periyar* Lake during pre-monsoon. Significant amount of Diatoms (*Bacillariophyta*) were found at all the stations. About 19 species of Diatoms were reported in the pre-monsoon period at different stations. *Melosira granulata* and *Pinnularia* sp.1 were the diatoms found at all stations in significant numbers. *Melosira granulata* was the most abundant diatom at all stations during the pre-monsoon. *Asterionella* sp-1 was found only at station 1 and *Stauronies anceps* Ehr. was found only at station-2. Diatom density was found minimum at station 5 (130 cells/L– 23% of the total) and maximum at station-4B (260/L– 58% of total plankton). Percentage of Diatoms among total plankton at stations-1, 2, 3 and 4A were 36, 38, 43, and 34 % respectively. *Chlorophyta* was the most dominant group of algae in all the stations except station-4B where it was only 38% of the total plankton. The highest *Chlorophyta* content was recorded at station-5 (60%). At other stations the percentage of *Chlorophyta* among total phytoplankton was 46% (station-1), 49% (station-2), 43% (station-3) and 53% (station-4A). Of the total 21 species of *Chlorophyta* present 12 were *Chlorococcales* and 9 were Desmids. *Closteriopsis longissima* was the only *Chlorococcales* member, which was found most abundantly at all stations except at station-1, where the genus *Chlorella* and *Closterium* were the most prominent ones. Among *Chlorococcales*, *Pediastrum tetras* was found at stations-1 and 5 only and *Closterium parvulum* was found absent at both these stations. Percentage content of *Chlorococcales* among *Chlorophyta* was the maximum (65%) at station-4B. Fifty-six percentage of *Chlorophyta* were *Chlorococcales* at stations-1 and 4A. The lowest percentage (30%) of *Chlorococcales* among *Chlorophyta* was found at station-3. At station-5, *Chlorococcales* content was 45% of the *Chlorophyta* and at station-2 it was 35% of the *Chlorophyta*. The highest density of Desmids, 70% of total *Chlorophyta*, was recorded at station-3 and the lowest density (35%) of Desmids was recorded at station-4B. Desmids recorded were 44%, 65%, 44% & 55% of the *Chlorophyta* at stations-1, 2, 4A and 5 respectively. The maximum Desmid diversity was found at station-3.

Table: 177- Phytoplankton density and diversity during pre-monsoon period

Sl. No	Algal Groups	Number of cells in water (No/L)					
		Station (1)	Station (2)	Station (3)	Station 4A	Station 4B	Station (5)
A. Cyanophyta							
1	<i>Agmenellum gelatinosa</i>			10			
2	<i>Microcystis aeruginosa</i>	10		10	10	10	20
3	<i>Anabena Sp</i>	30	30	30			30
4	<i>Spirulina sp</i>	30	20	20	20		20
<i>Total Density and number of species of Cyanophyta and % among total density of all</i>		70 (3) (13%)	50 (2) (11%)	70 (4) (15%)	30 (2) (6%)	10 (1) (2%)	70 (3) (13%)
B. Euglenophyta							
5	<i>Dinobryon Sp.</i>						10
6	<i>Euglena acus</i>	10			10	10	
7	<i>Euglena viridis</i>	10			10		10
8	<i>Phacus acumminatus</i>	10					10
9	<i>Trachelomonas armata</i>		10		10		
<i>Total Density and no of species of Euglenophyta, and % among total density of all.</i>		30 (3) (5%)	10 (1) (2%)	0 (0) (0%)	30 (3) (6%)	10 (1) (2%)	30 (2) (6%)
C. Bacillariophyta							
10	<i>Asterionella Sp.1</i>	20					
11	<i>Asterionella Sp.2</i>	10		10		10	10
12	<i>Cyclotella meneghiniana Kuetz.</i>		30	20			
13	<i>Cyclotella ocellata</i>		10	20		10	
14	<i>Cyclotella Sp.</i>	10	30	10	10		10
15	<i>Cocconies placentula Her. Ehr.</i>			30			
16	<i>Diplonies subovalis Cleve.</i>		10			10	
17	<i>Diplonies Sp.</i>	10	10	10			10
18	<i>Melosira granulata (Her.) Ralfs</i>	70	50	40	40	70	70
19	<i>Navicula Sp.1</i>	2			30	70	
20	<i>Navicula Sp.2</i>				10		
21	<i>Navicula Sp.3</i>			20	10		
22	<i>Pinnularia borealis Ehr.</i>				10		
23	<i>Pinnularia viridis</i>	30					
24	<i>Pinnularia Sp.1</i>	20	10	20	20	40	10
25	<i>Pinnularia Sp.2</i>		20	10	10		10
26	<i>Synedra Sp.1</i>				10	50	
27	<i>Synedra Sp.2</i>	10		10	10		10
28	<i>Stauronies anceps Ehr.</i>		10				
<i>Total Density and No of species of Diatoms, and percentage among total density of all.</i>		200 (9) (36%)	180 (9) (38%)	200 (11) (43%)	160 (10) (34%)	260 (7) (58%)	130 (7) (23%)
D. Chlorophyta							
(a) Chlorococcales							

29	<i>Closterium parvulum</i>		10	10	20	20	
30	<i>Closterium Sp.1</i>	40			10	10	
31	<i>Closteriopsis longissima</i>	30	30	30	30	40	40
32	<i>Chlorella Sp.</i>	40	30		10	10	
33	<i>Pediastrum duplex (turp) duplex</i>	10					10
34	<i>Pediastrum sp.</i>	10		10		10	30
35	<i>Coelastrum microsporum (Naeg)</i>		10	10	10	10	30
36	<i>Coelastrum Sp.</i>				20	10	
37	<i>Scenedesmus Sp.1</i>						20
38	<i>Scenedesmus Sp.2</i>				30		
39	<i>Pediastrum tetras (Ehr) Ralf.</i>	10					20
40	<i>Selenastrum westii</i>				10		
Density and Total No of species of Chlorococcales among Chlorophyta (Lake average 48% of Chlorophyta)		140 (6) (56%)	80 (4) (35%)	60 (4) (30%)	140 (8) (56%)	110 (7) (65%)	150 (6) (45%)
(b) Zygnematales (Desmids)							
41	<i>Staurastrum paradoxum</i>	40	40	20	20		70
42	<i>Staurastrum leptocladum</i>	40	40	30	30	20	40
43	<i>Staurastrum Sp.</i>		20	20	10		10
44	<i>Cosmarium contractum</i>	30	20	30	30	30	60
45	<i>Cosmarium Sp.1</i>		20	10			
46	<i>Cosmarium Sp.2</i>			10			
47	<i>Cosmarium Sp.3</i>				10		
48	<i>Euastrum insulare (Wittr) Roy</i>		10	20	10	10	
49	<i>Gonatozygon sp</i>						10
Total density and No. of species of Desmids and % among Chlorophyta (Lake average 52% of Chlorophyta)		110 (3) (44%)	150 (6) (65%)	140 (7) (70%)	110 (6) (44%)	60 (3) (35%)	190 (5) (55%)
Total density of Chlorophyta, No. of species, and % among total density of all		250 (9) (46%)	230 (10) (49%)	200 (11) (43%)	250 (14) (53%)	170 (10) (38%)	340 (11) (60%)
Total Density of all the Alga groups (No/L) in the Lake & Total No of Species (Lake Average of pre-monsoon 418 / L)		550 (24)	470 (22)	470 (26)	470 (29)	450 (19)	570 (18)

4.10.1-c: Density and diversity of phytoplankton during southwest monsoon

Species diversity of phytoplankton during southwest monsoon of 2004 at all stations is given in **Table 178**. During the southwest monsoon, altogether 40 genera of phytoplankton were recorded from different stations of the Lake, of which 21 were identified up to the species level and the rest up to the genus level only. The phytoplankton recorded belongs to 4 major groups. Station-wise percentage distribution of each group of plankton is also clear from the table. In the southwest monsoon,

Cyanophyceae was found about 4, 5, 3 and 8 % of the total count at stations-1, 2, 3 and 5 respectively. Of the total phytoplankton, *Cyanophyceae* was 6% at station-4A but only 3% at station-4B. Compared to pre-monsoon, there was a general decrease in the percentage of *Cyanophyceae* at all stations during the southwest monsoon. *Euglenophyta* were recorded at stations-1 (4 species), 4A (only one species) and 5 (two species) only during the southwest monsoon. In this season, 7% of total phytoplankton at station-1 was *Euglenophyta* but the percentage of *Euglenophyta* at stations-4A was just 3% and they were 4% in station-5. *Euglenophyta* were the least occurring group of phytoplankton in the *Periyar* Lake during southwest monsoon except at station-1, where the least occurring group of phytoplankton was *Cyanophyceae*.

Only 14 genera of Diatoms (*Bacillariophyta*) were recorded in the Lake during this season. When compared to pre-monsoon (19 genera of diatoms were reported in the pre-monsoon period) there was a decrease in species diversity of Diatoms during the southwest monsoon. Three common species reported at all the stations during this season were *Melosira granulata*, *Melosira sp.* and *Cyclotella sp.*, found at all stations in significant numbers. *Melosira granulata* was the most abundant Diatom at all stations except at station-4B during the southwest monsoon. At station 4B *Cyclotella* was the most abundant species in this season. *Cocconies placentula* Her. Ehr. was found only at station-5 and an unidentified *Pinnularia sp.* was found only at station 4B. Highest Diatom density was found at station-4A (230/L – 61% of total plankton). Percentage of Diatoms among total plankton at stations-1, 2, 3 and 4B was 34, 43, 34, and 56 % respectively. At station-5 the percentage of Diatoms was 38%. Eighteen species of *Chlorophyta* were recorded in the Lake during the southwest monsoon among which 8 were *Chlorococcales* and 10 were Desmids. *Closterium parvulum* and *Closteriopsis longissima* were the 2 species of *Chlorococcales* which were found in all stations during the southwest monsoon and the latter was the most abundant species of *Chlorophyta* at all stations. Among *Chlorococcales*, *Scenedesmus quadricauda* was found at stations-1 and 5 only. *Chlorophyta* represented the largest group (more than 50%) of total phytoplankton at all stations except 4A and 4B during the southwest monsoon. The highest percentage content of *Chlorophyta* recorded was at station-3 (63%). Percentage content of *Chlorococcales*

among *Chlorophyta* was highest (55%) at station-2 and 4B. Forty three percentage of *Chlorophyta* were *Chlorococcales* at station-1. The lowest percentage of *Chlorococcales* among *Chlorophyta* found at station-5 (37%). At station-5, *Chlorococcales* content was 42% of the *Chlorophyta* and at station-3 it was 41%. In general Desmids were higher than *Chlorococcales* at all stations except at station-2 and 4B during the southwest monsoon. They were found in lesser numbers than *Chlorococcales* at stations-2 (100, 45 % of *Chlorophyta*) and station-4B (50, 45% *Chlorophyta*). Desmids recorded at stations- 1, 3, 4A and 5 were 57%, 59%, 58% and 63% of the *Chlorophyta* respectively. Maximum of Desmids diversity was found at stations-1 and 3(7 species); only 4 species of Desmids were found at station-4B.

Table-178: Phytoplankton density and diversity during southwest monsoon period

Sl. No	Algal Groups	Number of cells in water (No/L)					
		Station (1)	Station (2)	Station (3)	Station 4A	Station 4B	Station (5)
A. Cyanophyta							
1	<i>Agmenellum gelatinosa</i>	10					10
2	<i>Anabena Sp.</i>					10	10
3	<i>Microcystis aeruginosa</i>	10		10	20		10
4	<i>Spirulina Sp.</i>		20				10
<i>Density, No of species of Cyanophyta and % among total density of all</i>		20 (2) (4%)	20 (1) (5%)	10 (1) (3%)	20 (1) (6%)	10 (1) (3%)	40 (4) (8%)
B. Euglenophyta							
5	<i>Dinobryon Sp.</i>	10					
6	<i>Euglena acus</i>	10					10
7	<i>Euglena viridis</i>	10			10		10
8	<i>Trachelomonas armata</i>	10					
<i>Density, no of species of Euglenophyta, and % among total density of all</i>		40 (4) (7%)	0 (0) (0%)	0 (0) (0%)	10 (1) (3%)	0 (0) (0%)	20 (2) (4%)
C. Bacillariophyta							
9	<i>Cyclotella meneghiniana Kuetz.</i>	20	40	20	20		30
10	<i>Cyclotella sp.</i>	10	20	20	30	40	40
11	<i>Cyclotella ocellata</i>			10			
12	<i>Cocconies placentula Her. Ehr.</i>						10
13	<i>Diplonies subovalis Cleve.</i>	20					
14	<i>Melosira granulata (Her.) Ralfs</i>	50	30	20	50	30	40
15	<i>Melosira sp.</i>	30	20	10	30	40	30
16	<i>Navicula cuspidata</i>	20	10				10
17	<i>Navicula sp.1</i>	10	10	20	20		
18	<i>Nitzschia palea</i>		20				
19	<i>Nitzschia sp.</i>	20	30	20	20		20
20	<i>Pinnularia viridis</i>	20			20	20	20
21	<i>Pinnularia sp.1</i>					20	

22	<i>Stauronies anceps Ehr.</i>				40	30	
	<i>Density, No of species of Diatoms, and % among total density of all</i>	200 (9) (34%)	180 (8) (43%)	120 (7) (34%)	230 (7) (61%)	180 (6) (56%)	200 (8) (38%)
D. Chlorophyta : (a) Chlorococcales							
23	<i>Closterium parvulum</i>	30	20	20	10	20	20
24	<i>Closterium Sp.1</i>	20	20	10			20
25	<i>Closterium Sp.2</i>	20	30	10			
26	<i>Closteriopsis longissima</i>	40	30	20	20	20	40
27	<i>Chlorella Sp.</i>	10	10	10		20	
28	<i>Selenastrum westii</i>	10	10				
29	<i>Scenedesmus quadricauda</i>	20					20
30	<i>Scenedesmus Sp.1</i>			20	20		
	<i>Density, Total No of species of Chlorococcales & % among Chlorophyta (Lake average 45% of chlorophyta)</i>	150 (7) (43%)	120 (6) (55%)	90 (6) (41%)	50 (3) (42%)	60 (3) (55%)	100 (4) (37%)
(b)Zygnematales (Desmids)							
31	<i>Cosmarium contractum</i>	40	20		10		30
32	<i>Cosmarium sp.1</i>			10		10	10
33	<i>Cosmarium Sp.2</i>			10	10	20	
34	<i>Cosmarium Sp.3</i>	10					
35	<i>Euastrum insulare (Wittr) Roy</i>	30		10			20
36	<i>Euastrum Sp.</i>		10				
37	<i>Staurastrum paradoxum</i>	50	40	30	20	10	50
38	<i>Staurastrum leptocladum</i>	40	20	20	20	10	40
39	<i>Staurastrum chaetoceras</i>	10		10	10		
40	<i>Staurastrum Sp.</i>	20	10	40			20
	<i>Density, Total No of species of Desmids & % among Chlorophyta (Lake average 55% of Chlorophyta)</i>	200 (7) (57%)	100 (5) (45%)	130 (7) (59%)	70 (5) (58%)	50 (4) (45%)	170 (6) (63%)
	<i>Density of Chlorophyta, No. of species and % among total density of all phytoplankton</i>	350 (14) (56%)	220 (11) (52%)	220 (12) (63%)	120 (7) (31%)	110 (7) (37%)	270 (10) (51%)
	Total Density of all the groups & Total No of species in the Lake (Lake average 431/L)	610 (29)	420 (20)	350 (20)	380 (16)	300 (14)	530 (24)

4.10.1-d: Density and diversity of phytoplankton during pre-monsoon

Species diversity of phytoplankton during northeast monsoon of 2004 at all stations is given in **Table-179**. During the northeast monsoon, altogether 42 genera of phytoplankton were recorded from different stations of the Lake, of which 18 were identified up to the species level and the rest up to the genus level. The Phytoplankton recorded belongs to 4 major groups. The station wise percentage distribution of each group at all stations also is clear from the table below. In the northeast monsoon, *Cyanophyceae* was found at 12, 15, 14, 12, 15% of the total count at stations-1, 2, 3, 4A and 5 respectively. However, at station-4B

Cyanophyceae was just 4% of the total phytoplankton. Compared to the other seasons, the count of *Cyanophyceae* decreased, while the percentage of *Cyanophyceae* among all phytoplankton was found increased at all stations during the northeast monsoon. *Microcystis* sp. of *Cyanophyceae* was found throughout the Lake at all stations during this season. Unlike in the southwest monsoon, *Euglenophyta* were recorded at all stations except in station-4B during the northeast monsoon. Altogether 5 species of *Euglenophyta* were recorded during this season. At station-1, the maximum diversity of 4 species of *Euglenophyta* was noticed. At station-2 there was only one species, at stations- 3, 4A and 5, two species each were recorded in the season. During the northeast monsoon season, 10% of total phytoplankton at station-1 was *Euglenophyta* but the percentage of *Euglenophyta* at station-2 was just 3%, at station-3 it was 7% and at station-4A it was 6% and at station-5 it was 5%. The percentage of *Euglenophyta* among phytoplankton in the Lake increased during northeast monsoon. Fourteen genera of Diatoms (*Bacillariophyta*) were recorded in the Lake during this season just as in the case of southwest monsoon. However, some of the species noticed during northeast monsoon were new to this season, which include *Fragillaria* sp, *Pinnularia borealis* and certain other species of the same genus. Some of the species which were present in the southwest monsoon were found absent in the northeast monsoon which included *Cocconies placentula* Her. Ehr., *Diplonies subovalis* Cleve., *Nitzchia palea*, *Nitzchia* sp., etc. *Cyclotella meneghiniana* Kuetz., and *Melosira granulata* (Her.) Ralfs were the 2 species found common in all the stations during this season in significant numbers. *Melosira granulata* was the most abundant Diatom at all stations except at station-4B during the northeast monsoon. At station-4B *Pinnularia borealis* Her. was the most abundant species in this season. *Fragillaria* sp-1 was found only at station-4B and an unidentified species of *Pinnularia* was found only at station-5. Seventeen species of *Chlorophyta* were recorded in the Lake during the northeast monsoon among which only 8 were *Chlorococcales* and 9 were Desmids. *Closteriopsis longissima* was the only species of *Chlorococcales* found in all stations in the northeast monsoon and it was also the most abundant species of *Chlorophyta* at all stations except at station-1, where *Staurastrum leptocladum* (desmids) was the most abundant one. *Chlorophyta* represented the largest group of phytoplankton at all stations except at 4B during the northeast monsoon. The highest percentage content (65%) of *Chlorophyta* recorded during northeast monsoon season was at station-4A. Percentage

content of *Chlorococcales* among *Chlorophyta* was below 50% at all stations except at station-4B, where it was 80%. In general Desmids were higher than 50% among *Chlorophyta* at all stations except station-4B during the northeast monsoon. Maximum of Desmids diversity (total 7 species) was found at station-3; only 1 species of Desmid was found at station-4B.

Table-179: Phytoplankton density and diversity during northeast monsoon period

Sl. No	Algal Groups	Number of cells in water (No/L)					
		Station (1)	Station (2)	Station (3)	Station 4A	Station 4B	Station (5)
A. Cyanophyta							
1	<i>Agmenellum gelatinosa</i>	10	10	10	10		10
2	<i>Microcystis aeruginosa</i>	10	10	10	10		10
3	<i>Microcystis sp.1</i>	20	20	10	20	10	20
4	<i>Microcystis sp.2</i>	10	10	10			20
5	<i>Microcystis sp.3</i>		10				
<i>Total Density & No of species of Cyanophyta & % among total density of all</i>		50 (4) (12%)	60 (5) (15%)	40 (4) (14%)	40 (3) (12%)	10 (1) (4%)	60 (4) (15%)
B. Euglenophyta							
6	<i>Dinobryon Sp.</i>	10					
7	<i>Euglena acus</i>	10		10	10		10
8	<i>Euglena viridis</i>	10	10				
9	<i>Euglena sp.</i>	10		10			
10	<i>Trachelomonas armata</i>				10		10
<i>Total Density & No of species of Euglenophyta & % among total density of all</i>		40 (4) (10%)	10 (1) (3%)	20 (2) (7%)	20 (2) (6%)	0 (0) (0%)	20 (2) (5%)
C. Bacillariophyta							
11	<i>Cyclotella meneghiniana Kuetz.</i>	10	10	10	10	10	10
12	<i>Cyclotella Sp.1</i>		20	10			
13	<i>Fragillaria Sp.1</i>					10	
14	<i>Fragillaria Sp.2</i>	10		10			10
15	<i>Melosira granulata (Her.) Ralfs</i>	40	30	10	30	20	40
16	<i>Melosira Sp.1</i>	10					10
17	<i>Navicula cuspidata</i>	20	10			20	30
18	<i>Navicula Sp.1</i>				10		
19	<i>Pinnularia borealis Ehr.</i>	10	20			40	
20	<i>Pinnularia viridis</i>		10			30	
21	<i>Pinnularia Sp.1</i>	20	10	10	10	30	
22	<i>Pinnularia Sp.2</i>						10
23	<i>Pinnularia Sp.3</i>	10					10
24	<i>Stauronies anceps Ehr.</i>	20	20				
<i>Total Density and no. of species of Bacillariophyta and % among total density of all</i>		150 (9) (37%)	130 (8) (33%)	50 (5) (18%)	60 (4) (18%)	160 (7) (70%)	120 (7) (32%)

D. Chlorophyta : (a) Chlorococcales							
25	<i>Closterium parvulum</i>	20	20	10	30		20
26	<i>Closterium Sp.1</i>	10	10		10	10	10
27	<i>Closterium Sp.2</i>	10		10		10	10
28	<i>Closteriopsis longissima</i>	20	40	30	40	10	30
29	<i>Closteriopsis Sp.</i>		10				
30	<i>Coelastrummicrosporium (Naeg)</i>					10	
31	<i>Coelastrum Sp.1</i>	10	10	10	10		
32	<i>Chlorella Sp.</i>						
Total Chlorococcales, No. of species and % among total Chlorophyta (Lake average 38% of Chlorophyta)		70 (5) 41%	90 (5) 45%	60 (4) 35%	90 (4) 41%	40 (4) 80%	70 (4) 39%
(b) Zygnematales (Desmids)							
33	<i>Cosmarium contractum</i>	20	30	20	20		30
34	<i>Cosmarium Sp.1</i>						10
35	<i>Euastrum insulare (Wittr) Roy</i>		10	10			
36	<i>Euastrum Sp.1</i>	10		10	10		
37	<i>Euastrum Sp.2</i>	10		10	10		10
38	<i>Penium sp</i>					10	
49	<i>Staurastrum leptocladum</i>	30	30	30	40		20
40	<i>Staurastrum chaetoceras</i>	20	20	20	30		20
42	<i>Staurastrum Sp.</i>	10	20	10	20		20
Density and Total no. of species of Desmids, and % among total Chlorophyta (Lake average 62% of Chlorophyta)		100 (6) 59%	110 (5) 55%	110 (7) 65%	130 (6) 59%	10 (1) 20%	110 (6) 61%
Total Density of Chlorophyta, No. of species and their percentage among total phytoplankton		170 (11) (42%)	200 (10) (50%)	170 (11) (61%)	220 (10) 65%	50 (5) (22%)	180 (10) (48%)
Total Density of all the groups & Total No of species in the Lake Lake average (340/l)		410 (27)	400 (24)	280 (22)	340 (19)	230 (14)	380 (23)

4.10.2. Periphyton

Periphyton algal community was studied at stations-1 and 4A. The details of the Periphyton community structure during the three seasons of 2004 are given in **Table-180**. In both the pre-monsoon and northeast monsoon the Periphyton quantity was much higher in station 1 than station-4A. But during the southwest monsoon season the Periphyton quantity in station-4A was found higher than that of station-1. In general Periphyton community at station -1 was found dominated by *Chlorophyta* throughout the three seasons of the year whereas at station-4A the dominant group was Diatoms throughout the three seasons of the year. *Euglenophyta* were recorded during the southwest monsoon alone

and that too only at station 1. During the pre-monsoon and southwest monsoon *Spirogyra*, *Chlorella*, and *Oedogonium* were the most common members of *Chlorophyta* recorded at station-1 whereas *Staurastrum paradoxum* and *Cosmarium contractum* were the common *Chlorophyta* at station-4A.

Table 180 -Periphytic algal community structure of three seasons in 2004

Sl. No	Algal Groups & Major Species	Number of cells in water (No/ml of concentrate)					
		Pre-monsoon		Southwest monsoon		Northeast monsoon	
		Station (1)	Station 4A	Station (1)	Station 4A	Station (1)	Station 4A
A. Chlorophyta							
1	<i>Oedogonium Sp</i>	18		12			
2	<i>Spirogyra communis</i>	20		9		5	
3	<i>Chlorella Sp.</i>	4		3			
4	<i>Staurastrum paradoxum</i>	11	9	11	15	9	4
5	<i>Cosmarium contractum</i>	9	6	9	5	17	7
6	<i>Closterium sp</i>	29	13	14	20	15	3
Total of the group		91 (46%)	28 (30%)	58 (34%)	40 (27%)	46 (35%)	14 (21%)
B. Diatoms							
7	<i>Navicula cuspidata</i>	17	3	13		8	5
8	<i>Melosira granulata</i>	11	7	11	15	18	9
9	<i>Synedra Sp</i>	6		13			
10	<i>Pinnularia sp</i>		11	8	15	10	8
11	<i>Cyclotella sp</i>	11	16	12		22	12
Total of the group		45 (25%)	37 (40%)	57 (33%)	30 (20%)	58 (43%)	34 (50%)
C. Euglenophyta							
12	<i>Phacus acuminiatus</i>	18		19		9	
13	<i>Euglena sp</i>	14		20		8	
Total of the group		32 (18%)	0 (0%)	39 (23%)	0 (0%)	17 (13%)	0 (0%)
D. Cyanophyta							
14	<i>Microcystis sp</i>	17	20	18	60	9	19
15	<i>Agmenellum sp.</i>	13	8	1	20	3	1
Total of the group		30 (17%)	28 (30%)	19 (11%)	80 (53%)	12 (9%)	20 (29%)
Total of all the Groups		198	93	173	150	133	68

4. 10. 3. Benthon

Benthic algal community structure of the Lake was analyzed at three stations- 1, 4A and 4B throughout the three seasons in 2004. The details of the benthic

community structure during these three seasons from pre-monsoon to northeast monsoon are given in **Tables-181,182,183** respectively. It is clear from the tables that in general, benthic algal diversity gradually decreases from pre-monsoon to northeast monsoon at all the three stations. Moreover, a decrease in total benthic algal diversity is found from station1 to 4B as well. During the pre-monsoon period, there was no significant reduction in the diversity of Diatom species in the three stations examined. However, there was significant reduction in the diversity of *Chlorophyta*, *Cyanophyta* and *Euglenophyta*.

During pre-monsoon Diatoms was the most diverse group of algae in the benthon. About 17-18 species of Diatoms were recorded at all the stations. *Chlorophyta* formed the second most diverse group with about 15 species at station 1; 12 at station-4A and 11 at station 4B. Seven species of *Cyanophyta* and 2 species of *Euglenophyta* were found in station-1 in this season whereas both were represented by only a single species each at station-4A in the season. During the pre-monsoon period *Euglenophyta* and *Cyanophyta* were found totally absent in station-4B.

Table 181: Percentage density of benthic algae during pre-monsoon 2004 (P- present, N- numerous, A- absent)

Sl. No.	Group & Name of Species	S1	S4A	S4B
A. DIATOMS (BACILLARIOPHYTA)				
1	<i>Amphora ovalis</i>	P	P	P
2	<i>Cocconies placentula</i>	P	P	P
3	<i>Cymbella affinis</i>	P	P	P
4	<i>Cyclotella ocellata</i>	P	P	P
5	<i>Cyclotella meneghiniana</i>	P	p	p
6	<i>Diplonies subovalis</i>	P	P	P
7	<i>Fragillaria sp.</i>	P	P	P
8	<i>Gomphonema parvulum</i>	P	P	P
9	<i>Melosira granulata</i>	P	P	P
10	<i>Navicula cuspidata</i>	P	P	P
11	<i>Nitzschia palea</i>	P	P	P
12	<i>Pinnularia borealis</i>	P	P	P
13	<i>Pinnularia viridis</i>	P	P	P
14	<i>Pinnularia sp</i>	P	P	P

15	<i>Synedra ulna</i>	P	P	P
16	<i>Stauronies sp.</i>	P	P	P
17	<i>Sourirella robusta</i>	A	P	P
18	<i>Tabellaria sp.</i>	P	P	P
Total species of the group present		17(41%)	18(57%)	18(62%)
B. CHLOROPHYTA				
1	<i>Ankistrodesmus falcatus</i>	P	A	A
2	<i>Cosmarium contractum</i>	P	P	P
3	<i>Cosmarium obsoletum</i>	P	P	P
4	<i>Closterium parvulum</i>	P	P	P
5	<i>Closteriopsis longissima</i>	P	P	P
6	<i>Euastrum insulare</i>	P	P	P
7	<i>Netrium digitus</i>	P	P	P
8	<i>Penium marginatum</i>	P	P	P
9	<i>Scenedesmus quadricauda</i>	P	P	P
10	<i>Scenedesmus dimorphus</i>	P	A	A
11	<i>Scenedesmus bijugatus</i>	P	P	A
12	<i>Staurastrum paradoxum</i>	P	P	P
13	<i>Staurastrum leptocladum</i>	P	P	P
14	<i>Selenastrum gracile</i>	P	P	P
15	<i>Ulothrix zonata</i>	P	A	A
Total species of the group present		15(36%)	12(38%)	11(37%)
C. CYANOPHYTA				
1	<i>Anabena sp.</i>	P	A	A
2	<i>Agmenellum gelatinosa</i>	P	A	A
3	<i>Cylindrospermum sp.</i>	P	A	A
4	<i>Microcystis aeruginosa</i>	P	P	A
5	<i>Nostoc sp.</i>	P	A	A
6	<i>Oscillatoria sp.</i>	P	A	A
7	<i>Spirulina sp.</i>	P	A	A
Total species of the group present		7(18%)	1(3%)	0(0%)
D. EUGLENOPHYTA				
1	<i>Euglena acus</i>	P	P	A
2	<i>Trachelomonas armata</i>	P	A	A
Total species of the group present		2(5%)	1(3%)	0(0%)
Total Diversity		41	32	29

Total benthic algal diversity at stations 1, 4A and 4B during the southwest monsoon were 41, 30 and 22 respectively. Among these, 16 species of Diatoms were at both stations-1 and 4A, but only 14 species of Diatoms were found at station-4B. At

stations-1, 4A and 4B there were 16 species, 10 species and 7 species of *Chlorophyta* respectively. There were about 6 species of *Cyanophyta* and 3 species of *Euglenophyta* at station-1 where as only 2 species of *Cyanophyta* and *Euglenophyta* each were found at station-4A, and *Cyanophyta* was totally absent in station-4B during this season. *Euglenophyta* was represented with 1 species at this station.

Table-182: Percentage density of benthic algae during southwest monsoon 2004

Sl. No.	Group & Name of Species	S1	S4A	S4B
A. DIATOMS (BACILLARIOPHYTA)				
1	<i>Cymbella affinis</i>	P	P	P
2	<i>Cymbella sp.1</i>	P	P	P
3	<i>Cocconies placentula</i>	P	P	P
4	<i>Cyclotella ocellata</i>	P	P	P
5	<i>Cyclotella menhnginiana</i>	P	P	P
6	<i>Diplonies subovalis</i>	P	P	P
7	<i>Diatoma sp.</i>	P	P	P
8	<i>Melosira granulata</i>	P	P	P
9	<i>Navicula cuspidate</i>	P	P	P
10	<i>Navicula sp.1</i>	P	P	P
11	<i>Nitzchia palea</i>	P	P	P
12	<i>Pinnularia borealis</i>	P	P	A
13	<i>Pinnularia viridis</i>	P	P	P
14	<i>Synedra ulna</i>	P	P	P
15	<i>Stauronies sp.</i>	P	P	P
16	<i>Sourirella robusta</i>	A	P	P
17	<i>Tabellaria sp.</i>	P	A	A
Total species of the group present		16(41%)	16(53%)	14(63%)
B. CHLOROPHYTA				
1	<i>Cosmarium contractum</i>	P	P	P
2	<i>Cosmarium viridis</i>	P	A	A
3	<i>Cosmarium spinulosum</i>	P	P	A
4	<i>Closteridium Sp.</i>	P	P	P
5	<i>Closterium parvulum</i>	P	P	P
6	<i>Characium</i>	P	A	A
7	<i>Euastrum spinulosum</i>	P	P	A
8	<i>Euastrum insulare</i>	P	P	P
9	<i>Gymnodinium</i>	P	P	A
10	<i>Pediastrum duplex</i>	P	A	A
11	<i>Pediastrum tetras</i>	P	A	A
12	<i>Staurastrum chetoceras</i>	P	P	P
13	<i>Spondylosium Sp.</i>	P	A	A
14	<i>Selenastrum westii</i>	P	P	P
15	<i>Scenedesmus quadricauda</i>	P	P	P
16	<i>Temnogametum</i>	P	A	A
Total species of the group present		16(39%)	10(33%)	7(32%)
C. CYANOPHYTA				
1	<i>Anabaena Sp.</i>	P	A	A

2	<i>Agmenellum gelatinosa</i>	P	A	A
3	<i>Cylindrospermum Sp.</i>	P	A	A
4	<i>Microcystis aeruginosa</i>	P	P	A
5	<i>Nostoc Sp.</i>	P	P	A
6	<i>Spirulina Sp.</i>	P	A	A
Total species of the group present		6(15%)	2(7%)	0(0%)
D. EUGLENOPHYTA				
1	<i>Euglena acus</i>	P	P	A
2	<i>Phacus accuminatus</i>	P	A	A
3	<i>Lepocinclis Sp.</i>	P	P	P
Total species of the group present		3(7%)	2(6.6%)	1(4.5%)
Total Diversity		41	30	22

Table 183: Percentage density of benthic algae during northeast monsoon 2004

Sl. No.	Group & Name of Species	S1	S4A	S4B
A. DIATOMS (BACILLARIOPHYTA)				
1	<i>Accanthus sp.</i>	P	P	P
2	<i>Cyclotella ocellata</i>	P	P	P
3	<i>Cyclotella menhnginiana</i>	P	P	P
4	<i>Diplonies subovalis</i>	P	P	P
5	<i>Diatoma sp.</i>	P	P	P
6	<i>Melosira granulata</i>	P	P	P
7	<i>Navicula cuspidata</i>	P	P	P
8	<i>Navicula sp.</i>	P	P	P
9	<i>Nitzchia palea</i>	P	P	P
10	<i>Pinnularia borealis</i>	P	P	A
11	<i>Stauronies sp.</i>	P	P	P
12	<i>Tabellaria sp.</i>	P	A	A
Total species of the group present		12(39%)	11(52%)	10(67%)
B. CHLOROPHYTA				
1	<i>Cosmarium contractum</i>	P	P	P
2	<i>Cosmarium viridis</i>	P	P	A
3	<i>Closteridium sp.</i>	A	P	P
4	<i>Euastrum insulare</i>	P	P	P
5	<i>Gymnodinium</i>	P	A	A
6	<i>Mougeotia quadrata</i>	P	P	A
7	<i>Spondylosium sp.</i>	P	A	A
8	<i>Selenastrum westii</i>	P	P	A
9	<i>Staurastrum chetoceras</i>	P	P	P
10	<i>Scenedesmus quadricauda</i>	P	P	P
Total species of the group present		9(29%)	8(38%)	5(33%)
C. CYANOPHYTA				
1	<i>Anabaena sp.</i>	P	A	A
2	<i>Agmenellum gelatinosa</i>	P	A	A
3	<i>Cylindrospermum sp.</i>	P	A	A
4	<i>Microcystis aeruginosa</i>	P	A	A

5	<i>Nostoc sp.</i>	P	A	A
6	<i>Oscillatoria sp.</i>	P	A	A
7	<i>Spirulina sp.</i>	P	P	A
Total species of the group present		7(22%)	1(4%)	0(0%)
D. EUGLENOPHYTA				
1	<i>Euglena acus</i>	P	A	A
2	<i>Phacus accuminatus</i>	P	P	A
3	<i>Lepocinclis Sp.</i>	P	A	A
Total species of the group present		3(10%)	1(4%)	0(0%)
Total Species Diversity		31	21	15

Total benthic algal diversity at stations 1, 4A and 4B during the northeast monsoon were 31, 21 and 15 respectively. There were 12 Diatom species at station-1, 11 at station-4A and only 10 at 4B. *Chlorophyta* was found represented by 9 species at station-1, 8 species at station-4A and 5 species at station-4B. There were about 7 species of *Cyanophyta* and 3 species of *Euglenophyta* At station-1 whereas only 1 species of *Cyanophyta* and 1 species of *Euglenophyta* were found in station-4A, and *Cyanophyta* and *Euglenophyta* were totally absent in station-4B during this season.

4.11. Correlations- phytoplankton density and water quality parameters

Correlation tendencies of phytoplankton density with different physico-chemical water quality parameters were not identical at all stations (**Table-184**). In station-1 significant positive correlations were observed between total phytoplankton density and water temperature, TDS, total hardness, alkalinity, salinity, EC, CO₂, BOD, total P, total nitrogen, Mg, Na, COD, oil and grease. However, significant negative correlations were observed for total plankton density and secchi depth, pH, DO, K, and Silica at this station. At station-2, significant positive correlations were noticed between phytoplankton density and water temperature, TDS, alkalinity, CO₂, total nitrogen, nitrate, Cl and Na but negative correlations were observed for total solids, pH, salinity, DO, Ca, K, silica, and COD. At station-3, water temperature, TS, EC, BOD, total nitrogen, nitrate, Mg, Na, oil and grease were the parameters those showed a significant positive relation with that of plankton density. However, significant negative correlations were observed between plankton density and pH, DO, total Cl, Ca, and K at this station. At station-4A positive correlations were observed for TDS, secchi depth, total alkalinity, salinity, EC, CO₂, BOD, total nitrogen, nitrate, total Cl, and Na but negative correlations

were observed between water temperature, pH, DO, total P, Ca, and Silica with that of total plankton density. At station-4B positive correlations were observed for water temperature, TS, total hardness, total alkalinity, salinity, BOD, total P, total nitrogen, total Cl, Ca, Mg, Na, COD, oil and grease, but this station showed significant negative trends in TDS, secchi depth, CO₂, and DO. At station-5, significant positive correlations were observed for water temperature, Total solids, total hardness, total alkalinity, EC, BOD, total P, total nitrogen, nitrate, total Cl, Ca, Mg, Na, COD, oil and grease with that of phytoplankton density. But there were negative trends between TDS, secchi depth, salinity and CO₂ with that of phytoplankton.

4. 12. Correlations- Phytoplankton groups density and water quality parameters

Different algal groups showed different correlation tendencies with different quality parameters. Moreover, the same quality parameter sometimes showed contradictory correlations at different stations (**Table-185**).

4.12.1. Cyanophyta and physico-chemical parameters

This algal group showed significant positive relationship with water temperature at stations 2, 3, and 5 but negative correlations with the same parameter at station-4A. At station-1 and 4B the relationship between water temperature and *Cyanophyta* was quite insignificant. With TS this algal group showed negative relations at stations-2, 4A and 5. Relationships with this parameter at other stations were insignificant. Positive correlations between *Cyanophyta* and secchi depth were noted at stations-2, 3, 4A, but the trends were negative at 1, and 5. At station-4B the relationship was insignificant between *Cyanophyta* and secchi depth.

The group showed positive tendency with pH at station-5 alone, at all the other stations the relationship was insignificant. The group was positively correlated with total hardness at station-1 only, but correlations were negative at stations-2 and 3. At stations-5 and 4B the relationship observed was quite insignificant. Total alkalinity was correlated positively with this group at stations-1, 2 and 5, whereas negatively correlated at station-3. There were no significant trends of relationships at other stations for this parameter. Salinity was correlated positively with *Cyanophyta* at stations-1 and 3 only, whereas

negatively correlated at stations-2, and 5. Station-4A and 4B showed no significant positive or negative trends. There were positive significant trends of correlations with EC and *Cyanophyta* at stations 2, and 3 whereas negative correlation was noticed only at station-1. At stations-4A, 4B and 5, the relationship was insignificant.

Cyanophyta correlated positively with dissolved CO₂ at stations-1, 2, and 3, but negatively correlated at station-5. At other stations correlation was insignificant. With DO, this algal group showed significant negative tendencies at all stations except 4B, where neither positive nor negative relations were noticed.

Correlation of the group with Ca was positive at station-5 but negative at stations-2 and 3. At other stations the correlations were quite insignificant. There were no significant positive correlation between *Cyanophyta* and Mg at any station except station-1, but negative correlations were noticed at station-4A only. The algal group showed no positive tendency with K at any station where as it showed negative trends at stations-1, 3,4A, and 5 and the relationships at stations-2 and 4B were insignificant. With Na, the group showed positive correlations at station-1, 3, and 5 while no significant relationship was noticed at other stations. The algal group was found positively correlated with Cl at stations-2,4A and 5 but negatively correlated at station-3. At other stations the correlations were insignificant.

Total P was positively correlated at stations-1 and 5 but negatively correlated at stations-2 and 4A, while other stations showed insignificant correlations. This algal group showed positive relationships with total nitrogen at all stations except at 4B, where the relationship was quite insignificant. With Nitrate, the algal group showed positive correlations at stations-3, 4A, and 5, but at other stations the relationship was insignificant. *Cyanophyta* showed only negative correlations with Silica at all stations except at station-4B where the relationship was insignificant.

Cyanophyta showed positive correlations with BOD at stations-1, 2, 3, 4A and 5, no negative correlations observed. COD correlations were positive at stations-1 and 5 only, but at other stations the correlations were found insignificant. Negative correlations

were observed between oil and grease, and *Cyanophyta* at stations-3, and 4A but the relationships were quite insignificant at other stations.

4.12.2. Euglenophyta and physico-chemical parameters

As in the case of *Cyanophyta*, *Euglenophyta* also showed different correlations with different parameters and also with same parameter at different stations. No negative correlation trends were noticed between *Euglenophyta* and physico-chemical parameters at station-4B. The group showed positive trend with water temperature at stations-2, 4B, and 5 but negative trends at station-1. At other stations the relationships were insignificant. With secchi depth, the correlations were positive at stations-1, and 3; but at all the other stations this parameter showed insignificant relationship with *Euglenophyta*. Relationships with pH were positive at stations-1 and 3, but negative at station-4A. At other stations relationships were quite insignificant. The group showed positive relations with total hardness at 4B and 5 but negative relations at 1 and 3 at other stations the relations were insignificant. Correlations with total alkalinity was positive at stations-2, 4A, 4B and 5 but negative at 1 and 3. Relations with EC were positive at 4A, 4B, and 5 but negative at station-1. At stations-2 and 3 the relations were insignificant. With salinity, the trend was positive at stations- 3, 4A, 4B but negative at stations-2. At station-5 an insignificant relationship was noticed.

Correlations with dissolved CO₂ were positive at stations-2, 3 and 4A, but the relations were negative at station-1. At stations-4B and 5 the relations were quite insignificant. With DO the trend noticed was positive at stations-1 and 3 but negative at 2, 4A, 4B and 5. At station-5 significant negative correlations were noticed only for DO.

Relationship of the group with Ca was positive at stations-4B and 5 only but negative at stations 1, 3 and 4A. At stations-2 the relation was insignificant. Correlations with Mg were positive at stations-4A, 4B and 5 but negative at station-1 and 3. *Euglenophyta* showed positive correlations with K at stations-1, 2, and 4B but negative correlation at station-3. At stations-4A and 5 the relations were insignificant. With Na, the group showed a positive trend at stations-4A, 4B and 5 but negative trend at station-3

and at stations-1 and 2 the trends were insignificant. With Cl the algal group showed a positive tendency at stations-2, 3, 4A, 4B, and 5 but negative relations at station-1.

Relationship of the group with total nitrogen was positive at stations-2, 4A, 4B and 5 but negative at station-1. At station-3, the relationship was insignificant. With Nitrate, the group showed positive correlations at stations-2, 3, 4B, 5 but negative at station-1, where as at 4A the relation was insignificant. *Euglenophyta* showed positive correlations with total P at stations-4B and 5 but negative at stations-1 and 2; at stations-3 and 4A there were no significant correlations.

Correlations with BOD was positive at stations-2, 4A, 4B, and 5 but negative at station-1. Station-3 showed insignificant tendency. Relationship with oil and grease was positive at stations-3, 5 but negative at stations-1; at other stations the relations were insignificant. Correlations with COD was positive at stations-4A, 4B, and 5 but negative at station-1 and 2.

4.12.3. Bacillariophyta and physico-chemical parameters

This group showed a significant positive correlation with water temperature at stations-1, 3, 4A, and 4B but negative relations at station- 5; no significant correlation was observed at station-2. At all stations the group showed a positive correlation with total solids. Similarly relations with total hardness were positive at all stations except station-5. At this station the relationship with total hardness was insignificant. Relations between total alkalinity and the algal group were positive only at stations-1 and 4B but at station-2 negative and at all other stations the relationships were quite insignificant. With salinity, the group showed positive trends at stations-2, 3, 4B and 5 but negative trends at station-1; at station-4A the relation was insignificant. Correlations with EC was positive at stations-3 and 5 but negative at stations-1and 2. At stations-4A and 4B the relations were insignificant.

The relations with dissolved CO₂ were negative at all stations except at station-5 where the correlation was insignificant. *Bacillariophyta* showed positive correlation with DO only at station-5. With DO the correlations were negative at station-2, 3 and 4B. But at stations 1 and 4A the relations were insignificant.

Correlations with Ca were positive at stations-1, 2 and 4B but at other stations the correlations were insignificant. With Mg the correlation was positive at all stations. No negative tendencies observed for this parameter at any stations during any seasons. Positive correlations with Na were observed at stations-1, 2, 3 and 4B, but at 4A and 5 the correlations were found insignificant. Correlations with K were positive at stations-1 and 4A, 4B and 5 but at 2 and 3 the relations were insignificant. Correlations of the group with total Cl were positive at station-1 and 4B but negative at stations-3,4A and 5. No significant trend was observed at station-2.

Relationship between total P and *Bacillariophyta* was positive at stations-1, 2, 3, 4A, and 4B but insignificant at station-5. With Nitrate the correlation was positive at stations- 1 and 2, but negative at stations-4A and 5; at other stations the relations were quite insignificant. The group showed positive correlation with total nitrogen only at station-4B but negative correlations with total nitrogen at stations-1,4A and 5 whereas at other stations the relations were found quite insignificant. Relations with Silica were positive at stations-1, 2, 3, 4A, 5, but at other stations the relations were insignificant.

The algal group showed positive relations with BOD at stations-3 and 4B but negative relations at stations-4A and 5; at other stations the relation was insignificant. Correlations with COD was positive at stations-1, 3, 4A, 4B but negative at stations 2 and 5. With Oil and grease this algal group showed positive correlations at all stations.

4.12.4. Chlorophyta and physico-chemical parameters

Positive correlation coefficients were observed for *Chlorophyta* and water temperature at all stations except at station-4A where the correlations observed were insignificant. Relations with TS were positive at stations-1, 2, 3,4B and 5 but at station 4A the relation was negative. With secchi depth the relation was found negative at stations-2, 3, 4B, 5 but at stations 1 and 4A the relations were insignificant. Correlations with pH was not positive at any station but it was negative at stations-1, 2, 3, 4A, and 4B and at station-5 no significant trend was observed for this parameter. With total hardness, positive correlations were noticed at stations-2, 3 and 4B, but at other stations the relationship was quite insignificant. The algal group showed a positive correlation with

total alkalinity at stations-4A, 4B and 5, while the relations at other stations were quite insignificant. Relationship between salinity and the algal group was positive at stations-2, 3, 4A and 4B, but negative at station-1; at other stations no significant trends were observed for this parameter.

Chlorophyta showed a positive correlation with dissolved CO₂ at station-4A only, whereas negative relations were observed at all the other stations. Relations between the algal group and DO were not positive in any station. But the algal group showed negative trends with DO at stations-2, 3, 4A, and 4B.

Correlations with Ca were positive at stations-1, 3, 4B, 5 but negative at 4A; at station-2 the relation was insignificant. This algal correlation with Mg was positive at stations- 2, 3, 4B, and 5 but insignificant at other stations. With Na, the relation was positive at stations-2, 4A, 4B, and 5. At stations-1 and 3 its relations with Na was insignificant. Correlations of the algal group with K were positive at 1, 3, 4B, and 5 but at other stations the relations were quite insignificant. With Cl, the relation was positive at stations-1,4A and 5 but negative at station-3; at other stations the trend was insignificant.

Correlations with total P were positive at stations-2, 3, 4B, and 5 whereas at stations-1 and 4A there was an insignificant tendency. Positive relations with total nitrogen were observed at stations-4A, 4B, 5 but the trend was negative at stations-1, and 3. Relationship with Nitrate was positive at stations-1, 2 and 5 but negative at station-3; at other stations relationship was insignificant. With Silica positive correlations were observed at stations-1, 2, 3 and 4B but negative correlation coefficients were observed at station-4A; at station-5 the correlation was quite insignificant.

Correlations with BOD was positive at stations-4A, 4B and 5 but negative at stations-1, 2 and 3. With COD the algal group showed a positive correlation at stations-3, 4B and 5 but negative correlations at station-2. At other stations the correlations were insignificant. *Chlorophyta* showed a positive correlation with oil and grease at station-1, 2, 4B, and 5 but at other stations only insignificant relationship was noticed.

Table 184 : Correlation co-efficients of plankton density with water quality parameters

	water temp-s	total solid-S	TDS-S	lecchi dept	pH-S	Total hard-s	total alkali-s	salinity-s	EC-s	CO2-s	DO-S	BOD-s	total-P	total-N	nitrate-N	tot Chloride	Ca-S	Mg-s	Na-s	K-s	silica-s	COD	oil grease-t	plank den.
Station-1																								
PM	27	310	28.2	1	7.5	8.7	17.8	16.3	29.3	2.5	6.2	2	0.08	2.6	7.4	7.8	2.6	5.4	3.7	1.4	0.1	3.5	1871.7	470
SW	26	298.7	23.2	1.2	7.7	7.5	18.2	15.5	22.8	2.4	6.7	1	0.06	1.8	7.2	7.2	2.6	4.7	2.5	1.7	0.2	2.8	1430.3	386.7
NE	25	213.3	22.3	1.3	7.9	6.5	15.8	16.5	29.3	2.5	6.8	1.6	0.03	2.2	6.4	6.4	2.3	4.5	2.3	1.4	0.01	2.8	962.3	386.7
	0.480086523	0.104159968	0.71884519	-0.6372	-0.48007	0.52538609	0.687017	0.770701	0.8772321	0.8772321	-0.9371794	0.96576246	0.577523	0.999739	0.166479	0.305635	-0.02287	0.725055	0.77825	-0.67723	-0.54538	0.725055	0.466186	430
Station-2																								
PM	27.6	186	22	1.4	7.3	8.3	15.8	13.3	27.2	2.4	6.1	1.1	0.04	2.4	6	6.8	2.3	5.2	2.9	1.3	0.09	1.7	1094	350
SW	26	206.7	21.8	1.5	7.6	7.8	15.4	13.7	28.3	2.2	6.9	1.1	0.04	1.7	5.8	6	2.5	4.8	2.4	1.5	0.18	2	871	316.7
NE	26.3	133.3	22	1.7	7.7	6	15.8	12.6	31.8	2.7	7	1.3	0.02	2.2	5.8	5.3	2.3	4.3	2.2	1.3	0.01	2	883	340
	0.840313895	-0.482622989	0.95622843	-0.10684	-0.54635	-0.018485	0.866228	-0.55972	-0.0158313	0.5933946	-0.6586557	0.22468679	-0.2247	0.999673	0.731532	0.974429	-0.95823	0.230805	0.513733	-0.95823	-0.70624	-0.73153	0.311772	340
Station-3																								
PM	27.3	240	21.7	2	7.5	8.1	15.7	15.4	26.7	2.4	6.5	1.6	0.04	2.4	5.8	5.6	2.2	5.2	3.4	1.2	0.14	1.5	1033	333.3
SW	25.3	253.3	22	1.7	7.6	8.3	16.7	13.2	23.4	2	6.8	0.6	0.04	1.7	5.7	5.8	2.4	4.8	2.4	1.4	0.26	1.5	603.3	290.7
NE	24.3	190	21.4	2.2	7.7	6	15.8	13.3	24.1	2.6	7.2	1.2	0.01	2.2	5.8	5.8	2.1	3.7	2.2	1.2	0.02	1.4	458.3	308.7
	0.824790901	0.055492565	-0.2643124	0.373198	-0.70307	0.17660917	-0.77201	0.974294	0.9979003	0.2643124	-0.7581463	0.9319403	0.253317	0.878219	0.71112	-0.82479	-0.44181	0.493862	0.811587	-0.71112	-0.29431	0.253317	0.871515	308.7
Station-4A																								
PM	27	210	22.6	1.5	7.5	9.2	18.9	17	30	2.4	6.6	1.3	0.03	2.5	5.8	6	2.5	5.7	3.9	1.4	0.17	1.5	471	400
SW	27	223.3	21.6	1.5	7.6	8.2	15.1	12.6	18.2	2.1	7.9	1	0.03	1.5	5.8	5.5	2.7	5.4	2.4	1.3	0.24	1.2	427	313.3
NE	25.3	183.3	21.7	1.7	7.6	6.3	15.1	12.5	21.8	2.7	7.3	1.5	0.02	2.4	5.8	5.9	2.7	4.1	2.3	1.1	0.01	1	310.3	400
	-0.5	-0.755321287	0.57656688	0.5	-0.5	-0.1783689	0.5	0.483055	0.7351024	0.8660254	-0.8428867	0.91766294	-0.5	0.986871	0.5	0.981981	-0.5	-0.33942	0.45091	-0.18898	-0.73455	0.114708	-0.25271	400
Station-4B																								
PM	28	156.7	20.8	1.2	7.5	9.1	18.8	16.1	21.7	2.2	7.1	1.8	0.03	1.9	5.5	5.8	2.9	5.2	3	1.6	0.19	1	307.7	303.3
SW	25.3	170	22.1	1.5	7.4	7.3	16	12.6	19.4	2.1	7.8	0.6	0.03	1.6	5.2	5.2	2.6	5.3	2.3	1.2	0.34	0.6	344	263.3
NE	25	123.3	22.7	1.5	7.6	5.8	14.6	11.8	21.8	2.5	7.7	1.1	0.02	1.5	5.5	5.5	2.4	3.9	2.2	1.1	0.02	0.9	154.7	253.3
	0.995082099	0.420220023	-0.9823358	-0.98198	-0.18896	0.96078892	0.989743	0.999424	0.2923064	-0.4538206	-0.9484206	0.81515784	0.654654	0.998625	0.327327	0.544705	0.976221	0.604917	0.997176	1	0.22427	0.755929	0.507318	253.3
Station-5																								
PM	26.3	313.3	33.4	0.85	7.7	9.6	19.7	17.8	63	2.5	8.1	2.6	0.06	3	8.1	8.3	3	5.9	4.3	1.5	0.11	3.6	1732	490
SW	25	355.7	38.6	1.2	7.5	9.2	17.8	21.8	60.9	2.8	6.7	1.4	0.06	2.1	6.6	6.5	2.8	5.9	3.1	1.6	0.24	3.4	1680.7	390
NE	25.3	253.3	35	1.2	7.8	6.5	17.6	17.2	52.8	2.8	6.1	1.8	0.06	2.4	7	7.1	2.8	4.9	2.7	1.4	0.07	3.5	1080.7	336.7
	0.840887829	0.433532002	-0.4610561	-0.93854	-0.1587	0.83711487	0.839544	-0.05381	0.8768652	-0.8395439	-0.1732203	0.77568958	0.939544	0.7757	0.819855	0.7757	0.938544	0.766324	0.994288	0.342428	0.052838	0.642455	0.809905	336.7

Table 185 : Correlation co-efficients of phytoplankton group's density with water quality parameters

2004	water temp-s	total solids-s	secchi depth	pH-s	total hard-S	total alkali-s	salinity-S	conductivity-S	Co2-s	Do-s	BOD-s	total P	total N	Nitrate	total chloride-S	Ca-s	Mg-s	Na-s	K-S	Silica	COD	Oil grease	plank den	Cyanophyta	Euglenophyta	Bacillariophyta	Chlorophyta		
Station-1																													
pm	27	310	1	7.5	8.7	17.8	16.3	29.3	2.5	6.2	2	0.08	2.6	7.4	7.8	2.6	5.4	3.7	1.4	0.1	3.5	1871.7	550	70	30	200	250		
swm	26	296.7	1.2	7.7	7.5	16.2	15.5	22.8	2.4	6.7	1	0.05	1.8	7.2	7.2	2.6	4.7	2.5	1.7	0.2	2.8	1430.3	610	20	40	200	350		
nm	25	213.3	1.3	7.9	6.5	15.6	16.6	29.3	2.5	6.6	1.6	0.03	2.2	6.4	6.4	2.3	4.5	2.3	1.4	0.1	2.6	962.3	410	50	40	150	170		
pk den	0.68204829	0.911510175	-0.5315541	-0.682048	0.6427799	0.47407678	-0.84702436	-0.731307136	-0.73131	-0.03683	-0.400075	0.5936596	-0.292306	0.883652	0.807982196	0.956325	0.426099	0.35172791	0.731307	0.987071	0.426099	0.6942993	0.6942993	0.6942993	0.6942993	0.6942993	0.6942993	0.6942993	
cyanophyta	0.39735971	0.012256242	-0.5636215	-0.39736	0.4447121	0.617281422	0.82603319	0.917662935	0.917663	-0.90113	1	0.5	0.9933993	0.705054	0.216777492	-0.11471	0.658648	0.71720421	-0.91766	-0.62015	0.658648	0.3818082	0.658648	0.658648	0.658648	0.658648	0.658648	0.658648	
euglenophyta	-0.8660254	-0.6058936	0.94491118	0.866025	-0.8910421	-0.96457886	-0.32732684	-0.5	-0.5	0.98198	-0.802955	-0.917663	-0.866025	-0.654654	-0.755928946	-0.5	-0.97736	-0.99124071	0.5	0.300373	-0.97736	-0.857459	-0.857459	-0.857459	-0.857459	-0.857459	-0.857459	-0.857459	
bacillariophyta	0.8860254	0.991918766	-0.7559289	-0.866025	0.8386279	0.710742316	-0.65465367	-0.5	-0.5	-0.32733	-0.114708	0.8029551	-1.54E-16	0.981981	0.944911183	1	0.671932	0.6099428	0.5	0.850439	0.671932	0.8743445	0.8743445	0.8743445	0.8743445	0.8743445	0.8743445	0.8743445	
chlorophyta	0.44353276	0.755172897	-0.2661637	-0.443533	0.3959484	0.20150272	-0.96392785	-0.89625816	-0.89626	0.251459	-0.846221	0.3377973	-0.554416	0.712468	0.604917398	0.83224	0.148601	0.06833904	0.896258	0.999433	0.148601	0.458603	0.458603	0.458603	0.458603	0.458603	0.458603	0.458603	
Station-2																													
pm	27.6	186	1.4	7.3	8.3	15.8	13.3	27.2	2.4	6.1	1.1	0.04	2.4	6	6.6	2.3	5.2	2.9	1.3	0.09	1.7	1094	470	50	10	180	230		
swm	26	206.7	1.5	7.6	7.8	15.4	13.7	28.3	2.2	6.9	1.1	0.04	1.7	5.8	6	2.5	4.8	2.4	1.5	0.18	2	871	420	20	0	180	220		
nm	26.3	133.3	1.7	7.7	6	15.8	12.6	31.6	2.7	7	1.3	0.02	2.2	5.8	6	2.3	4.3	2.2	1.3	0.01	2	863	400	60	10	130	200		
pk den	0.89679211	0.503477061	-0.9078413	-0.99926	0.8483175	0.240192331	0.42341516	-0.866025404	-0.38573	-0.98393	-0.720577	0.720577	0.5	0.960759	0.693375245	-0.24019	0.953357	1	-0.24019	0.24458	-0.96077	0.9753547	0.9753547	0.9753547	0.9753547	0.9753547	0.9753547	0.9753547	
cyanophyta	0.44245216	-0.86400859	0.41931393	-0.038462	-0.5294879	0.970725343	-0.90593976	0.5	0.922613	-0.17854	0.6933752	-0.693375	0.8660254	0.27735	0.720576692	-0.97073	-0.30184	2.9584E-16	-1	-0.96963	-0.27735	-0.220643	-0.220643	-0.220643	-0.220643	-0.220643	-0.220643	-0.220643	
euglenophyta	0.64490202	-0.71778376	0.18898224	-0.27735	-0.3102281	1	-0.77771377	0.277350098	0.802955	-0.40964	0.5	-0.5	0.9607889	0.5	0.866025404	-1	-0.06402	0.24019223	0.5	-0.8825	-0.5	0.0200893	0.0200893	0.0200893	0.0200893	0.0200893	0.0200893	0.0200893	
bacillariophyta	0.33942212	0.961876005	-0.9449112	-0.693375	0.9784116	-0.5	0.93325653	-0.970725343	-0.91766	-0.58521	-1	-1	-0.240192	0.5	0.5	0	0.5	0.896258	0.72057669	0.188982	0.848555	-0.5	0.855906	0.855906	0.855906	0.855906	0.855906	0.855906	
chlorophyta	0.62861856	0.819368112	-1	-0.891042	0.9921593	-0.18898224	0.76426526	-0.995870595	-0.73704	-0.81839	-0.944911	0.9449112	0.0907841	0.755929	0.327326835	0.188982	0.992065	0.9078413	0.188982	0.628619	-0.75593	0.9779858	0.9779858	0.9779858	0.9779858	0.9779858	0.9779858	0.9779858	
Station-3																													
pm	27.3	240	2	7.5	8.1	15.7	15.4	26.7	2.4	6.5	1.6	0.04	2.4	5.8	5.6	2.2	5.2	3.4	1.2	0.14	1.5	1033	470	70	0	200	200		
swm	25.3	253.3	1.7	7.6	8.3	16.7	13.2	23.4	2	6.9	0.6	0.04	1.7	5.7	5.8	2.4	4.8	2.4	1.4	0.26	1.5	603.3	350	10	0	120	220		
nm	24.3	190	2.2	7.7	6	15.8	13.3	24.3	2.8	7.2	1.2	0.01	2.2	5.8	5.9	2.1	3.7	2.2	1.2	0.02	1.4	458.3	280	40	20	50	170		
pk den	0.99922611	0.641022389	-0.2550087	-0.986554	0.7296736	-0.23934426	0.91589031	0.838923716	-0.36424	-0.98766	0.5306699	0.7810942	0.4185208	0.15021	0.397226106	-0.95382	0.844688	0.96909229	0.917663	0.503181	0.994643	0.8897517	0.8897517	0.8897517	0.8897517	0.8897517	0.8897517		
cyanophyta	0.65465367	-0.19924443	0.59603956	-0.5	-0.0784987	-0.9078413	0.8854475	0.948644751	0.5	-0.56949	0.9933993	0	0.9707253	0.866025	-0.654653671	0.65465	0.257485	0.77771377	-0.86603	-0.5	0	-0.695145	-0.695145	-0.695145	-0.695145	-0.695145	-0.695145	-0.695145	
euglenophyta	0.18898224	-0.97994982	0.80295507	0.866025	-0.9995192	-0.41931393	0.53445032	-0.315442323	0.866025	0.821995	0.1147079	-1	-0.240192	0.5	0.759228946	-0.75593	-0.96628	-0.62861856	-0.5	-0.86603	-1	0.9713131	0.9713131	0.9713131	0.9713131	0.9713131	0.9713131	0.9713131	
bacillariophyta	0.75592895	0.72300324	-0.361771	-0.99926	0.801715	-0.12901967	0.46473941	0.772642126	-0.46632	-0.99904	0.4323604	0.8461538	0.3140975	0.038462	-0.988522468	0.290742	0.954847	0.94638178	-0.03846	0.466321	0.846154	0.9713131	0.9713131	0.9713131	0.9713131	0.9713131	0.9713131	0.9713131	
chlorophyta	0.92857143	0.978435341	-0.9736842	-0.59604	0.9460195	0.099053606	0.7289862	-0.087602681	-0.9934	-0.52802	-0.5	0.9176629	-0.608143	-0.802955	-0.433554985	0.953821	0.784408	0.28782783	0.802955	0.993399	0.917663	0.3522592	0.3522592	0.3522592	0.3522592	0.3522592	0.3522592	0.3522592	
Station-4A																													
pm	27	210	1.5	7.5	9.2	16.9	17	30	2.4	6.6	1.3	0.03	2.5	5.6	6	2.5	5.7	3.9	1.4	0.17	1.5	471	470	30	30	160	250		
swm	27	223.3	1.5	7.6	8.2	15.1	12.6	18.2	2.1	7.9	1	0.03	1.5	5.6	5.5	2.7	5.4	2.4	1.3	0.24	1.2	427	380	20	10	230	120		
nm	25.3	183.3	1.7	7.6	6.3	15.1	12.5	21.8	2.7	7.3	1.5	0.02	2.4	5.8	5.9	2.7	4.1	2.3	1.1	0.01	1	310.3	340	40	20	60	220		
pk den	0.73704347	0.47603417	-0.7370435	-0.953821	0.9226851	0.953820966	0.95948497	0.821186677	-0.30038	-0.70788	-0.188982	0.7370435	0.3045077	-0.737043	0.397359707	-0.95382	0.844688	0.96909229	0.917663	0.503181	0.994643	0.8897517	0.8897517	0.8897517	0.8897517	0.8897517	0.8897517	0.8897517	
cyanophyta	-0.8660254	-0.98180476	0.8660254	0	-0.644902	0	-0.0194576	0.297639272	1	-0.46108	0.9933993	-0.866025	0.8170572	0.866025	0.755928946	0	-0.78427	-0.0557856	-0.65465	-0.97542	-0.39736	-0.702626	-0.702626	-0.702626	-0.702626	-0.702626	-0.702626	-0.702626	
euglenophyta	0	-0.32645008	0	-0.866025	0.3394221	0.866025404	0.85613267	0.95755939	0.5	-0.99902	0.5960396	0	0.9078413	0	0.944911183	-0.86603	0.844688	0.836784	0.327327	-0.29687	0.59604	0.2649149	0.2649149	0.2649149	0.2649149	0.2649149	0.2649149	0.2649149	
bacillariophyta	0.91224546	0.995995908	-0.9122455	-0.101361	0.719047	0.101360607	0.102669877	-0.199339572	-0.99485	0.368766	-0.976656	0.9122455	-0.754409	-0.912245	-0.685679631	-0.10136	0.825697	0.15670106	0.727903	0.99273	0.488328	0.7711318	0.7711318	0.7711318	0.7711318	0.7711318	0.7711318	0.7711318	
chlorophyta	-0.2968681	-0.59233531	-0.92668613	-0.87551	0.0448782	0.678551144	0.6813007	0.866429994	0.734535	-0.94081	0.8075397	-0.296868	0.9913951	-0.296868	-0.433554985	0.953821	0.784408	0.28782783	0.802955	0.993399	0.917663	0.3522592	0.3522592	0.3522592	0.3522592	0.3522592	0.3522592	0.3522592	0.3522592
Station-4B																													
pm	28	156.7	1.2	7.5	9.1	18.8	16.1	21.7	2.2	7.1	1.8	0.03	1.9	5.5	5.6	2.9	5.2	3	1.6	0.19	1	307.7	450	10	10	260	170		
swm	25.3	170	1.5	7.4	7.3	16	12.8	19.4	2.1	7.8	0.6	0.03	1.6	5.2	5.2	2.6	5.3	2.3	1.2	0.34	0.8	344	300	10	0	180	110		
nm	25	123.3																											

Chapter-V

DISCUSSION

5. 1. Introduction

Lakes are socio-economically and bio-aesthetically important aquatic systems. Although there are extensive back waters in Kerala, natural fresh water lakes are only a few. The freshwater systems in Kerala are mainly reservoirs of dams constructed across west flowing rivers situated in the Western Ghats. Among them, the *Periyar* Lake is a unique one. This three-year investigation enabled us to generate ample knowledge about the hydrobiology and physico-chemical characteristics of the Lake water.

Monitoring is a purposeful intermittent surveillance carried out in order to ascertain the extent of compliance with predetermined standard or the degree of deviations from an expected norm. It is purposeful to control pollution. But survey is an exercise in which a set of quantitative or qualitative observations are made, usually by means of a standard procedure and within a restricted period of time, but without any preconception of what the findings ought to be (Newson, 1994). The present investigation may be considered a three-year continuous survey or monitoring as well. A perusal of literature on Lakes in Kerala reveals that the freshwater reservoirs in the Western Ghats in general are oligotrophic. The present investigation was to test this hypothesis. Therefore, this study fits more to the concept of monitoring.

Spatial and temporal variation is evident in all the physical and chemical parameters of fresh water systems (Chandrasekhar *et al.*, 2003). Since the morphometry of *Periyar* Lake is complex with a lot of dendrite structures along its whole length, and the base of the flooded plane in the reservoir in general has an undulating topography, accounting of spatial variation due to natural environmental difference was not easy in this system. However, six field stations were identified in the present investigation to assess all the spatial variations existing in the Lake.

Natural lakes in temperate latitudes usually have a relatively stable water regime but this is not the case in some natural lakes in the tropics, particularly those that occur in areas where the climate is divided into distinct wet and dry seasons (Osborne *et al.*, 1987). *Periyar* Lake is a high altitude tropical Lake with constant and much frequent short duration fluctuations in rain fall and out flow. Therefore, the three year monitoring was minimal to assess the general ecological tendencies of the system.

In monitoring investigations of aquatic systems in Kerala, monthly data are usually pooled and divided into three seasons for getting reliable trends for explaining the features (Koshy, 2002). In previous studies of freshwaters in Kerala (Koshy and Nayar, 1999; Jayaraman *et al.*, 2003; Radhika *et al.*, 2004), the three seasons usually recognized are post-monsoon (Nov–Dec–Jan) pre-monsoon (Feb–March–April–May) and monsoon (June–July–August–Sept–Oct). However, there exist two monsoons in Kerala, the southwest and northeast, which quite often differ in the nature and amount of precipitation. The gap between these two monsoon seasons is quite narrow and sometimes they overlap. There is a recognizable gap in between the northeast monsoon of one year and the southwest monsoon of the next year, which is the pre-monsoon. There exist fluctuations in duration of the two monsoons and the pre-monsoon between years. Therefore, to enable a better comparison of the exact seasonal tendency of the Lake system between years, monthly observations were grouped into three seasons, the pre-monsoon (Jan–Feb–March–April), southwest monsoon (May–June–July–August) and northeast monsoon (Sept–Oct–Nov) in the present study.

The results of this study are discussed under various subheadings such as: (1) Climate of the area and hydrology of the Lake, (2) Physical and chemical characteristics of the Lake water, (3) The phytoplankton community.

5.2. Climate of the area and hydrology of the Lake

5. 2. 1. Air Temperature

Air temperature and precipitation were the major climatic features assessed in the present study at all stations. Since changes in air temperature show a close proportionality to that of the water (Kaul *et al.*, 1980), simultaneous measurements of both are

significant. Spatial fluctuations in air temperature experienced during a particular season might be due to the timing of collection and the influence of weather, which quite fluctuate diurnally and seasonally in the *Periyar* Lake. Since the air temperature was recorded during the actual visit to a station every month, the time of record was not uniform at all the stations and this is the reason for a significant difference in air temperature across different stations in the Lake area. Jayaraman *et al.* (2003) recorded similar fluctuations in air temperature in different stations in *Karamana* River in Thiruvananthapuram district, Kerala.

The maximum seasonal air temperature recorded in the PTR was 30 °C during pre-monsoon at station 3 and 4A in the noon time and the minimum recorded temperature was 24 °C in the morning (around 8 AM) during the northeast monsoon at station -1, 2,3 and 4B. **Tables 1 to 3** shows that in the pre-monsoon and the northeast monsoon, variations in air temperature across the stations and over the years were insignificant whereas the same during the southwest monsoon were significant. Southwest monsoon is therefore the season of maximum air temperature fluctuations in the system. A comparison of three-year average values of air temperature of different seasons (**Table-4**) showed significant variations over the different seasons and across the different stations during all the seasons. This is a clear indication that the pattern of division of monthly observations into the three-seasons in the present study was similar to differences in air temperature regimes of the Lake area.

5. 2.2. Precipitation

Seasonal and monthly precipitation showed certain fluctuations during the three-year period (**Table-5**). However, southwest monsoon remained the season of highest rainfall except in 2003. In 2003 there was only a slight increase in the northeast monsoon rainfall than that of the southwest monsoon. The fluctuations in total rainfall of southwest monsoon during the three-year period of study were very high (695mm in 2002, 609mm in 2003, and 1190mm in 2004). The month of highest rainfall during southwest monsoon varied from June to August during the study. The highest monthly fall recorded during the period of study varied from 203-511mm. The month of lowest rainfall during southwest monsoon was recorded during May in 2002 (134 mm) and 2003 (41 mm), but

it was July during 2004 (145 mm). Thus it became clear that fluctuations in monthly maximum precipitation also occur in this season.

The fluctuations in northeast monsoons varied between 422mm (in 2002) to 648mm (2003). During the northeast monsoon, throughout the entire period of study, December remained the month of the lowest rainfall (1-41mm) and October remained the month of the highest fall (249 mm to 488 mm). In general, fluctuations in total precipitation over years were less in northeast monsoon than the southwest monsoon. During the three-year period of study monthly fluctuations in precipitation over years was minimum during the northeast monsoon.

The pre-monsoon rainfall was 158-193mm throughout the period of study. The fluctuation in pre-monsoon rain fall between years during the three-year period of study was very narrow when compared to other seasons. In the pre-monsoon period January remained the month of the lowest rain fall (0-2mm) during the entire period of study. The month of highest rain fall was April in 2003 and 2004 but it was March in 2002.

The comparison of rainfall between different seasons showed that just like air temperature, precipitation also was a major atmospheric factor which contributes to seasonal variations in climate in the system. In the present investigations difference in rainfall pattern was evident between the seasons. Southwest monsoon season remained the season of maximum monthly fluctuations in the system between years. Since the southwest, northeast and the pre-monsoon seasons showed quite distinct precipitation rates and statistically significant variations in air temperature, the present pooling of monthly data to develop three seasonal trends - the two different monsoon trends and the pre-monsoon trend in a year, was found quite reasonable and fruitful. An unusual increase in the rate of precipitation during the pre-monsoon and the southwest monsoon was the reason for the very high annual precipitation account of the year 2004.

Each of the inland water body is characterised by unique hydrological features. In general, thorough and continuous vertical mixing is achieved in rivers due to the prevailing currents and turbulence. Currents within a lake are multi-directional with mixing regulated by the climatic conditions and lake depth. Reservoirs are intermediate between rivers and lakes. Large variations in the water residence time occur in different

types of inland water bodies. The hydrologic characteristics of each type of water body are highly dependent on its size, climatic conditions, and the drainage pattern associated with it. However, a comparison of fluctuations in water quantity in the *Periyar* Lake system revealed that the management of water in this Lake is ill-ecological without any concern for its hydrobiology, or giving no importance to its role played in the PTR ecosystem.

The major management concern at present in this Lake was found exploitation of as much water as possible as and when the inflow increases. Consequently the water level continuously fluctuates between diurnally and seasonally, and the fluctuations are quite unpredictable. According to Osborne *et al.* (1987) the implications of fluctuations of water level on chemical composition and productivity of water body as a whole is not obvious. Becht and Harper (2002) found that an 'equilibrium' lake level is essential to the biodiversity conservation and to maintain the general ecology of a lake.

During the three-year period of studies, no efforts were found from the authorities of the *Mullaperiyar* Dam to maintain an optimum water level in the Lake. An optimum water level is essential to keep an aquatic system stable and viable. Hence a specific study to understand the safe and sustainable use of *Periyar* water in terms of a sustainable lake is essential. The water level for the sustainable existence of the Lake as a natural biological system supporting the wildlife sanctuary and its economical use as water body supporting international tourism, and as a reservoir for irrigation and power generation purpose in TN as well as the water resource to sustain the viability of *Periyar* River down the Dam is very essential.

5. 3. Physico-chemical parameters

Quality of an aquatic ecosystem is dependent on the physical and chemical qualities of water (Bhatt *et al.*, 1999). Results of variations in all the physical and chemical characteristics of water in a lake at a particular place during different seasons and also the variations at different places during a particular season reveal some of the significant ecological tendencies of the lake system.

5. 3. 1. Water Temperature

Water temperature is of enormous significance as it regulates various abiotic characteristics and biotic activities of an aquatic ecosystem which is recognized by many authors (Mc Combie, 1953; Hutchinson, 1957; Jana, 1973; Chari, 1980; Kataria *et al.*, 1995; Iqbal and Katariya, 1995; Sharma and Sarang, 2004; Radhika *et al.*, 2004). It is clear from the **Tables-7,8** and **9** that there were no significant variations in surface-water temperature across stations and over years during the pre-monsoon and the northeast monsoon in the Lake, whereas the differences in surface water temperature across the stations and over the years were significant during the southwest monsoon. A comparison of the average of surface-water temperature of the three-year period (**Table 10**) showed that the variations in temperature across the different stations were insignificant but the differences in temperature over the three different seasons were very significant.

The surface-water temperature at all the stations during a particular season throughout the period of study, showed a maximum fluctuation of 1-2⁰C only. At all the stations, in between different seasons the temperature variation was 2⁰C to 5⁰C. The lowest seasonal surface-water temperature noticed in the Lake during the entire period of study was 24 ⁰C, in the northeast monsoon period of 2004 and the maximum noticed was 29 ⁰C during the pre-monsoon of 2005. Kataria *et al.* (1995) reported a temperature variation of 21.4⁰C to 34.2 ⁰C in *Tawa* reservoir in the North India. Jayaraman *et al.* (2003) observed a difference in surface water temperature of 25⁰C (post-monsoon or northeast monsoon) to 30.6⁰C (pre-monsoon) in *Karamana* river near Thiruvananthapuram, in Kerala. Thus it became clear that unlike north Indian waters, water bodies in Kerala has narrow annual fluctuations in water temperature. This is in tune with climatic conditions as well. The observations of surface water temperature in *Periyar* Lake showed that the seasons of lowest and highest temperature in the Lake area are similar to that of aquatic systems elsewhere in Kerala, such as that in *Karamana* River, but the range of fluctuation in *Periyar* Lake is narrower than that of other water bodies in the State. Moreover, the maximum surface-water temperature observed in *Periyar* Lake was lower than that of the other fresh water systems in the State. This is on account of the high altitude location of the lake as well as the presence of thick evergreen

forests around. The present observation of surface water temperature in *Periyar* Lake agrees with the observations of Kaul *et al.* (1980) that surface water temperature usually remains close to the air temperature.

The spatial and vertical difference in temperature of water in a Lake in general is influenced by the temperature of inflowing waters, extent of vertical mixing as well as process like exchange of heat with the atmosphere and other localized phenomena also influence the distribution of temperature. Comparison of bottom-water temperature across stations showed that there were significant variations in it (**Tables- 11, 12 and 13**) during the pre-monsoon; but during the southwest and the northeast monsoon periods the difference in bottom water temperature across stations were insignificant. The differences in bottom water temperature over the years were insignificant during the pre monsoon but significant during the southwest and northeast monsoon periods. The three-year average temperature of bottom-water of different seasons (**Table -14**) showed that there were significant differences in temperature over the three different seasons and that across all the stations during each season in the Lake.

The differences in bottom-water temperature at different stations were high at the points of major inflow (1-4⁰C at stations 4A and 4B), whereas it was very less at the points of outflow (1-2⁰C at stations 1 and 5). At the mid stations, station-2 and 3, the differences in bottom water temperature was 1-3⁰C. At stations 2 and 3, the depth of sample collection was constantly 6-10 meters at all the seasons; whereas at the final point of outflow (station-5) the depth varied from 2-6 meters according to the seasons. At station-3, where the depth was constantly 10 meters, the bottom temperature was constantly 24 ⁰C in the pre-monsoon, 22-25⁰C in the southwest monsoon and 22-24⁰C in the northeast monsoon, during the entire period of study. Since the fluctuation in bottom water temperature was high during the southwest monsoon, it may be concluded that it is at this season there is maximum vertical mixing in this Lake. As in the case of surface-water, the bottom-water also exhibited a slight seasonal trend in temperature with a slight increase in the pre-monsoon, a decrease during the northeast monsoon and moderate values during the southwest monsoon. Radhika *et al.* (2004) made a similar observation in the *Vellayani* Lake, in Kerala.

5. 3. 2. Transparency (Secchi depth)

Solar radiation is the major source of light energy in an aquatic system, governing the primary productivity. It measures the light penetrating through the water body. Transparency is a characteristic of water that varies with the combined effect of colour and turbidity. Turbidity is caused due to suspended solid materials such as clay, silt, colloidal organic matter, planktons and is the reason for less transparency. Increase in turbulence of waters usually increases all the suspended materials, especially in shallow waters. In a Lake the secchi depth measurement can be affected by factors such as time of the day, clarity of the sky at the time of measurement (cloudy or not), and suspended solids in water including phytoplankton. In shallow waters secchi depth is affected by disturbance such as boat movement for measurement. The secchi depth measurement at the *Periyar* Lake was subjected to all these factors.

Comparison of variations in secchi depth showed that the fluctuations in it over the years during all the seasons were not significant (**Table 15, 16 & 17**) whereas those across different stations in all the seasons were significant. Average secchi depth of the three-year period (**Table-18**) showed that the variations in secchi depth over seasons and that across different stations during all the seasons were significant.

In general the secchi depth was found least during the pre-monsoon, highest during the northeast monsoon and moderate during the southwest monsoon at all the stations. Among the different stations, station-3 usually had the highest transparency and station-5 had the lowest transparency throughout the three-year period of observations. Other stations showed moderate transparency in between these extremes at all seasons during the entire period of study. Thus, unlike the observations in different tropical freshwaters (Suvarna and Somashekar, 1997; Amarasinghe and Viverberg, 2002), the transparency of waters in *Periyar* Lake increased only during the monsoon seasons. This is owing to undisturbed watershed which keeps the soil system intact during monsoon. Higher turbidity during pre-monsoon is due to higher impact of boat activity combined with lesser water level. Radhika *et al.* (2004) observed an increase in turbidity during pre-monsoon in *Vellayani* Lake, Kerala, which they attributed to high productivity coupled with excessive plankton growth.

Station wise analysis of secchi depth explained the spatial variation of parameters in the Lake. The highest secchi depth noticed during the study period was 2.2m at station-3 (Dam site) during the northeast monsoon of 2004 and the lowest measure was 0.85m at station-5 during the pre-monsoon, 2003. This observation agrees with that of Bhade *et al.* (2001) that turbidity is 3 to 4 times higher in the riverine stretch compared to the Dam site. Transparency observed in *Jaisamand* Lake, Udaipur (Sharma and Sarang, 2004) was 22 to 167 cm; in a forest Lake in Kashmir (Kaul *et al.*, 1980) it was 80 cm to 200 cm and the same observed in *Vellayani* lake in Kerala (Radhika *et al.*, 2004) was only 28cm to 58.5 cm. In *Periyar* Lake, the higher transparency at station-3 corresponds to higher depth and lesser turbulence. Amarasinghe and Viverberg (2002) reported a similar influence of depth on increased transparency in waters of a tropical reservoir in Sri Lanka. The lowest transparency observed at station-5 of the Lake was due to the combined effect of both sewage inflow as well as the impact of turbulence due to boat activity at station-1, which is close to it. The second lowest transparency at station-1 is definitely due to lower depth and highest boat turbulence at this site. Hilton and Philips (1982) reported a similar increase in turbidity due to boat activity in a river. The same author observed that increased turbidity reduce light penetrations, which reduce growth of planktons. But according to Bhatt *et al.* (1999) transparency of water is negatively proportional to primary productivity. Kataria *et al.* (1995) considered turbidity as an expression of light scattering and absorbing properties of water.

5. 3. 3. Electric Conductivity (EC)

EC is a basic index to select the suitability of water for agricultural purposes (Kataria *et al.*, 1995). EC in water is due to ionization of dissolved inorganic solids and is a measure of total dissolved solids (Bhatt *et al.*, 1999) and salinity. Salts that dissolve in water break in to positive charge and negative charge ions. Dissolved solids affect the quality of water used for irrigation or drinking. They also have a critical influence on aquatic biota, and every kind of organism has a typical salinity range that it can tolerate. Moreover, the ionic composition of the water can be critical. Koshy and Nayar (2000) observed that the EC value of 250 μ S per centimeter is quite normal for aquatic life of freshwaters. EC of tap water ranges between 50 and 800 μ S depending on the source

(Web Report, 2004). In *Periyar* Lake, the highest average seasonal EC observed during this study was 80 μS at station-5 during the pre-monsoon (2004) and lowest EC reported was just 15.2 μS at station-4B during the northeast monsoon 2004. Therefore, the EC values in *Periyar* Lake may be considered quite normal.

However the spatial and seasonal difference in EC value in the Lake explained certain definite tendencies. The EC value at station-5 was much higher (almost double or more) than that of the other stations throughout the study period. Station-2 showed the second highest EC during all seasons whereas station-4B in general showed the lowest EC values during most of the seasons of the entire period of study. There were significant fluctuations in EC across the different stations in the Lake during monsoon season. Moreover, at all the stations there were fluctuations in EC over different seasons as well as over different years during a particular season. These observations pointed out that EC is a highly variable factor in freshwaters. Tiwari (1999) reported an EC of 230 to 300 μS at 30⁰C in *Upper Lake* water of Bhopal. Kataria *et al.* (1995) found an EC of 150 to 256 μS in *Tawa* Reservoir, India. Garg (2002) observed an average EC of 769.62 μS in River *Mandakini*, Chitrakoot and the author also found a seasonal trend in EC in the same river: minimum in monsoon due to addition of rain water but maximum in post monsoon (Northeast monsoon). Radhika *et al.* (2004) reported that in *Vellayani* Lake, Kerala, the EC of surface waters varied from 91.2 to 320 μS during the pre-monsoon, 76.3 to 230 μS during the southwest monsoon and 96 to 226.6 μS during the northeast monsoon (post-monsoon). Suvarna and Somashekar (1997) reported that EC usually decrease after rainfall following increase in inflow, culminating in dilution. Taheruzzaman and Kushari (1995) observed an increase in EC in water bodies of *Burdwan*, West Bengal, during monsoon which according to them is due to voluminous runoff carrying diverse types of electrolytes from the nearer as well as distant areas. But according to Sarojini (1996) seasonal EC fluctuations are closely related to evaporation and concentration of soluble salts.

Compared to the previous reports on EC of Indian waters, *Periyar* waters showed a very low EC. Low ionic content in natural waters is generally attributed to slow chemical weathering in the catchments (Blakar *et al.*, 1990) Moreover, apart from slightly random spatial and yearly fluctuations, water in this Lake did not express definite

seasonal trends in EC value. Occasional fluctuations in EC at stations 1 to 4B in this Lake at a particular season between the years were quite normal as in all natural systems and were due to differences in the rate of local inflow.

Highest average seasonal EC of bottom water during this study was 86.7 μS from station-5 during the southwest monsoon of 2004 and lowest EC reported was just 15.6 μS at station-4B during the northeast monsoon 2004. Except at station-5, the bottom water at all the other five stations showed more or less the same EC values. Mortimer (1941) reported that mineralization of organic matter under the influence of reducing conditions prevailing in the bottom water is accompanied by a release of minerals. Kaul *et al.* (1980) finds this as the reason for higher EC in bottom-water than surface-water and also observed that, mixing of water results in the prevalence of the same conductance values throughout the vertical profile of water. Since no significant differences in conductivity of both the surface and bottom waters were observed in *Periyar* Lake, it may be concluded that there exist quite good vertical mixing of waters to the depth examined in the Lake.

There were no significant variations in EC in the bottom-water over years during all the three seasons (**Tables 31 to 33**); but across the stations the fluctuations were insignificant during the northeast monsoon only. The fluctuations in EC of bottom-water across the stations during the pre-monsoon and the southwest monsoon were significant. As in the case of surface waters, a comparison of the three-year average of EC of bottom-water (**Table 34**) during different seasons showed that variations across the different stations were very significant in all the seasons whereas that over seasons at a particular station were insignificant. This indicated that though the impact of inflow from different areas of the watersheds is different, such differences were not due to factors of seasonal significance.

5. 3. 4. pH

pH is one of the very significant chemical characteristic of all waters, which explains certain significant biotic and abiotic ecological characteristics of aquatic systems in general. pH balance in an ecosystem is maintained when it is within the range of 5.5 to 8.5 (Chandrasekhar *et al.*, 2003). pH of a water body is a diurnally variable property

according to temperature variation in the system (Ojha and Mandloi, 2004). Kaul and Handoo (1980) found that increased surface pH in water bodies is due to increased metabolic activities of autotrophs, because in general they utilize the CO₂ and liberate O₂ thus reducing H⁺ ion concentration. The same authors are also of the opinion that in the bottom of water bodies liberation of acids from decomposing organic matter under low O₂ concentration result in low pH.

The surface water of *Periyar* Lake in general always showed a neutral or slightly alkaline pH. Comparison of pH of surface water showed that the fluctuations in it across the stations were insignificant (**Tables 19 to 21**) during all the seasons; but fluctuations in pH over years were significant during the pre-monsoon and southwest monsoon. The fluctuations in pH over the years during the northeast monsoon were insignificant. Three-year average pH (**Table 22**) of surface water during different seasons showed that the variations in it across the different stations were insignificant whereas that over the different seasons were significant. Thus, it seems that pH is a more seasonal dependent characteristic in freshwaters surrounded by undisturbed watersheds as is found in *Periyar* Lake.

During the entire period of study the pH of surface waters changed only once below neutral value. It was in the pre-monsoon of 2005 at stations 2, 3 and 4A alone. But pH of surface waters reached 8 or moved above 8 at two seasons during the period of study—in the pre-monsoon of 2003 at stations—2, 3 and 4A and in the northeast monsoon of 2004 at station-1 alone. The pH of bottom water was in the range of 6.9 to 7.9 during the entire period of study at all the stations.

Comparison of pH of bottom-water (**Tables 23 to 26**) showed that the fluctuations were insignificant across the stations during all the seasons. The fluctuations over the years were significant during the pre-monsoon and the southwest monsoon alone, but insignificant during the northeast monsoon. As in the case of surface-water, the three-year average of pH of bottom-water during different seasons showed that the variations in pH across the different stations were insignificant whereas that over the different seasons were significant. Thus it became clear that the fluctuations in pH of both surface and

bottom waters were quite similar in *Periyar* Lake. This is an indication that a more or less stable chemical quality exists throughout this water body.

Kataria *et al.* (1995) pointed out that a suitable range of pH is necessary for fish survival in water bodies and acid waters reduce the appetite of fish and their growth. The same author also emphasized that the suitable pH is above neutrality, and the Environment Protection Agency of United State's criteria for pH of fresh water aquatic life is 6.5 to 6.9. According to ICMR (1975) and WHO (1985) safe pH limit is 7 to 8.5. But ISI (1991) range is 6.5 to 8.5. A pH range of 6 to 8.5 is normal according to the United States Public Health Association (De, 1999). When compared to all these Standards, pH observed in *Periyar* Lake water in general was within the safe limits. The low value of pH 6.5, noticed in surface water at stations-2 during the pre-monsoon 2003 may be considered as a rare incident. However, such rare occurrence during a three-year period of observation is enough to suggest a careful continuous monitoring for a better management of the system, especially when the significance of this Lake as the nucleus of the precious PTR. Bhatt *et al.* (1999) observed a pH of 7.7 to 8 in *Taudaha* Lake, Katmandu. Koshy and Nayar (1999) observed a pH of 6.1 to 6.9 during post monsoon (Northeast monsoon), 6.3 to 7.1 during Pre-monsoon and 6.2 to 6.9 during the southwest monsoon in River *Pampa*, Kerala. Radhika *et al.* (2004) also observed a difference in pH between southwest monsoon and post-monsoon (northeast monsoon) of waters in *Vellayani* Lake, Kerala. Garg (2002) found that pH in general is more during the southwest monsoon than the summer. Jayaraman *et al.* (2003) observed maximum pH in the southwest monsoon, minimum during the northeast monsoon and medium during summer, in *Karamana* River, Kerala. Such significant seasonal variations were not visible in *Periyar* Lake. Tiwari (1999) pointed out that pH values of 7.25 to 8.9 is a safe range for drinking water as well as irrigational purposes. The pH of *Periyar* water therefore, is in the safe range as a drinking as well as irrigational water resource.

The three-year average pH during the pre-monsoon at the inlets was 7.5 and that at the outlet was 7.6. The three-year average pH during the southwest monsoon at the inlet and outlet were 7.5. The three year average pH during the northeast monsoon at the inlet was 7.6 and that at the outlet was 7.8. The pH in a lake clearly demonstrates the stabilizing effect when the yearly variation is smaller at the outlet than at the inlet, and

the stabilizing effect is related to the retention time as well (Halvorsen, 2004). The maximum variation of pH noticed during the three-year period of study was 7.4 to 8 and 7.1 to 7.7 at the two major inlets (stations-4A and 4B) respectively whereas at the outlet (station-5) the variation was 7.3 to 7.9. Comparison of fluctuations in pH between the inlet and outlet showed that its fluctuations across the inlet and outlet were quite insignificant in *Periyar* Lake. The retention time of water in *Periyar* Lake is very short as it is continuously drawn downwards to eastern plains in the Western Ghats for electricity generation and irrigation purpose. Therefore, it appeared that pH of water in the entire *Periyar* Lake remain stable during all the seasons.

5. 3. 5. Salinity

Salinity is a direct measure of the amount of salts in the water. Because dissolved ions increase salinity as well as EC; the two measures are related. Salinity is a well recognized parameter for studying the mixing processes. Bhade *et al.* (2001) observed 1.25 to 2 times higher salinity in the river zone than at a dam site in central India. As in the case of EC, the surface water at station-5 in general showed a higher salinity range (16-24 ppm) and the lowest salinity range noticed was 11-17ppm at station-4B. At station-2, surface water showed the 2nd highest salinity. The lowest recorded average seasonal salinity of surface waters during the period of this investigation was 11.4 ppm at station-4B during the northeast monsoon of 2003 and the highest recorded salinity was 24 at the station-5 during the southwest monsoon in 2002. The general increase in salinity at station-5 during the southwest monsoon may be due to the influence of increased amount of sewage waters joining the system at this site.

Comparison of the variations in salinity of surface water (**Tables 35 to 37**) showed that the fluctuations in it over the years during the pre-monsoon were slightly significant, whereas that across the different stations were insignificant. In the southwest and northeast monsoon there were very significant variations in salinity of surface-water across the stations. The three-year average salinity of surface-water during the different seasons (**Table 38**) showed that the variations of salinity across the different stations were significant whereas that over the different seasons were insignificant in the Lake.

Unlike surface water, fluctuations in salinity of bottom water over different years were insignificant during all the seasons (**Tables 39 to 41**). The fluctuations across the different stations during the pre-monsoon were also insignificant. However, the year wise fluctuations across different stations were slightly significant during the southwest and the northeast monsoons. There were no significant fluctuations in the three-year average salinity over the different seasons (**Table 42**) of bottom water but the fluctuations were significant across the different stations.

There was no significant difference in salinity between the surface and bottom waters. These results suggested that, in general, the salinity range of *Periyar* Lake was quite normal. However, the trend of increased salinity at station-5 and its reflection on salinity range of station-1 were quite alarming. These are definitely due to the inflow of sewage from Kumily township at these sites. Therefore, the sewage inflow shall be controlled to keep the system safe from the influence of sewage waters.

5. 3. 6. Total Solids (TS)

The TS is a direct measure of all the dissolved and suspended matters in water. It comprises dissolved salts, suspended particles, soil particles, discharged effluents and decomposed organic matter. Taheruzzaman and Kushari (1995) observed TS of 50 to 2240 mg/l in *Ganga* waters and also found that it was lower during the lean months of winter and summer when the interferences due to flood and precipitation were quite lesser. In *Periyar* Lake the TS of surface water varied from 110 mgL⁻¹ (at station-4B during northeast monsoon of 2004) to 530 mgL⁻¹ (at station-5 during the southwest monsoon of 2002). The TS values of surface water of station-5 remained higher than that of the other stations during the entire period of study. Similarly the 2nd highest TS were noticed at station-1. Comparison of TS (**Tables 43 to 45**) showed that fluctuations in it across the different stations and over the years were significantly different during all the seasons. The highest content of total solids at both these stations was observed in the southwest monsoon of 2002. The three year average of TS during different seasons (**Table 46**) showed that fluctuation in TS across stations and that over different seasons were significantly different in the Lake. Thus TS seems to be a highly fluctuating parameter in *Periyar* Lake.

5. 3. 7. Total dissolved solids (TDS)

TDS is a direct measure of all the dissolved substances, both organic and inorganic in waters. In *Periyar* Lake the TDS of surface-water varied from 19 mgL⁻¹ (pre-monsoon of 2004 at station-2) to 44.2 mgL⁻¹ (southwest monsoon of 2003 at station-5) and that of bottom-water varied from 18.8 mgL⁻¹ (northeast monsoon of 2002 at station-2) to 47.2 mgL⁻¹ (northeast monsoon of 2003 at station-5). The TDS at station-5 (29.8 mgL⁻¹ to 44.2 mgL⁻¹ for surface water and 29.8 to 47.2 mgL⁻¹ for bottom water) in general were comparatively higher than other stations during the entire period of study. The 2nd highest TDS was noticed at station-2 (20 to 28.2 mgL⁻¹) for surface-water and 18.5 to 28.2 mgL⁻¹ for bottom-water). At other stations (2, 3, 4A and 4B) the variations in TDS were quite narrow (19 to 24.4 mgL⁻¹) during the entire period of study.

Comparison of the TDS of surface and bottom waters showed that (**Tables 47 to 49 and 51 to 53**) fluctuations in it over the years during all the seasons were found insignificant, but that across the different stations were very significant. The three-year average of TDS of the three seasons of both surface and bottom waters (**Table 50 and 54**) showed that the fluctuations of it over the seasons were insignificant, but that across the stations were very significant. In general the TDS at station-5 was found always significantly higher than that at all the other stations. TDS at station-1 was the 2nd highest, except in the northeast monsoon during which TDS at this station was almost equal to that at other stations.

Tiwari (1999) observed a TDS of 150 to 192 mgL⁻¹ (mean value 170 mgL⁻¹) in the 'Upper Lake' water of Bhopal. Dwivedi and Sonar (2004) reported a TDS of 150 mgL⁻¹ in a small reservoir in eastern Himalayan State of Arunachal Pradesh in India. Gupta and Gupta (1999) reported a TDS of 175-414 mgL⁻¹ in drinking waters in Satna, MP State of India. Compared to those reports TDS at *Periyar* Lake was found very low at all the stations during the entire period of study. However, the increase in TDS noticed at station-5 followed by station-1 points to the increased influence of waste water from Kumily township on the *Periyar* Lake, which is a tendency of pollution and must be seriously curbed.

5. 3. 8. Total Alkalinity

Total alkalinity is caused by bicarbonates, carbonates, OH ions, borates, silicates and phosphates (Kataria *et al.*, 1995). Alkalinity is a measure of buffering capacity of water and is important for aquatic life in a freshwater system because it equilibrates the pH changes that occur naturally as a result of photosynthetic activity of phytoplankton (Kaushik and Saksena, 1989). Alkalinity of water is its capacity to neutralize a strong acid and is characterized by presence of all hydroxyl ions capable of combining with hydrogen ions (Koshy and Nayar, 2000). Alkalinity is used as criteria for determining the nutrient status of waters (Sorgensen, 1948; and Moyle, 1949).

In pure natural waters alkalinity is mostly due to dissolved CO₂ or bicarbonate ions and it represents the main carbon source for assimilation during photosynthesis. Kaul *et al.* (1980) found that with increase in atmospheric temperature and the consequent increase in the photosynthetic process in hot season, alkalinity values usually decrease in summer. They observed significant difference in alkalinity between surface and bottom waters: lower in surface waters than in the bottom, in *Nilnag* Lake, Kashmir. In that Lake they found the amount of Ca three times higher than Mg, and bicarbonate as the most dominant ion. According to Ruttner (1963), in lakes, calcium bicarbonate is the most dominant buffer, a fact which normal lakes share with most of the hard water lakes. Osborne *et al.* (1987) observed that an increase in concentration of cations was balanced by increase in concentration of bicarbonates and the increase in bicarbonate in a lake is probably due to absorption of atmospheric CO₂ if pH increased during the period. According to them if there is no increase in the relative concentration of the probable counter ions such as Ca and Mg, the dissolution of carbonates can be ruled out as a possible mechanism.

In *Periyar* Lake the alkalinity varied between 13.1 mgL⁻¹ (at station-4A and 4B during the southwest monsoon of 2004) to 22.5 mgL⁻¹ (at station-5 during the pre-monsoon of 2005). Haniffa *et al.* (1993) reported that alkalinity vary from 4.3 to 31.3 mgL⁻¹ in *Tambraparni* river, TN, India. Sharma and Sarang (2004) observed a total alkalinity of 190 to 350 mgL⁻¹ in *Jaisamand* Lake, Udaipur, Rajasthan, India. Bhatt *et al.* (1999) reported an alkalinity variation of 156 to 191 mgL⁻¹ in *Taudaha* Lake in

Katmandu. When compared to those reports it became clear that the total alkalinity in surface as well as bottom waters of *Periyar* Lake remained within the very safe level at all the stations during the entire period of study. In the Lake, total alkalinity was solely due to bicarbonates and no carbonate alkalinity could be traced at any station during the entire period of study. However when the alkalinity level is used as a criterion for assessing the nutrient status (Sorgensen, 1948; and Moyle, 1949) this Lake water is moderately nutrient rich. According to their classifications waters are grouped into three different nutrient status groups on the basis of alkalinity: (a) 1 to 15 mgL⁻¹ as nutrient poor, (b) 16-60 mgL⁻¹ as moderately rich, and (c) more than 60 mgL⁻¹ as nutrient rich. The *Periyar* water at its inlet zones with 13 mgL⁻¹ of total alkalinity (stations-4A and 4B) might be considered as nutrient poor, where as at the outlet (station-5) with 22 mgL⁻¹ of total alkalinity might be considered as a water of moderately rich in nutrient status.

Comparison of the total alkalinity of surface water showed that (**Tables 55 to 57**) the fluctuations in it over years were very significant during the pre-monsoon and the southwest monsoon, but that was insignificant during the northeast monsoon. During all the seasons, fluctuations in total alkalinity across the stations were insignificant. The three-year average of total alkalinity of surface-water of the different seasons (**Tables 58**) showed that variations in this factor over the seasons and across the different stations were always significant. Comparison (**Table 59-61**) of total alkalinity of bottom-water showed that fluctuations in it over the years were significant during south west monsoon and it across the stations was insignificant during all the seasons (**Table-62**). The three-year average total alkalinity of bottom-water of different seasons showed that it was significantly different over the seasons but the difference was insignificant across the stations.

Total alkalinity of both the surface and the bottom water during all the seasons in general showed a decreasing tendency from the pre-monsoon period to the northeast monsoon at all the stations during the entire period of study. It may be assumed that, as the monsoon progresses the alkalinity content decreases or water quality stabilizes in the Lake. However, the total alkalinity of surface and bottom waters at Station -5 was found equal in the pre-monsoon and the northeast monsoon during 2004. Among all the

stations, station-5 showed a slightly higher surface water alkalinity than the same at the other stations.

The observations of seasonal difference in total alkalinity in *Periyar* Lake in general agrees with the opinions of Bhatt *et al.* (1999) and Trivedy and Goel (1986) who argued that alkalinity is usually higher during the pre-monsoon than the monsoon. Venkateswarlu (1969) also observed that alkalinity is affected by rain fall. Jayaraman *et al.* (2003) observed a variation in total alkalinity from 4mgL^{-1} (during northeast monsoon) to 1920mgL^{-1} during pre-monsoon, in *Karamana* River, Kerala. Radhika *et al.* (2004) also observed an increase in alkalinity during summer in *Vellayani* Lake, Thiruvananthapuram, Kerala. Garg (2002) observed a total alkalinity of 159.43mgL^{-1} in river *Mandakini*, Chitrakoot, where the minimum is recorded in summer and maximum at winter. *Mandakini* is a Himalayan river where summer is characterized by high inflow of water. Iqbal and Katariya (1995) reported a different observation in the *Upper* Lake of Bhopal, MP State, India, where they found a maximum total alkalinity value of 160mgL^{-1} (during monsoon) and a minimum value of 68.2mgL^{-1} (during summer).

In *Periyar* Lake, the surface water of station-5 when compared to other stations, showed a higher alkalinity in all seasons during entire period of study. It is at this station the sewage of *Kumily* township joins the surface water of the Lake and hence the slight increase in alkalinity in surface waters at this site was a sign of anthropogenic impact on the system. The absence of such a tendency of higher alkalinity in bottom water underlines this assumption.

5. 3. 9. Hardness

Hardness is governed by the contents of Ca and Mg, and the major contribution to hardness is usually Ca. It may be due to other ions such as Fe^{++} as well. Practically hardness is a measure of the capacity of water to precipitate soap. The total hardness is defined as the sum of Ca and Mg concentrations, both expressed as CaCO_3 in mgL^{-1} . Carbonates and bicarbonates of Ca and Mg cause temporary hardness. Sulphates and chlorides cause permanent hardness. Water with total hardness $0\text{-}60\text{mgL}^{-1}$ is considered soft; $60\text{-}120\text{mgL}^{-1}$ is considered medium and above 120mgL^{-1} is considered very hard.

Reid (1961) observed that hard water lakes have little or no carbonate alkalinity and the bicarbonate alkalinity results in high buffer capacity which keeps the pH relatively constant. According to Durfer and Baker's classification when hardness is less than 75 mgL⁻¹ of CaCO₃, water is soft (Adak *et al.*, 2002). According to Moyle (1949) and Pandey and Soni (1993) a lake with an alkalinity value over 90 mgL⁻¹ is hard. Bhatt *et al.* (1999) reported a total hardness of 352 mgL⁻¹ (during summer) to 280 mgL⁻¹ (during monsoon) in *Taduaha* Lake, Katmandu. Kataria *et al.* (1995) reported a hardness of 20-410 mgL⁻¹ in *Tawa* reservoir, MP State, India. Dwivedi and Sonar (2004) reported a hardness of 84 mgL⁻¹ (during pre-rainy season) to 58 mgL⁻¹ (post-rainy season) in water reservoirs in Arunachal Pradesh State, India. Iqbal and Katariya (1995) also reported higher hardness values in summer and lower in monsoon in *Upper* Lake of Bhopal, MP State, India. Garg (2002) observed a difference in hardness between seasons in river *Mandakini*, Chitrakoot.

Comparison of surface (**Table 63 to 65**) and bottom water (**Table-67-69**) hardness of different seasons showed that variations in it over the years were very significant during all the seasons in both samples. In the case of bottom water the variations across the different stations were insignificant during all the seasons. Variations in hardness of surface water across the different stations were insignificant during the pre-monsoon and the northeast monsoon, whereas it was slightly significant during the southwest monsoon. Comparison of the three-year average of total hardness of surface and bottom waters showed that fluctuations in hardness were significant over different seasons whereas such fluctuations were insignificant across stations.

The highest hardness in surface water noticed was during the pre-monsoon season (12.5 mgL⁻¹ at station-5 in 2003), moderate during the southwest monsoon (6.5 mgL⁻¹ at station-4B in 2004), and lowest during the northeast monsoon season (5 mgL⁻¹ at station-5 and the same at station-3 in 2004). In *Vellayani* Lake, Kerala, Radhika *et al.* (2004) observed hardness of 16.25 to 30.75 mgL⁻¹ in surface water whereas in bottom water the hardness was slightly higher, which varied from 17 to 37.25 mgL⁻¹ in surface water. Compared to hardness of similar fresh waters in the country, the *Periyar* water showed a uniquely low hardness throughout the period of study. In general, the surface water at station-5 showed comparatively higher hardness than that at the other stations in all the

seasons during most of the period of studies. Jain *et al.* (2002) observed an increase in hardness of freshwaters due to anthropogenic influence. It is at the station-5, the sewage of *Kumily* town joins the surface water of *Periyar* Lake and hence the slight increase in hardness in surface water at this site was a sign of anthropogenic impact on the system just as in the case of alkalinity. The absence of such a tendency of higher hardness in bottom water at all the stations, also underlines this assumption.

5. 3.10. Free Carbon Dioxide (CO₂)

Although CO₂ is a minor component of air it is abundant in water because of its solubility which is 30 times more than that of oxygen, and the amount of CO₂ in water usually shows an inverse relationship with oxygen (Radhika *et al.*, 2004). Free CO₂ is essential for photosynthesis and its concentration affects the phytoplankton, and its productivity. Excess of it gets dissociated into carbonic acid. The limit of free CO₂ as per acceptable Standards is 10 mgL⁻¹ of surface water. Increase in CO₂ indicates increase in pollution load (Koshy and Nayar, 1999).

Dwivedi and Sonar (2004) observed an average of 2 mgL⁻¹ of free CO₂ in water of reservoirs in Arunachal Pradesh State, India. Radhika *et al.* (2004) reported an annual variation of 2.42 to 10.47 mgL⁻¹ of CO₂ in *Vellayani* Lake in Kerala. The same author found that there was a gradual change in concentration of CO₂ in the Lake from the pre-monsoon to the southwest monsoon to the northeast monsoon; the maximum being in the northeast monsoon, minimum during the southwest monsoon and moderate during the pre-monsoon. Sharma and Mathur (1992) noted maximum free CO₂ in monsoon and minimum in winter in north Indian waters.

Comparison of the dissolved (**Tables 71 to 73**) CO₂ of surface water showed that there were no fluctuations in it over different years and across the different stations in each season. CO₂ content of the different seasons (**Table 74**) showed that the variation in it in surface water was significant over the different seasons but insignificant across the different stations. There were no fluctuations in CO₂ content of bottom water over the different years and across the different stations in the southwest and the northeast monsoon seasons (**Tables 75 to 77**). But in the pre-monsoon the fluctuations in dissolved CO₂ of bottom water was found significant over the years and not across the stations. The

three year average of dissolved CO₂ of bottom water (**Table 78**) during the different seasons showed that the variations in this factor were significant over the different seasons and across the different stations in *Periyar Lake*.

The CO₂ content of surface water varied from 1.6 mgL⁻¹ (at station-3 during the southwest monsoon of 2004) to 3.4 mgL⁻¹ (at station-5 during the southwest monsoon of 2004). In general both the surface and bottom waters at station-5 showed a comparatively higher CO₂ content than that at the other stations during the entire period of study. Another significant trend observed was a slight increase in the CO₂ content of the surface water at station-4A during the northeast monsoon. In other stations during the entire period of study the CO₂ content of surface water did not show much fluctuation. CO₂ content of bottom water showed a slight increase during the pre-monsoon to the northeast monsoon at all the stations. In general the free CO₂ in the Lake remained quite normal for an oligotrophic freshwater system and never exceeded the standard values during the entire period of study.

5. 3. 11. Dissolved Oxygen (DO)

DO is the sole source of oxygen for all the aerobic aquatic life and hence it is considered as an important measure of purity for all waters. Oxygen content is important for direct need of many organisms and affects the solubility and availability of many nutrients and therefore the most significant parameter affecting the productivity of aquatic systems (Wetzel, 1983). DO reflect the water quality status and physical and biological processes in waters and show the metabolic balance of a lake. DO is an important water quality parameter in assessing water pollution (Lalraj *et al.*, 2002). The factors affecting oxygen content in natural waters include input due to atmosphere and photosynthesis and output from respiration, decomposition and mineralization of organic matter as well as losses to atmosphere. Hence, the oxygen balances in water bodies become poorer as the input of oxygen at the surface and photosynthetic activity decreases and as the metabolic activities of heterotrophs are enhanced. Fluctuation in DO is also due to fluctuation in water temperature and addition of sewage waste demanding oxygen (Koshy and Nayar, 2000).

Higher DO means rate of oxygen replenishment in water is greater than O₂ consumption and this is healthy for almost all aquatic systems (Adak *et al.*, 2002). Rabalais (2002) used the term 'hypoxia' for low oxygen content and 'anoxia' for no oxygen content in waters. According to the author, where excess carbon is produced and accumulates in waters, secondary effects of eutrophication often occur such as noxious algal blooms (including toxic ones) decreased water clarity, and low DO. A low DO content is a sign of pollution (Bhatt *et al.*, 1999).

The fluctuations of DO of surface water were significant across the different stations during all the seasons, whereas fluctuations over the years were significant during the northeast monsoon and the pre-monsoons alone (**Tables 79 to 81**). In the southwest monsoon the fluctuations in DO over the years were insignificant. The three year average DO of surface water (**Table 82**) during the different seasons revealed that fluctuations in it over the seasons and across the stations were always significant. Variations in DO of bottom water over the years were significant during the northeast and the pre-monsoon, but found not at all significant during the southwest monsoon (**Tables 83 to 85**). However, variations across stations were significant during all the seasons. The three year average seasonal DO of bottom water (**Table 86**) showed that significant variations in DO occur over seasons and across the different stations.

The DO in surface water of *Periyar* Lake varied from 4.6 mgL⁻¹ (at station-2, during the pre-monsoon of 2004) to 8.3 mgL⁻¹ (at station-4B during the pre-monsoon of 2005). The minimum limit of DO required for freshwaters as per ICMR (1975) and the ISI (1991) standards is 5 to 6 mgL⁻¹. Therefore, the DO of the Lake can be considered almost normal for a natural lake except at certain points during certain seasons and years. Kaul *et al.* (1980) observed DO value of 5.7 to 11.7mgL⁻¹ in *Nilnag* Lake, Kashmir. Koshy and Nayar (1999) observed a DO content of 3.1 mgL⁻¹ to 12.6 mgL⁻¹ in *Pampa* River, Kerala. Garg (2002) reported DO of a minimum of 6 mgL⁻¹ (during summer) and maximum 8.12 mgL⁻¹ (during the monsoon) in river *Mandakini*, Chitrakoot. Singh and Rai (1999) reported a DO variation of 0.9 to 9.83 mgL⁻¹ in *Ganga* River at Varanasi. Jayaraman *et al.*, (2003) observed that DO vary month wise and station wise in waters of *Karamana* River, Kerala, India and maximum DO was observed in rainy season.

Unlike the above reports, *Periyar* Lake remained stable with only meager fluctuations in DO throughout the entire period of study. The fluctuations in DO observed in the Lake were quite random. There were no visible seasonal trends in the average DO of surface and bottom waters at all the stations in the Lake. Spatial difference in DO of surface water was also quite narrow. The maximum surface water DO was observed at station-4B (5.5 to 8.3 mgL⁻¹) and the minimum (4.7 to 7.1 mgL⁻¹) at station-5 in all the seasons during the entire period of study. This trend was identical for both surface and bottom waters. The slight general reduction in DO at station-5 can be due to the impact of organic load through the sewage from Kumily township reaching the site. Except during the pre-monsoon of 2004, the year wise fluctuations in DO were not significant at all the stations.

At all the stations except at 2, 3 and 4A, there were no significant difference in DO between surface and bottom waters. The uniformity in DO at certain stations was because of the low bottom sample depth (below 3 meters) at all those stations. At stations-2, 3 and 4A, where the average sample depth was consistently around 10 meters, a difference in DO between both surface and bottom waters was quite evident. At station-2 the bottom water DO fluctuation during the three-year period was 4.6 to 6.5 mgL⁻¹ (surface - 4.6 to 7.4 mgL⁻¹), at station-3 it was 2.1 to 5 (surface - 5.1 to 7.6 mgL⁻¹) and at station-4A, it was 2 to 7.24 mgL⁻¹ (surface 5.2 to 8.2 mgL⁻¹). At the Dam site (station-3) where the depth of bottom sample was consistently 10 meters in all the seasons throughout the entire period of study, the bottom DO was also consistently lower than that of its surface content; 2.1 to 5 mgL⁻¹ during the pre-monsoon, 4.9 to 7.2 mgL⁻¹ during northeast monsoon and 4.4 to 6.9 mgL⁻¹ during the northeast monsoon.

The organic matter produced during photosynthesis ultimately get deposited in the Lake mud where for its decomposition it utilizes the oxygen present in the water layer close to it (Kaul *et al.*, 1980). The amount of trophogenesis occurring in the epilimnion is correlated with hypolimnetic oxygen depletion and is thus a reflection of its degree of eutrophy (Hutchinson, 1938). In Lakes depletion of oxygen in the lower layers near the bottom is an indication of eutrophication (Kaul, 1977). The rate of oxygen depletion noticed in bottom layers in deep zones of the *Periyar* Lake may be an indication of the changing of the system into a more eutrophicated type. However, this cannot be

attributed to the freshly deposited organic matter in the Lake. Because freshly sedimented organic matter usually has higher proportion of less resistant tissue, appears to be highly refractory to oxidative breakdown by aerobic bacteria, and hence there is an increased chance of oxygen depletion after heavy rains (monsoons) in such Lakes which receive inflow of organic matter from the watersheds (Kaul *et al.*, 1980). In the Lake since the bottom depletion of oxygen was much more intense during the summer (pre-monsoon) season, the monsoon influence was positive than negative, and hence the bottom depletion in the pre-monsoon can be attributed to lowering of general water level and to the heavy deposit of organic matter which may be existing at the extreme bottom from early inception of the Reservoir. Moreover, there is the chance of re-oxygenation of water during the monsoon due to circulation and mixing by inflow after the monsoon rains (Hannan, 1979). The northeast monsoon corresponds to the winter season during which cooling down of water body enable much more dissolution in waters than during warm seasons. Depletion of oxygen may occur in summer due to increase in temperature as well. The oxygen cycle in water involves a rapid decrease during summer at a steady increase through autumn till maximum content is reached in winter, following the well known solubility of gases (Kaul *et al.*, 1980). Bhade *et al.* (2001) observed a direct anoxic hypolimnion in the Lake zone extending 25 m down to 45 m in *Tawa* reservoir. Such an examination of DO of extreme depth could not be done in *Periyar* Lake during this study.

5. 4. Major cations in the water

5. 4. 1. Calcium (Ca)

The general acceptable limit of Ca in waters is usually 75 mgL^{-1} whereas its maximum permissible limit is 200 mgL^{-1} (ICMR, 1975). The source of Ca in natural waters is basically leaching from Ca rich mineral rocks such as lime stone or mineralization of organic matter by the bacteria. Therefore, Ca in natural waters differs according to difference in geographic regions or anthropogenic impact.

In Lake *Murray* of Papua New Guinea Ca content varied from 39 to 60 mgL^{-1} and the amount was inversely proportional to water level; increased during low water levels and decreased during high levels (Osborne *et al.*, 1987). But in a Norwegian mountain

lake the annual variation in Ca reported is from 0.62 to 0.93 mgL⁻¹ (Halvorsen, 2004). Laluraj *et al.* (2002) observed an amount of 220 to 338 mgL⁻¹ of Ca in waters at *Kayamkulam* estuary Kerala, India and found that the Ca content generally reaches the maximum during the pre-monsoon. They also observed that Ca in bottom water in this estuary is higher than that of surface water which according to them may be due to dissolution of detritus materials at the bottom. Annual average amount of 30 mgL⁻¹ of Ca is found in *Nilnag* Lake, Kashmir and the amount decreased in summer. Summer decrease of Ca in water is attributed to photosynthetic activity of macrophytes attaining their peak growth and production during the season (Kaul *et al.*, 1980).

In *Periyar* Lake the seasonal average of Ca content in waters varied from 2 mgL⁻¹ to 3.6 mgL⁻¹. In general there was a slight increase in Ca ion in waters at station-5 (the outlet) from that at the Dam site (the culmination of all inlets). Fluctuations in Ca content of surface-water over the years and across the stations were insignificant during the southwest and northeast monsoons, whereas it was significant during the pre-monsoon (**Table 99 to 101**). The three-year average of Ca content of surface-water (**Table 102**) during the different seasons showed that the fluctuations of it over the seasons were insignificant but that across the stations were significant in all the seasons. Ca of bottom-water (**Table 103 to 105**) showed that the fluctuation in it over the years and across the stations were insignificant throughout the period of study, but a comparison of the three-year average value of the three seasons (**Table 106**) showed that the fluctuations of Ca in bottom-water were significant over the seasons and across the stations.

As in the case of other quality parameters this slight increase in Ca at the outlet from that of the inlet was definitely an impact of sewage waters from the Kumily town joining at this site. Even though the Ca level was found quite normal at all the stations and the fluctuations noticed were quite irregular between the seasons throughout the period of study. The order of the major cations in freshwater is generally a progression-Ca>Mg>Na>K, but Suvarna and Somasekhar (1997) observed different ionic composition of Na>Ca>Mg>K in the water body they studied. In *Periyar* Lake the Ca ions were found lesser than that of Mg ions.

5. 4. 2. Magnesium (Mg)

The general acceptable limit of Mg in water is usually 50 mgL^{-1} whereas its maximum permissible limit is 100 mgL^{-1} (ICMR, 1975). Halvorsen (2004) reported 0.12 to 0.16 mgL^{-1} of Mg in a Norwegian mountain lake. In lake *Murray*, Papua New Guinea, concentration of Mg (6 to 16 mgL^{-1}) varied according to water level, increased during low water levels and decreased during high levels (Osborne *et al.*, 1987). Laluraj *et al.* (2002) found that in *Kayamkulam* estuary, the Mg content varied from 637 to 1158 mgL^{-1} and there the Mg and Ca generally reached the maximum during pre-monsoon. Kaul *et al.* (1980) observed an average Mg content of 7.4 mgL^{-1} (3.4 to 10.6 mgL^{-1}) in *Nilnag* Lake, Kashmir.

The seasonal average of Mg ions in *Periyar* waters varied from 3.1 to 6.6 mgL^{-1} , which is quite below the standards prescribed. However, unlike the mineral composition of other lakes, the water of *Periyar* Lake is characterized by a higher amount of Mg than Ca. There were not much difference in Mg ions in both surface and bottom waters. As in the case of Ca, there was a general increase in the average amount of Mg ions in water at station-5 than at all the other stations during the entire period of study.

The fluctuations of Mg in surface-water over the years were significant only during the southwest monsoon but that across the stations were insignificant in all the seasons (**Tables 107 to 109**). The three-year average (**Table 110**) of the same showed that the fluctuations were significant over the seasons and across the stations during the entire period of study. In the bottom samples (**Tables 111 to 113**) the fluctuations of Mg over the years and across the stations were insignificant in all the seasons. The three-year average values (**Table 114**) showed that the fluctuations over the seasons were significant and that across the stations were insignificant. The maximum Mg content reported in the bottom-water was 7.3 mg L^{-1} (at station-5 during the pre-monsoon 2003) and the minimum amount reported was 3.1 mg L^{-1} (at station 2 during the pre-monsoon of 2003).

5. 4. 3. Potassium (K)

Halvorsen (2004) reported 0.23 to 0.30 mgL^{-1} of K in a Norwegian mountain Lake. In river *Mandakini*, Chittrakoot, seasonal variation in K content (2 to 12 mgL^{-1}) was

not same at all stations; at certain stations the maximum content recorded was during summer and at certain others during monsoon (Garg, 2002). K in an estuary of Kerala varied from 210 to 290 mgL⁻¹ (Lalraj *et al.*, 2002). In Lake *Murray* of Papua New Guinea concentration of K (3 to 6 mgL⁻¹) varied according to water level, increased during low water levels and decreased during high levels (Osborne *et al.*, 1987). K content in *Nilnag* Lake in Kashmir waters varied from 0.3 to 0.94 mgL⁻¹ during winter and recorded a decrease in K ionic content during summer (Kaul *et al.*, 1980).

In *Periyar* Lake the amount of K ions in both the surface and bottom waters did not vary much. In both surface and bottom water the K content varied from 0.9 mg L⁻¹ (at station-5 and 1 during the southwest monsoon of 2002 and 2003) to 2 mg L⁻¹ (at station-4B during the northeast monsoon of 2003). K content in the surface-water showed that (**Table 115 to 117**) the fluctuations in it over the years were significant in all the seasons, whereas the fluctuations across the different stations were significant during the northeast monsoon alone. K content in the bottom-water showed (**Tables 119 to 121**) that the fluctuations in it over the years were significant during the southwest monsoon alone and the fluctuations across the stations were insignificant during all the seasons. The three-year average of K ions in surface water (**Table 118**) during the different seasons showed that there were no significant fluctuations in K ions in the Lake over the different seasons and across the different stations. There were no fluctuations in the three-year average of K ions in bottom-water (**Table 122**). Insignificance of fluctuations in K⁺ over the seasons and across the stations in the Lake evidence the absence of agricultural pressure of all kinds on the system.

5. 4. 4. Sodium (Na)

Halverson (2004) reported 0.29 to 0.39 mgL⁻¹ of Na in a Norwegian mountain Lake. In river *Mandakini*, Chitrakoot, seasonal variation in Na content (7 to 14 mgL⁻¹) in water was not same at all the stations; at certain stations the maximum content was recorded during the winter and at certain others during the monsoon (Garg, 2002). In Lake *Murray*, Papua New Guinea concentration of Na (22 to 31 mgL⁻¹) varied according to water level, increased during low water levels and decreased during high levels

(Osborne *et al.*, 1987). Na content in *Nilnag* Lake, Kashmir waters varied from 2.7 to 5.4 mgL⁻¹ (Kaul *et al.*, 1980).

In *Periyar* Lake the seasonal average of Na ions varied from 1.9 (at Station-4B) to 6.5 mgL⁻¹ (at station-5). There were not much difference in Na ions in both surface and bottom waters. There were significant fluctuations in the Na ions over different years during all the seasons but the fluctuations across the stations were significant during the southwest and the northeast monsoon seasons only (**Table 123 to 125**). Significant fluctuations were observed in the three year average of Na ions in the surface and bottom waters (**Table 126 and 130**) over the different seasons and across the different stations. Na ions in bottom water of the different seasons (**Tables 127 to 129**) showed that the fluctuations in it over the years were significant during the northeast monsoon alone whereas insignificant during the pre-monsoon and the southwest monsoon. Across the different stations such fluctuations were significant during the southwest monsoon alone. Three-year average of the content of Na ions in the bottom-water (**Table 130**) showed that the fluctuations in it were significant over the different seasons and across the different stations during all the seasons. In general, the water at station-5 showed a higher amount of Na at all the seasons during the entire period of study. Significant fluctuations in Na over the seasons and across the stations show that Na⁺ in tropical freshwaters is related to differences in quality and quantity of inflow.

5. 5. Major anions in the water

5. 5. 1. Chloride (Cl)

Cl ions in sea-water is around 20,000 mgL⁻¹, in rainwater it is 2 mgL⁻¹ and in unpolluted rivers the amount of Cl ions is usually 2-10 mgL⁻¹; and when the amount is above 200 mgL⁻¹, the water is not used for human consumption (Koshy and Nayar, 1999). Maximum permissible limit with regard to Cl content in natural freshwaters according to WHO (1985) is 200 mgL⁻¹ and the same according to ICMR (1975) and ISI (1991) is 250 mgL⁻¹. Halvorsen (2004) reported 0.33 to 0.45 mgL⁻¹ of Cl in a Norwegian mountain lake. In river *Mandakini*, Chitrakoot, seasonal variation in Cl content (24 to 80 mgL⁻¹) was not same at all the stations (Garg, 2002). Jayaraman *et al.* (2003) observed a variation in Cl content of 1.2 to 15807 mgL⁻¹ in *Karamana* River which is subjected to

sea intrusion in pre-monsoon. They observed that in the river the Cl content increases from southwest monsoon to northeast monsoon to pre-monsoon. Pandey and Sharma (1999) reported a similar trend in *Ramaganga* River in U.P and Abbasi *et al.* (1997) in *Kuttiadi* River, Kerala.

Gowd *et al.* (1998) reported Cl concentration of 11-514 mgL⁻¹ during northeast monsoon and 10-418 mgL⁻¹ during pre-monsoon season at *Pedavanka* watershed, *Ananthapur* district, Andhra Pradesh, India. In Lake *Murray*, Papua New Guinea concentration of Cl (6 to 49 mgL⁻¹) varied according to water level, increased during low water levels and decreased during high levels (Osborne *et al.*, 1987). Dwivedi and Sonar (2004) observed a variation of Cl in reservoirs in Arunachal Pradesh from 21 mgL⁻¹ during pre-monsoon to 29.6 mgL⁻¹ during monsoon. Bhade *et al.* (2001) observed that Cl ions were 1.25 to 2 times higher in the riverine zone than the dam site in *Tawa* reservoir, M.P State, India. Excess Cl ions in water indicate degree of pollution and in natural waters the Cl ions are usually found associated with Na, K, and Ca, and Cl ions produce salty taste when concentration is 100 mgL⁻¹ (Kataria *et al.*, 1995). Gowd *et al.* (1998) observed that a high concentration of Cl imparts a salty taste to water. According to Chandrasekhar *et al.* (2003) the presence of Cl concentration in a water source is used as an indicator of organic pollution by domestic sewage.

The Cl ionic content in *Periyar* Lake ranged from 5 mgL⁻¹ (at station-4B during southwest monsoon of 2003) to 9.9 mgL⁻¹ (at station-5 during pre-monsoon of 2005). At the major inlet stations (4A and 4B) the Cl ionic content varied from 5 to 6.4 mgL⁻¹, whereas the same at station-5 varied from 6.3 to 9.9 mgL⁻¹. At station-1 (just inner to station -5) the Cl ionic content ranged from 6.2 to 9.9 mgL⁻¹, and at the other stations, lying between station-5 and the major inlet stations, the range of Cl ions was intermediary in amount. Another important trend noticed was that of an increase in Cl content at station-1 than that at station-5, during the southwest monsoon of both 2003 and 2004.

The Cl concentration serves as an indicator of pollution by sewage (Trivedi and Goel, 1986). In *Periyar* Lake the Cl content was more or less similar in both the surface and bottom waters and it varied from 5 to 9.9 mgL⁻¹. Throughout the period of study the

water at station-5 showed comparatively higher value for Cl than water at the other stations except during the southwest monsoon. During the southwest monsoon the Cl content at station 1 exceeded that of station-5. The lowest Cl content was recorded at station-4B throughout the study period. Cl ions in surface-water showed (**Tables 131 to 133**) that the fluctuations of it over the years were significant in the pre-monsoon and the northeast monsoon, but it was insignificant during the southwest monsoon. However, such fluctuations across the different stations were significant during all the seasons. The three year average of Cl ions in surface water (**Table 134**) was insignificant over the seasons but significant across the stations during all the seasons. In the bottom water, the fluctuations of Cl ion content over the years were significant during the pre-monsoon and the northeast monsoon, whereas insignificant during the southwest monsoon. Across the stations the fluctuations were significant during all the seasons. Fluctuations in the average three year value of Cl ion content were insignificant over the different seasons but significant across the stations during all the seasons.

5. 6. Major Nutrients in the water

5. 6. 1. Nitrogen (N)

An increase in trophic status of a lake is associated with an increase in its nutrient status. Nitrogen and Phosphorus are the major nutrients for all phytoplankton growth and the limited availability of these nutrients in water usually limits phytoplankton growth in natural aquatic systems. On the contrary excess availability of both of them triggers eutrophication. Accumulation of N and P in natural waters is more closely related to external factors such as cultural influences, fertilization, and the rate of flow (Hutchinson, 1938). In natural waters $150 \mu \text{gL}^{-1}$ of N is a critical value and when the content crosses the limit algal blooms occur (Sawyer *et al.*, 1945). Once N is transformed through microbial process in soils to biologically available N in ground and surface waters, there are a number of effects beginning with ground water contamination and surface water acidification. The maximum acceptable concentration of N in water for humans either for drinking or for recreation and aesthetics is 10mgL^{-1} (of nitrate or nitrate together with nitrite) or 1mgL^{-1} (nitrite alone), whereas a maximum concentration of 100mgL^{-1}

(nitrate or nitrate and nitrite together) or 10 mgL^{-1} (nitrite alone) is permissible for animals including wildlife (Riordan, 1993).

Nitrogen is generally considered the primary limiting nutrient for phytoplankton biomass accumulation (Rabalais, 2002). The accumulation of N in reservoirs and natural water bodies has become a common phenomenon which alters ecological process in many parts of the world due to intensive human activity. Increased nutrients along with altered nutrient ratios cause multiple and complex changes in aquatic ecosystems. The forms of N that affect aquatic ecosystems include inorganic dissolved forms; Nitrite (NO_2), Ammonium (NH_4), Nitrate (NO_3) and a variety of dissolved organic compounds such as amino acids, urea and composite dissolved organic nitrogen, and particulate nitrogen.

NH_4 in water is produced by microbiological degradation of organic nitrogenous matter. Free NH_4 is an important parameter indicating pollution. Surface waters generally have lesser NH_4 form than bottom waters because it is liberated often from the decomposing organic matter of the lakes and its release in the deep layers is governed by anoxic conditions (Kaul *et al.*, 1980). In surface layers the low NH_4 concentrations result through its utilization by plankton and other plants (Prochazkova *et al.*, 1970).

In general, NO_2 and NH_4 forms are present in natural waters in smaller quantities when compared to the NO_3 form. Nitrite is the product of intermediate oxidation state of N produced both in the oxidation of NH_4 to NO_3 and in the reduction of NO_3 . It is an intermediate compound in N cycle and is unstable. The low concentration of NO_2 is in consonance with its insignificant role in the environment and also with its short residence time in water (Malhotra and Zaroni, 1970). Presence of NO_2 in water depends on oxygen content of water.

NO_3 is the most highly oxidized form of N, which is the product of aerobic decomposition of organic nitrogenous matter. NO_3 is a plant nutrient and inorganic fertilizer that enters water supply sources from septic systems, animal feed lots, agricultural fertilizers, manure, industrial waste waters, sanitary landfills and garbage dumps. The most important source of NO_3 in waters is biological oxidation of nitrogenous organic matter of both autochthonous and allochthonous origin, which

include domestic sewage, Agricultural run-off and effluents from industries (Saxena, 1998). Maximum permitted limit of drinking water level of $\text{NO}_3\text{ N}$ is 20 mgL^{-1} according to ICMR (1975) and 45 mgL^{-1} according to ISI (1991). NO_2 form of N is formed by incomplete bacterial oxidation of organic nitrogen while NO_3 concentration depends on geochemical conditions such as degree of use of agricultural fertilizers and industrial discharges of nitrogenous compounds (Kataria *et al.*, 1995).

Abbasi (1997) did not detect any NO_3 in *Punnur puzha* while they reported lower values of the same in *Kuttiadi* dam. Osborne *et al.* (1987) observed that concentration of P and N increased during higher water levels. Closer coupling between benthic and pelagic process occur in deep lakes (Bengtsson, 1975). Nutrients are stored in sediments (Threkeld, 1994; Jeppesen *et al.*, 1997). In deep lakes settling of suspended matter can lead to low nutrients in the epilimnion during summer. Hence internal loading depends upon the intensity of turbulence across seasonal pycnocline that transports nutrient rich hypolimnetic water to the photic zone in summer (Jellison *et al.*, 1993 and Romero *et al.*, 1998). Blum (1956) reported that highest values of NO_3 in rainy season may be due to the addition of N in the form of runoff water and organic pollution due to sewage entry whereas NO_3 depletion in winter and summer may be due to the photosynthetic activity of the alga or due to the oxidation of organic compounds.

Nitrogen estimation could be carried out only for surface-water during this study. Total N includes inorganic forms nitrate/nitrite and ammonium, as well as organic nitrogen. Total kjeldal N is the sum of ammonium and organic nitrogen compounds. Total kjeldal N in *Periyar* Lake was extremely small, ranged from 1 to 3.9 mgL^{-1} whereas the NO_3 form of N ranged from 0.1 to 0.6 mgL^{-1} during the entire period of study.

Nitrate nitrogen content (**Table 139 to 141**) in the surface-water showed that there were significant fluctuations in it across the different stations during all the seasons. However, such fluctuations over the years were significant only during the southwest monsoon. Three year average of $\text{NO}_3\text{ N}$ (**Table 142**) in the surface water showed significant fluctuations across the different stations but the fluctuations in its value over the different seasons were insignificant. Total N content in the surface water showed

(Tables 143 to 145) that the fluctuations of it over the years were significant during the two monsoon seasons but insignificant during the pre-monsoon. But such fluctuations across the stations were significant during the southwest monsoon only. However, the three year average of total kjeldal N (Table 146) in the surface water showed significant fluctuations across the different stations and over the different seasons.

The present study showed that, in spite of the increasing anthropogenic influences, the N concentration in *Periyar* Lake never reached an alarming level at any stations during the entire period of study. However, certain interesting trends were visible in N content as in the case of other quality parameters. In general the N content (both the total kjeldal form and the NO₃ form) at station-5 (total kjeldal N was 1.7 to 3.5 mgL⁻¹; NO₃ was 0.3 to 0.6 mgL⁻¹) remained slightly higher than other stations during all the seasons throughout the period of study. The second highest content was found at station-1. There was a seasonal trend of a comparatively slightly higher amount of total kjeldal N during the pre-monsoon at all the stations, whereas the trend was not visible in NO₃ form of N. The lowest content of total kjeldal N was observed during the southwest monsoon. In 2004, the content of total kjeldal N during the northeast monsoon was comparatively higher than that of its content during other years at all the stations, and was almost equal to its content during the pre-monsoon at station-5.

5. 6. 2. Phosphorus (P)

P occurs almost solely as phosphates in natural waters. All forms of phosphates such as orthophosphates, condensed phosphates, and organically bound phosphates are found in waters. Phosphate is added to land through different ways; P containing fertilizers (manufactured from mined P), animal manures, and waste products from animals supplemented with P enriched feed. In natural waters P exists as soluble phosphates. P is the nutrient considered to be the critical limiting nutrient, causing eutrophications of fresh water systems (Rabalais, 2002). It is a major nutrient that triggers eutrophications and required by algae in small quantities (Bandela, *et al.*, 1999). Each P ion promotes the incorporation of seven molecules of N and 40 molecules of CO₂ in algae (Wetzel, 1983).

P enters surface water from human-generated wastes and land run off; domestic waste contains approximately 1.6 kg per person, per year of which 64 % is from synthetic detergents (Kataria *et al.*, 1995). P additions to landscape enter water via waste water effluents and soil erosions, and also from detergents. Therefore, P in large quantities in water is an indication of pollution through sewage and industrial waste. P is the primary limiting nutrient in most lakes and reservoirs. Just like N, higher P in bottom water may result from decomposition of organic matter and its release from sediments under the anoxic conditions. P limits the growth of all the algal forms most often, but N limits the algal growth of certain species alone. This is because of the fact that certain species of algae which fix nitrogen themselves are not affected by scarcity of N in the water they grow. Hence, the P nutrient assessment of waters is crucial to the monitoring investigations of natural freshwater bodies.

In the present study, phosphates at surface-water alone were monitored. P of the Lake was found varying from 0.01 to 0.1 mgL⁻¹ or 10 to 100 µgL⁻¹, during all the seasons throughout the period of study. According to Jeppesen *et al.* (1997), P content of 0.05 to 0.1 mgL⁻¹ is threshold of it as a nutrient for natural waters. Romero *et al.* (2002) considered Lake *Pamvotis* with a P content of 0.11 mgL⁻¹ as one of intermediate nutrient status. *Periyar* Lake with P less than 0.1mgL⁻¹ represents a freshwater body of oligotrophic status.

In *Periyar* Lake, the fluctuations in P content during the different seasons and different years were random. Fluctuations in the inorganic P of water (**Tables 147 to 149**) were significant across the different stations in all the seasons. But fluctuations in it over the different years were significant during the pre-monsoon and the southwest monsoon only. Three year average of P content during different seasons (**Table 150**) showed that there was significant difference in this value over the different seasons and across the different stations.

However, when P at the different stations were compared, waters at station-5 showed the highest values throughout the period of study and water at station-1 showed the 2nd highest values. According to Welch (1980) a water body may be considered as eutrophic if the total P value ranged in between 20-30 µgL⁻¹. In *Periyar* Lake the

maximum P content (50-100 μgL^{-1}) was noticed at station-5 followed by station-1 with P content in between 30 to 70 μgL^{-1} . The inlet zones showed minimum P content of 10 to 60 μgL^{-1} . At stations 2 and 3 the P content varied from 10 to 80 μgL^{-1} . Seasonal analysis showed that maximum P content was noticed at all the stations during the pre-monsoon and the minimum at the northeast monsoon. Moderate content of P was noticed during the southwest monsoon.

5. 6. 3. Silica

Silicates are any mineral that contain silica, and include quartz (SiO_2), feldspars, clays, and others. Silicon dioxide occurs in all natural waters in various forms. Much of the silica in water comes from the dissolution of silicate minerals. The source of silica is usually natural rock, and therefore freshwater contains higher concentrations. Many silicates are stable in acidic chemical environments, but tend to dissolve in alkaline (basic) chemical environments. Much rain is acidic and is not good at dissolving silica. However, the chemistry of water changes at the Earth's surface and underground, and some water is alkaline enough to dissolve many silicate minerals. For instance, acid water dissolves limestone, and in doing so it can become alkaline.

Silica is of significance as a major nutrient for Diatoms and may become a limiting nutrient during Diatom blooms. Unlike other nutrients, this is only a major requirement of Diatoms so it is not regenerated in the plankton ecosystem as efficiently as, for instance, nitrogen or phosphorus nutrients. This can be seen in maps of surface nutrient concentrations, as nutrients decline along gradients, silicon is usually the first to be exhausted (followed normally by N, then P). In a classic study, Egge and Aksnes (1992) found that Diatom dominance of mesocosm communities was directly related to the availability of silicate. When silicon content approaches a concentration of 2 mmol m^{-3} , Diatoms typically represent more than 70% of the phytoplankton community. Silica additionally limits the growth of Diatoms (Schindler, 1978). Other researchers (Milligan and Morel, 2002) have suggested that the biogenic silica in Diatom cell walls acts as an effective pH buffer, facilitating the conversion of bicarbonate to dissolved CO_2 .

In *Periyar* Lake the amount of dissolved silica in water was low (0.01 mg L^{-1} to 0.41 mg L^{-1}). The fluctuations in silica content (**Tables 151 to 153**) across the stations of

the Lake were significant during the southwest and the northeast monsoons only, whereas the fluctuations over the years were significant during the pre-monsoon and the southwest monsoon only. Three-year average of the silica content (**Table 154**) showed that the fluctuations in it over the different seasons were significant in the Lake. Whereas, the fluctuations across the different stations were insignificant in all the seasons.

5. 7. Organic waste in the Lake

5. 7. 1. Biochemical Oxygen Demand (BOD)

Biological or Biochemical Oxygen Demand is the amount of oxygen utilized by microorganisms in consuming the organic matter in waters. BOD is a measure of the actual oxygen demand of wastes under laboratory conditions similar to those found in the receiving waters, and is a good indicator of biodegradability of wastes. BOD increases as the bio-degradable organic content increases in waters. BOD above 6 mgL^{-1} in a water body is considered polluted and high BOD values are attributed to the stagnation of water body leading to the absence of self purification (Iqbal and Katariya, 1995). Water bodies with BOD of 225 to 323 mgL^{-1} are called septic or anaerobic systems (Chandrasekhar *et al.*, 2003).

In *Periyar* Lake the BOD of surface water varied from 0.4 (at station-1 and 3 during the southwest monsoon of 2003) to 3.1 mgL^{-1} (at station-5 during the pre-monsoon of 2003) during the three-year period of studies. The maximum BOD at station-3, and station-4A never exceeded 1.9 mgL^{-1} and the minimum at these stations were 0.4 and 0.6 mgL^{-1} respectively. The lowest seasonal BOD recorded during the three year period was 0.4 to 0.9 mgL^{-1} at station-3 in the southwest monsoon and the highest seasonal BOD noted was 1.7 to 3.1 mgL^{-1} at station-5 in the pre-monsoon. The minimum pre-monsoon BOD was found at station-2 (1 to 1.3 mgL^{-1}) and the maximum was at station-3 (1.7 to 3.1 mgL^{-1}) followed by station-1 (1.4 to 2.6 mgL^{-1}). Jayaraman *et al.* (2003) reported that the BOD variation from 8.3 mgL^{-1} (pre-monsoon) to 3.84 mgL^{-1} (northeast monsoon) in *Karamana* river, Kerala and attributed the occurrence of high BOD during the pre-monsoon to the accumulation of dead organic matter in the river during the season. Bhatt *et al.* (1999) observed a variation in BOD of 32 mgL^{-1} (in summer) to 6.5 mgL^{-1} (in

winter) in *Taudaha* lake, Katmandu, and the gradual decline of BOD from monsoon followed by winter was attributed to decrease in temperature which in turn retards microbial activity. In *Tawa* reservoir, M.P State, India, Kataria *et al.* (1995) reported BOD of 1.64 to 5.54 mgL⁻¹.

Compared to the reports of BOD from Lakes in different parts of India, the *Periyar* Lake was found unique with one of the lowest BOD values in all seasons throughout the period of study. However, a general increase in BOD, especially at station-5 and 1 must be seriously observed. Even though the maximum BOD noted in the Lake during this study was well below the minimum limit prescribed according to Standards, considering the extremely short residence time of water in the Lake, (water is continuously drawn eastwards) this is not a factor to be neglected. Comparison of BOD (**Tables 87 to 89**) showed that fluctuations in it in surface water over years were insignificant whereas that across the stations were significant during the pre-monsoon and the northeast monsoon periods. But during the southwest monsoon fluctuations in BOD were significant over the years and insignificant across the stations. The three-year average of BOD (**Table 90**) of surface waters during the different seasons showed that both the seasonal fluctuations and fluctuations across the stations were significant. BOD of bottom water (**Table 91-93**) showed that the values were insignificant both over the years and across the stations during the pre-monsoon and the southwest monsoons. But during the northeast monsoon the fluctuations in BOD over the years were significant and that across the stations were insignificant. The three year average BOD of bottom water (**Table 94**) during the different seasons showed that the fluctuations in it across the stations and over the different seasons were insignificant

5. 7. 2. Chemical Oxygen Demand (COD)

COD is the measure of oxygen consumed during the oxidation of oxidizable organic matter by a strong oxidizing agent. High COD indicates presence of all forms of organic matter, both biodegradable and non-biodegradable and hence the degree of pollution in waters. Singh and Rai (1999) recorded 26.16 mgL⁻¹ (monsoon) to 3.2 mgL⁻¹ (winter) in river *Ganga* at Varanasi. Adak *et al.* (2002) found COD of 32 to 44 mgL⁻¹ in river *Bramhani* and 9.8 to 12 mgL⁻¹ in water of a tube well in Orissa.

In *Periyar* Lake the COD at stations-1 and 5 were found very high, totally different from that of the other stations. Highest COD values were noted at station-5 during all seasons of the entire period of study, which varied from 3.1 (southwest monsoon) to 3.8 mgL⁻¹ (pre-monsoon). The 2nd highest COD values were obtained at station-1, which varied from 2.4 (southwest monsoon of 2004) to 3.7 mgL⁻¹ (pre-monsoon of 2005). The lowest COD values were obtained at station-4B (0.6 mgL⁻¹ during the southwest monsoon to 1.1 mgL⁻¹ during the pre-monsoon). The COD of surface water during different seasons throughout the period of study showed (**Tables 95 to 97**) that the fluctuations in its value across the stations were significant in all the seasons whereas that over the years were significant only during the southwest monsoon. The three year average value of COD (**Table 98**) during different seasons showed that the fluctuations in COD over the different seasons were insignificant but that across the stations were significant in all the seasons.

According to the Indian Standards, desirable limit of COD in freshwaters is 2.72 mgL⁻¹, whereas the maximum permissible limit is 100 mgL⁻¹ (BIS, 1992). At both the stations-5 and 1 (representing the outlet) the COD values were found almost above that of the desirable level whereas COD at the inlet (station-4A and 4B) and up to stations-2 the values remained within the desirable limits (0.9 to 2.2 mgL⁻¹). Organic matters of natural as well as anthropogenic inputs were the main contributory factors for the high COD values in natural waters. When compared to existing values of COD, for example that observed in natural waters of *Karamana* River (COD of 4.8 to 374 mgL⁻¹ (Jayaraman *et al.*, 2003) the COD of *Periyar* Lake was found normal.

5. 8. Oil and Grease due to boat activity

Oil contains hydrocarbons, sulphur, metals, aliphatics, aromatics, PAHs, PCBs and the effects of these compounds on aquatic components depend on grades and types, and the duration it has been in the water (Haile, 2000). Baker (1971) reported a growth stimulation following oil pollution. Bury (1972) observed the death of many garter snakes and pond turtle after a diesel oil spill into a *Californian* stream. In *St. Lawrence* River, many frogs and turtles were also found dead following a huge oil spill (Palm, 1979; Alexander *et al.*, 1981). Oil pollution affects all aquatic organisms including aquatic birds. In birds oil pollution may cause mineral imbalances such as zinc

deficiency, which can take the form of immune depression spanning multiple generations (Beach *et al.*, 1982).

It is well documented that sub lethal exposure of oil is known to increase susceptibility to disease, increase energy costs, perturb parental behavior and disturb hormone status in birds (Eppley, 1992). Secondary effects of oil spills have the potential to reduce short or long term reproductive success, and may affect its longevity. Tertiary effects may also impact unexposed seabirds if their prey or predator populations are affected, or if parents are affected (Eppley and Rubega, 1996). Trans-generational immune suppression could be disastrous to a population and might be important in cases like that of the Exxon Valdez spill in Alaska where impacted seabird population fail to completely recover (Warheit *et al.*, 1997). Later studies have suggested that immune suppression may be present in birds living in oil polluted sites and the effects of immune system injury are not evident until days or weeks later when mortality occurs; high mortality rates and poor breeding success of affected birds may be largely due to damage to the immune system (Briggs *et al.*, 1997).

Werner (1983) reported that an increased oxygen demand by the biological community, nutrient immobilization, a reduction in plant biomass accumulation and a heterotrophically dominated ecosystem are the general effect of oil pollution. According to the same author nutrient immobilization, rather than toxic effects of oil on plants, is the primary factor leading to the long-term imbalance between autotrophs and heterotrophs in aquatic systems; moreover, increased rates of oxygen utilization because of the oil were identified as a potential primary detrimental effect of oil pollution. Animals and plants may be affected by the physical properties of floating oil, which prevents respiration, photosynthesis or feeding whereas higher vertebrates, whose coats get covered in oil, lose buoyancy and insulation, (hypothermia) while the ingestion of oil may prove toxic. Many components of oil are toxic to organisms. Also a whole range of sub lethal effects of PCBs in particular are known to be both mutagenic and carcinogenic in some organisms. The main effect of oil discharges on microorganisms is one of stimulation and the hydrocarbons provide a food source. Another serious problem is that very small residues of oily wastes can cause the fish to taste of fuel oil.

Loss of amenity value, when a water body is covered in oil can be enormous, and have huge repercussion on the tourist industry. Gelda and Effler (2002) reported that the exchange of gasses across the air water interface is important in regulating concentration of various constituents of ecological and water quality concern. All over the world, if water is not free of oils, scum, grease and other floating materials it is not generally accepted as pure water. Bhattacharya *et al.* (2003) explained the toxicity of different oil components to freshwater organisms based on his experiments in laboratory microcosms. Luiselli and Akani (2003) revealed both direct and indirect effects of oil pollution on the complexity and habitat use of Nigerian freshwater communities of turtles and they also found that the main direct effect of oil pollution was a considerable reduction in the turtle specific diversity with 50% of the species being lost after oil spillage. They also noticed changes in habitat use in one species. The leak out motor oil creates an oil slick on surface water. It is estimated that the used motor oil causes about 40% of the pollution in U. S. waterways (Paul, 2004).

Enujiugha and Nwanna (2004) reported that introduction of significant quantities of oil into the aquatic ecosystem, will cause increase in BOD, reduction in DO concentration, increased temperature, and pH of the water body; and the resultant effect of these abnormal shifts in these impact indicators, cause disorders in the physiological status, and reduction in the immune status of aquatic organisms, which may lead to mortality. Oil in water changes the property of the feathers of birds, causing them to become matted and; this leads to a reduction in the birds waterproofing, insulation, capacity for flight, buoyancy and ability to find food and water (Neva, 2005). According to a Web Report (2006) if oil enters a slow-moving river it forms a rainbow-coloured film over the entire surface preventing oxygen from entering the water, and on larger stretches of water, the oil contaminates the feathers of water birds and when they preen the oil enters the gut and kills them. According to Vince (2006), unlike major oil spill that causes problems for a time and can be cleaned up, chronic oil pollution is continuous and hard to track or clean up because it comes bit by bit and it has a long-term negative effect on wildlife. Improperly disposed motor oil also can contaminate the soil, surface and drinking water. It is possible that they may sustain numerous forms of physiological

lesions after petroleum hydrocarbon ingestion, although they may not indicate, if any, outward signs of debilitation.

All these authors clearly explain the impact of oil pollution on the structure and function of aquatic ecosystem. Oil and grease were found on surface-water throughout the *Periyar* Lake, as constant broken film during the entire period of study. In different parts of the Lake the seasonal average of oil and grease was found varied from 89 to 2282 mg L⁻¹ during the three-year period of study. Fluctuations in oil and grease content of the Lake (**Tables 155 to 157**) over the different years were significant during the southwest and the northeast monsoon periods. Its fluctuations across the different stations were significant during all the seasons. Three-year average oil and grease (**Table 158**) showed that the fluctuations in it were significant over the different seasons and across the different stations during all the seasons.

Among the different stations in the Lake, the highest oil content (930–2282 mgL⁻¹) was found at stations-1 and 5 throughout the period of study, whereas the lowest oil content was (89-650 mgL⁻¹) at stations-4A and 4B. At station-2 the oil content varied from 330 to 1600 mgL⁻¹ and at station-3, it varied from 265 to 1313 mgL⁻¹. This showed that the oil content was directly related to intensity of boat activities, which pointed to a very deleterious anthropogenic influence on the Lake from tourist activities. The impacts of oil spill was found not restricted to the region of boat activity alone but found extended throughout the Lake, several hundreds of meters inside, even up to the core of the sanctuary area. There is no doubt that the wild animals which drink from the surface waters are continuously receiving a share of the oil film on surface-water at many points in the Lake. At all the stations the highest oil content was observed during the pre-monsoon, the lowest amount was found during the northeast monsoon and moderate oil content was found during the southwest monsoon.

Our observations have shown that it is in the pre-monsoon that many wild animals resort to the direct dependence on the main water body of the Lake. The increasing accumulation of oil in surface-water during this season is therefore a serious threat to the precious wildlife. This factor suggested the need of a thorough monitoring of oil impact in the Lake system including that on the endemic fish life in general and on the precious

wildlife in the sanctuary in particular; such studies should look into the impact of oil on the general health and reproductive biology of endangered wildlife including that of elephants, which depend on the Lake water the maximum (**Plate-9**).

5. 9. Conclusion on physico-chemical parameters

In order to ensure sustainable management and optimum exploitation of the aquatic resources, it is necessary to set safe limits for the pollution impact indicators. The goal of all types of monitoring programs is protection of the environment and its resources. Data collected from monitoring programs explains existing conditions and helps recording of changes in these conditions over time. In the want of prior knowledge of environmental conditions, monitoring establishes a baseline for future comparisons. The implementation of a biological criterion approach that directly measures biological integrity is, therefore, essential to account the status and trends in freshwater ecosystems. Freshwater ecosystem monitoring programs are usually long-term, data intensive programs that establish points of reference for environmental conditions, and then attempt to document and identify change in these conditions over a long period of time.

Long-term examination of the above water quality parameters explained that, in general, the pre-monsoon is the season at which certain parameters exceeded the limits of standards (oligotrophic to eutrophic) and the monsoon periods, especially the southwest monsoon, is the season of highest fluctuations in quality parameters over the years, and across the different stations in the Lake. Anthropogenic impacts from tourism were evident especially in the oil and grease content, nutrient status, in *Periyar* Lake. The accumulation of oil and grease is definitely due to careless boat transport associated with tourist visit which could be avoided if necessary precautions were taken. The general increase in nutrient content, pH and other quality parameters at station-5 followed by station-1 indicated that the 2nd major source of anthropogenic impact on the Lake is from the sewage channel of Kumily township joining the Lake at station-5.

5.10. *Coli form* Bacteria in the Lake

The entry of pathogenic microorganisms into drinking, irrigation and recreational water resources poses a risk to human health. Difficulties and expenses involved in the testing for specific pathogens hazardous to humans have generally led to the use of indicator organisms of enteric origin to estimate the persistence and fate of enteric

bacteria in the environment (Crane *et al.*, 1981). Water quality criteria of developed nations for recreational activities are usually 200 MPN FC/100ml (CCME, 1999). Total *Coli form* densities between 69 to 563 is acceptable for non-contact recreational use such as boating but contact recreation like swimming results in epidemiological outbreaks (Venkiteswaran and Natarajan, 1987).

In general, the average seasonal MPN fecal *Coli form* count in *Periyar* water (all over 2004 and the pre-monsoon of 2005) ranged from 133/100ml to 2487/100ml, except once during the pre-monsoon of 2004, when the *Coli form* count was found zero at station-4B. Count of *E. coli* was totally absent at station-4B during all the seasons. However, presence of fecal *Coli form* in quite high numbers at this station, during the southwest and the northeast monsoons revealed that this station is also not safe from bacterial contamination. However, these bacteria might be of animal origin owing to heavy wildlife stock in the sanctuary.

E. coli was also common in sufficient numbers (18-467/100 ml) in all other stations during all seasons in 2004 and pre-monsoon in 2005 (**Table 171**). Though, fecal indicators are common in water samples from non agricultural or pristine watersheds, their long periods of survival especially in the sediments points to the fact that if they are transported to streams during a season, they may effectively degrade in-stream water quality for several months. Therefore, control must be implemented to minimize bacterial transport to natural systems such as *Periyar* Lake. It is well known that if controls fail during even one rainfall event, surface water quality could be degraded for several months (Jamieson *et al.*, 2003).

The main sources of fecal *Coli form* in the Lake are sewage inflow from Kumily township into the lake at station-5, direct human sources (tribal fishermen and officials living inside the systems) and also from animal fecal matter. Animal fecal sources can be ignored because such *Coli form* bacteria in general are not hazardous to them (Mubiru *et al.*, 2000). But the human sources of fecal bacteria are dangerous to wild animals. Since the MPN count is found quite high, danger of spreading human disease to precious wildlife in the system cannot be underestimated. Therefore, an intensive monitoring of

fecal *Coli form* based on more water samples was found to be very essential in the Lake water.

5. 11. Primary Productivity in the Lake

Although extensive studies of primary production have been conducted in Africa and temperate regions of the world, relatively few studies have been conducted in the South and Southeast Asia (Talling and Limoaalle, 1998). Amarasinghe and Viverberg (2002) made a detailed study of the primary production in *Tessawewa* reservoir in Srilanka.

Primary production in tropical lakes is generally three times higher than in temperate lakes (Limoalle, 1981; Amarasinghe and Viverberg, 2002). High light intensity during the day and the much higher temperature contribute to the large difference in primary productivity between tropical and temperate aquatic systems (Lewis, 1987). Primary production is often affected by nutrient availability in tropical lakes (Talling and Lemoalle, 1998). Rain induced high primary productivity has been observed in some African lakes (Melack, 1979; Thomas *et al.*, 2000). In tropical regions the first rains after the start of the rainy season usually carry a lot of nutrients to the reservoir. If the residence time of water is very short, most of these nutrients will not remain long in the system. GPP and NPP show peaks towards the end of inter monsoonal periods.

There are many purposes for studying primary productivity in lakes. The direct approach that is receiving greater attention in the recent times is the correlation of fish yields with primary production (Smith and Swingle, 1938; McConnell, 1963; Hrbacek, 1969; Wolny and Grygievek, 1972; Sreenivasan, 1972; Melack, 1976; McConnell *et al.*, 1977; Oglesby, 1977; Noreiga-Curtis, 1979). One of the common methods of studying primary productivity in fresh waters is Winkler titration, which has a sensitivity of 0.15 mg O₂/L (Hall and Moll, 1975) to 0.02 mg O₂/L (Strickland, 1965). In principle, any measurement of a water sample in a closed glass bottle, even when carried out *in situ*, will not guarantee a primary production value which reflects that of the water of the site of collection.

Algal primary production studies are of paramount interest in understanding the effect of pollution on the system's efficiency. Pollution affects the production/respiration ratio, a proper level of which is very essential for the sustenance of the system. In non-polluted water, production usually exceeds respiration but in organically polluted systems, respiration exceeds production and no oxygen is left available for the normal aerobic bioactivity of the system leading to the impairment of the system. In *Periyar* Lake, seasonal average of GPP varied from 0.17 to 0.36 mg L⁻¹ of Oxygen/hr (63.75 to 135. mg C/m³/hr) and respiration varied from 0.08 to 0.24 mg L⁻¹ of Oxygen/hr. During the three-year monthly study, respiration never exceeded the GPP. The seasonal average of NPP in the Lake varied from 0.03 to 0.19 mg L⁻¹ of Oxygen/hr. Fluctuations in the GPP over the years (**Tables 159 to 161**) were insignificant during all the seasons but the fluctuations across the different stations were significant during the pre-monsoon and the southwest monsoon. The fluctuations in the three-year average of GPP (**Table 162**) were found significant over the seasons and across the different stations during all the seasons. The fluctuations in NPP over the different years (**Tables 163 to 165**) and across the different stations during all the seasons were insignificant in the Lake. Three-year average of the NPP during the different seasons (**Table 166**) showed that fluctuations in NPP over the different seasons and across the different stations during all the seasons were insignificant. Fluctuations in CR over the different years (**Tables 167 to 169**) were insignificant during all the seasons but fluctuations across the different stations were insignificant during the northeast and the pre-monsoons. In the southwest monsoon fluctuations in CR across the different stations were significant. Three-year average of CR during the different seasons (**Table 170**) showed that fluctuations in it over the different seasons and across the different stations were insignificant during all the seasons. In general, the study of primary productivity showed that this Lake system has a low and stable primary productivity, characteristic to an oligotrophic system.

5.12. Diversity and dynamics of phytoplankton

5.12.1. Relevance of the study

There are a number of reasons to look into the phytoplankton component of a freshwater system. Phytoplanktons are likely to play a key role in solving some

environmental problems, in studying photosynthesis, in understanding aquatic ecosystems and in the production of useful substances (Kurano and Miyachi, 2004). Biodiversity of all systems forms a vital resource that needs to be carefully conserved for our future generation, and planktons are especially important as they form the most sensitive component of the ecosystem and signal environment disturbances. However, biodiversity in aquatic ecosystems remains neglected (Gopal, 1997)

Algal studies are very essential for the assessment and abatement of water pollution. Phytoplankton and its seasonal successions can be a better predictor of long-term environmental changes in the aquatic systems than the more usual descriptors of biomass and productivity indices (Moline and Prezelin, 1996). Studies on polluted system with reference to various pollutants have thrown light on the effectiveness of plankton as bio-indicators (Joseph and Pillai, 1975). Water pollution causes not only changes in physical and chemical variables, and also in algal species composition (Mercado, 2003). Algae are sensitive to pollution or other events and are therefore commonly used for monitoring environmental contamination (Jiunn-Tzong, 1999). Moreover, algal growth in tropical inland water constitutes one of the principal causes deteriorating the potable potentials of water (Sedamkar and Angadi, 2003) and hence a study of it is significant to assess the quality of freshwater. Algae serve as bio-indicator of water quality and pollution analysis (Saladia, 1997). Palmer (1969) listed 60 genera and 80 species, tolerant to organic pollution. Toxic algal blooms and avian botulism are linked (Murphy *et al.*, 2000). Several methods of assessment of water quality based on algal community composition exist (Coesel, 2001).

Algal community analysis is important to analyze the trophic status of aquatic systems. Stoyneva (1998) emphasized that the composition of the phytoplankton is potentially a better indicator of trophic state of aquatic systems. Cronberg (1999) used plankton studies to explain the progression of Lake *Ringsjon* from mesotrophic to hypertrophic status. Bhade *et al.* (2001) examined the relationship between Limnology and eutrophication of *Tawa* reservoir, M.P State, India. According to Busing (1998) monthly water chemistry analysis and quantitative analysis of phytoplankton are part of routine monitoring investigations whereas extensive limnological studies such as

seasonality of the phytoplankton community and its species composition are significant steps to understand, resist and reverse eutrophication in Lakes.

Algal studies have certain significant practical applications such as bio-manipulations to control pollution. Many believe that accurate understanding of the factors shaping phytoplankton communities and specific responses of different algal classes to top down forces is required by lake managers prior to the development of bio-manipulation protocols for any particular water body since water transparency is directly related to the type of algal classes present (Bergquist *et al.*, 1985; Carpenter *et al.*, 1987).

Phytoplankton analysis enables us to learn the peculiarities of sensitive communities in very sensitive environments in general. Changes in phytoplankton community structure–diversity, dominance and biomass–driven by perturbations caused by turbulence and environmental variability have been emphasized by Harris (1986). Reynolds (1997) considers aquatic systems as extremely sensitive to environment changes and therefore, community organization there is usually fragile and primitive because the system is frequently disorganized.

Long-term study of phytoplankton component in relation to fluctuations of water quality parameters is useful in developing and evaluating significant general ecological ideas. Species composition of phytoplankton communities changes in response to environmental variation (Naselli-Flores, 2000). Study of aquatic communities and the factors affecting its stabilities is one of the central challenges of ecology since water bodies have always been of great importance for mankind as sources of water and food from fisheries (Kamenir *et al.*, 2004). In Ecology the study of patterns of community structure, underlying control mechanisms and resilience when subjected to ever-growing external climatic and anthropogenic impacts are significant from both theoretical and practical point of view (Odum, 1971; Begon *et al.*, 1996). Temporal variability in the structure and function of a phytoplankton community is of fundamental importance to aquatic system metabolism (Calijuri *et al.*, 2002). According to Wani (1998) since phytoplankton are the primary producers forming the first trophic level of food chain in lake systems, investigation of the phytoplankton community is very significant in the monitoring of such systems.

Algal studies are also important to understand the degree of anthropogenic impacts on aquatic systems. Hutchinson (1967) found that the nutrient increase in a lake due to human activities in the catchments lead to change of lake flora from diatom assemblage to those of greens and blue greens. Vollenweider *et al.* (1974) observed that the effect of anthropogenic influence in a Lake can be traced by the study of phytoplankton and its production. Similarly, knowledge of the bio-volume and composition of phytoplankton, which is one of the central themes in the study of pelagic ecosystem of lakes, is essential to understand the natural variation in the lake ecosystem (Brettum and Halvorsen, 2004).

Phytoplankton community structure and species type indicate some of the crucial environmental developments in aquatic systems. Pollution may be measured by either chemical or biological means (Sweeting, 1994). The role of a bio-indicator has been well established in aquatic ecosystems. Unlike terrestrial counterparts, aquatic organisms are more than often solely dependent and immersed in their water bodies (Miller, 1996). Sampling is costly and sampling frequently with sophisticated equipment, is still more costly. Therefore measurement of aquatic biota to identify structural or functional integrity of ecosystems is gaining wide acceptance (Norris and Thoms, 1999). Algal communities may be good representatives for monitoring general long term succession processes, as they have distinct ecological requirements and tolerances related to a range of water quality parameters (Hughes *et al.*, 1992). Water quality changes may affect community structure, cellular features or bioactivities of the organisms. In tropical and Mediterranean climates different species of algae dominance indicate eutrophication (Sullivan *et al.*, 1988; Fernandez-Pinas *et al.*, 1991; Siva, 1996).

The plankton on which whole of aquatic life depends directly or indirectly are governed by a number of physical, chemical and biological conditions, their interactions, and tolerance of organisms to variations of these conditions. Limnological studies are therefore significant in the understanding of aquatic community structure, algal biodiversity, trophic and pollution status, nature and degree of anthropogenic impacts on aquatic systems. This information is essential to the conservation of precious water resources as well as wildlife in relation to such systems. Therefore, quantitative and qualitative aspects of algal component, and its seasonal dynamics in relation to water

quality parameters of *Periyar* Lake are discussed in detail. Station wise monthly analysis of total algal count as well as density of different species of algae was carried out to assess the phytoplankton structure of the whole system. From these station wise monthly results, average of the total density and density of all the species of algae in the Lake in the different seasons as well as yearly average of all the stations and the Lake as a whole for the different years were derived and compared.

5. 12. 2. Seasonal changes in phytoplankton density

Monthly variations in density of phytoplankton of surface waters at different sampling stations of *Periyar* Lake were done for three years. From the monthly data seasonal, annual and the three-year average values for both were calculated **Chart-2**.

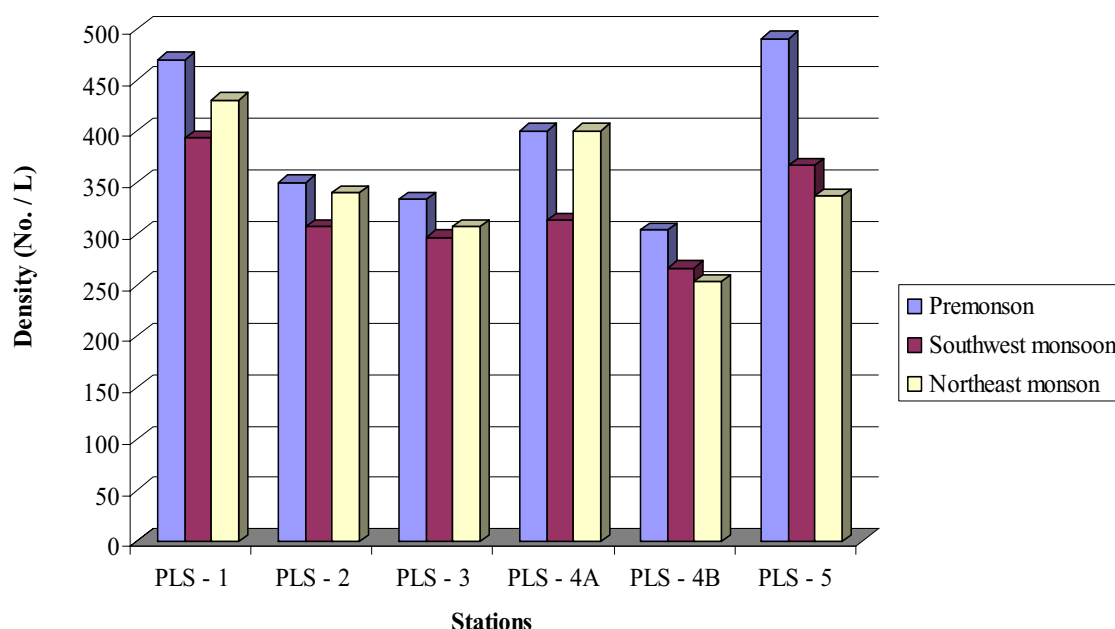
The fluctuations in algal density over the different years (**Tables 172 to 174**) were significant during the pre-monsoon and the southwest monsoon only whereas such fluctuations were insignificant during the northeast monsoon. Similarly fluctuations in algal density across the different stations were significant during the pre-monsoon and the northeast monsoon but insignificant during the southwest monsoon. The three-year average of algal density during the different seasons (**Table 175**) showed that its fluctuations over the different seasons and across the different stations were significant always. The yearly average of total phytoplankton density of the Lake for 2003 was 289 cells L⁻¹ and that for 2004 was 423 cells L⁻¹. The average phytoplankton density of the Lake during the entire study period was 356 cells L⁻¹; average for the pre-monsoon season was 391 cells L⁻¹, for southwest monsoon was 324 cells L⁻¹ and for the northeast monsoon was 344 cells L⁻¹.

Average seasonal density of phytoplankton of the three year period of study varied from 250 cells L⁻¹ (southwest monsoon of 2003) to 496 cells L⁻¹ (pre-monsoon of 2004). In general higher phytoplankton density was much more pronounced during the pre-monsoon than the monsoon periods in the Lake. However, variations between years were visible in the system. In 2003 the average phytoplankton density of the Lake remained 289 cells L⁻¹ and 255 cells L⁻¹ during the pre-monsoon and 250 cells L⁻¹ during the southwest monsoon respectively, but it went up to 363 cells L⁻¹ in the northeast monsoon. In 2004 the average phytoplankton density of the Lake was 496 cells L⁻¹ during

the pre-monsoon, 432 cells L⁻¹ during the southwest monsoon and 340 cells L⁻¹ during the northeast monsoon. Since the water level of the Lake fluctuates quite random, changes in algal densities may not be visible in systems like *Periyar*.

Comparisons of seasonal algal density of the three years showed quite random fluctuations. During the three year period of study, the highest algal count noticed was 610 (**Table-173**) cells L⁻¹ in the southwest monsoon of 2004 at station-1 and the lowest count noticed was 120 cells L⁻¹ at station-4B in the pre-monsoon of 2003. In 2003, the highest algal density was found in the northeast-monsoon at all the stations except at station-5. At station-5 the highest algal density of the year was noticed during the pre-monsoon. The lowest density at most of these stations during the year was in the pre-monsoon except at stations-1 and 5 where the lowest density of the year was observed in the southwest monsoon. In 2004 the highest algal density was in the pre-monsoon at all stations except at station-1, at which the highest density was noticed during the southwest monsoon. The lowest algal density of 2004 was during the northeast monsoon at all the stations. Since the northeast monsoon is a continuation of the southwest monsoon and it continues gradually into the pre-monsoon period and fluctuations in rainfall between seasons was usual, seasonal changes were not much pronounced. The highest density season at most of the internal zones was related to a balance between inflow and outflow which naturally contributed to excess nutrient input or nutrient accumulation in the system. The point to be noted is that at stations-5 and station-1 the highest algal density of the Lake varied from general tendencies which may be attributed to external impact of tourism visible at these stations. The average phytoplankton density of the Lake and phytoplankton density at different stations suggested that the nutrient impact on the system in general is low, characteristic to oligotrophic systems which is quite similar to previous observations in other regions in the Western Ghats such as Murugavel and Pandian (2000), who reported an yearly mean of total phytoplankton density of $159 \text{ L}^{-1} \pm 23 \text{ L}^{-1}$ in *Upper Kodayar* lake- a south Indian lake located in the Western Ghats and the phytoplankton density of $412 \text{ L}^{-1} \pm 155 \text{ L}^{-1}$ in a reservoir situated below.

Chart-2. Three-year average density of phytoplankton of the Lake (2002-2005)



5. 12. 3. Phytoplankton community structure

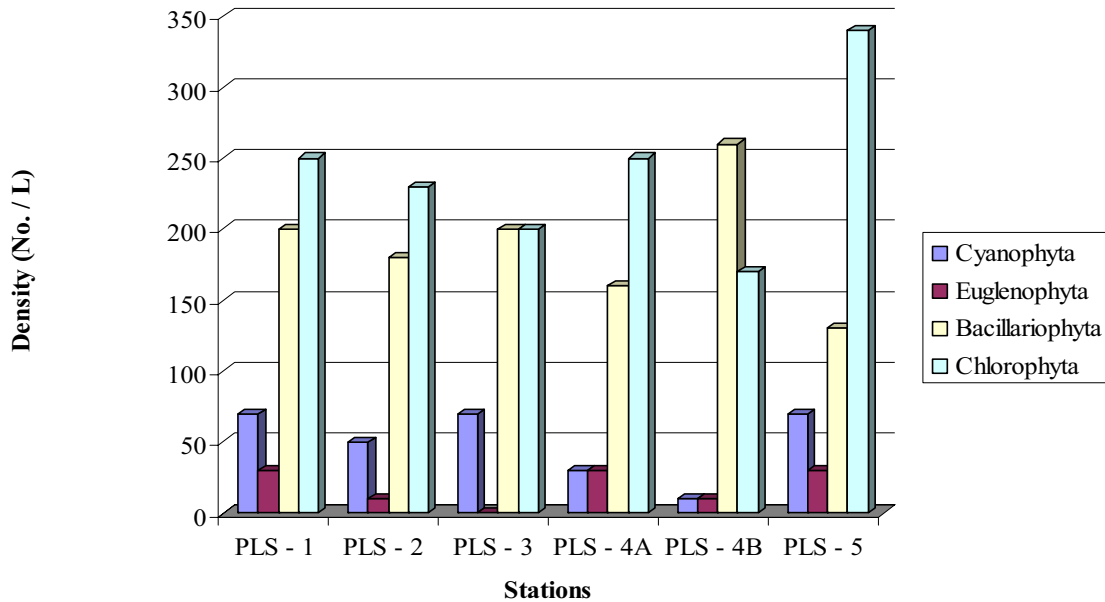
Diversity of algae is an indication of purity and the use of community structure to assess pollution is conditioned by four assumptions: the natural community will evolve towards greater species complexity which eventually stabilizes; this process increases the functional complexity of the system; complex communities are more stable than simple communities, and pollution stress simplifies a complex community by eliminating the more sensitive species (Cairns, 1974). *Periyar* Lake with annual phytoplankton diversity of 69 species may be considered as a sufficiently complex community, characteristic to systems of less pollution stress. The fluctuations in diversity of species at certain stations may be attributed to the impact of anthropogenic influence.

Komarkova (1998) observed that indices of phytoplankton diversity are weak indicators of trophic status and factors which influence diversity are seldom governed by trophic state. According to Bomans and Condie (1998) Physical environment (light intensity and temperature) influences the distribution of algal populations in lakes and

rivers. The principal influences on phytoplankton assemblages in an aquatic ecosystem include nutrients (Mortensen *et al.*, 1992), Carbon dioxide (Shapiro, 1997), light availability, and composition and abundance of zooplankton (Carpenter and Kitchell, 1993). However, the factors influencing phytoplankton assemblages in an aquatic system are related to its trophic status; nutrient availability in oligotrophic environments, zooplankton grazing in mesotrophic systems and underwater light climate and carbon dioxide availability in eutrophic systems (Naselli-Flores, 2000). Seasonal changes and station-wise fluctuations give much more explanation of the ecological tendencies of phytoplankton community in the Lake.

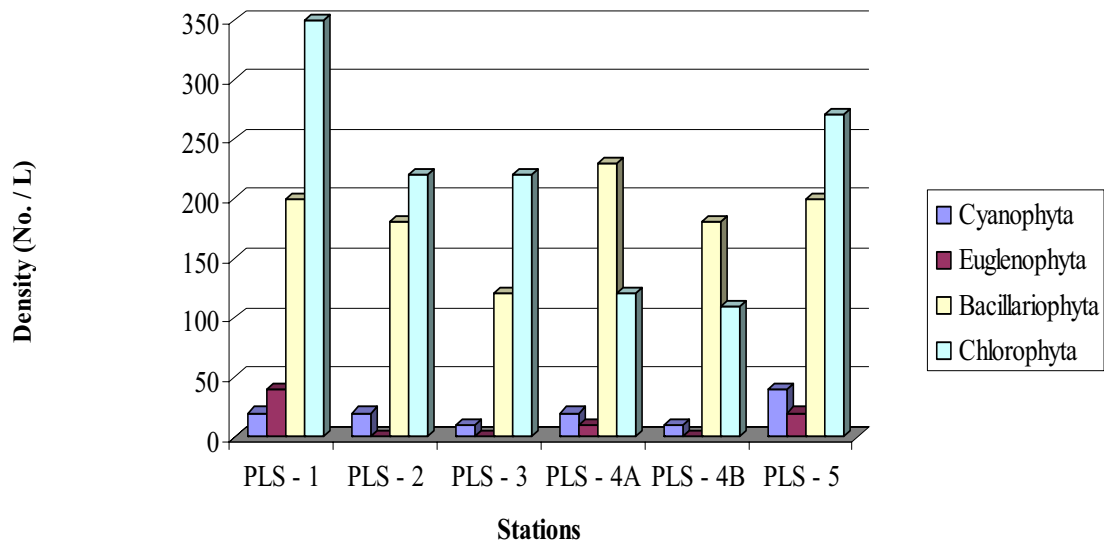
During the pre-monsoon a total of 49 species of phytoplankton were identified of which 24 were identified up to the species level and the rest up to the genus level only. In this season, phytoplankton of the Lake belonged to four classes – the *Cyanophyceae* (4 species belonging to 4 genera - 8% of the total diversity; 10% density) *Euglenophyceae* (5 species belonging to 4 genera, 10% of the total diversity; 4% density), *Bacillariophyceae* (19 species belonging to 9 genera – 39% of total diversity; 38% density) and the *Chlorophyceae* (21 species belonging to 11 genera- 43% of total diversity; 48% density). Among 21 species of *Chlorophyceae*, 12 species belonging to 8 genera (57% of *Chlorophyceae* or 24% of total diversity; 23% density) were *Chlorococcales* and 9 species belonging to 4 genera (43% of *Chlorophyceae* or 18 % of total diversity; 25% density) were Desmids. Station-wise analysis showed that at all the stations except at station-4B *Chlorophyta* formed the dominant group (43 – 60%); at station-4B the Diatoms formed the major group of algae (58%). The highest percentage (60%) of *Chlorophyta* was found at station-5 and the lowest percentage of *Chlorophyta* was found at station-4B (38%) (**Chart-3**).

Chart-3. Group wise density of phytoplankton during pre-monsoon period of 2004



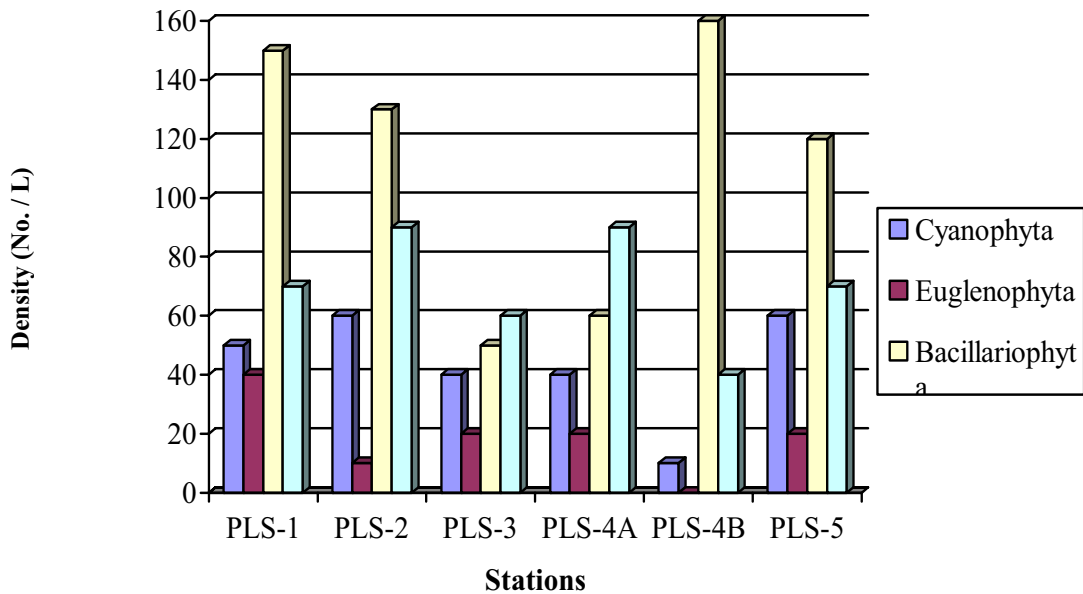
During the southwest monsoon 40 species of algae were recorded in the Lake. The phytoplankton community structure was as follows: *Cyanophyceae* with 4 species belonging to 4 genera representing 10% of the diversity and 5% density; *Euglenophyceae* with 4 species belonging to 3 genera representing 8% diversity and 2% density; *Bacillariophyta* with 14 species belonging to 8 genera representing 35% diversity and 44% density and *Chlorophyta* with 18 species belonging to 8 genera and representing 45% of total diversity and 49% density (8 species of *Chlorococcales* belonging to 5 genera representing 20% of total diversity and 22 % density; 10 species of Desmids belonging to only 3 genera representing 25% of total diversity and 27% density). At all stations except at stations-4A and 4B, *Chlorophyta* was the major group (51-63%). At stations-4A and 4B, Diatoms formed the major group (56-60%). The highest density of *Chlorophyta* was found at station-3 (63%), and lowest amount of *Chlorophyta* was found at station-4A (31%) (**Chart-4**).

Chart-4. Group wise density of phytoplankton during southwest monsoon period of 2004



In the northeast monsoon there were about 42 species of phytoplankton in the Lake. The phytoplankton community of the season included *Cyanophyta* with 5 species belonging to just 2 genera representing 10% of diversity and 12% density; *Euglenophyta* with 5 species belonging to 3 genera representing 12% diversity and 5% density; *Bacillariophyta* with 14 species belonging to 8 genera; and *Chlorophyta* with 18 species belonging to 8 (*Chlorococcales* with 8 species belonging to 5 genera; Desmids with 10 species belonging to 3 genera. At all the stations except at station-4B *Chlorophyta* formed the major group (42-65%). At station-4B, Diatoms formed the major group (70%). The highest density of *Chlorophyta* during this season was found at station-4A (65%) and the lowest density of *Chlorophyta* was at station-4B (22%) (**Chart-5**).

Chart-5. Group wise density of phytoplankton during northeast monsoon of 2004



Throughout the seasons *Chlorophyta* dominated at all the stations except station-4B and 4A in the Lake. At station-4B the dominant group was always the *Bacillariophyta* whereas at station 4A, only during the southwest monsoon the *Chlorophyta* was superseded by Diatoms. But during the northeast monsoon this station showed the highest density of *Chlorophyta* in the Lake. In general at station-5, the percentage of *Chlorophyta* was around 50% or above throughout the study period. Moreover, density of *Cyanophyta* was also more than 10% at this station during most of the study period. Another significant tendency noticed was the dominance of Desmids over *Chlorococcales* among *Chlorophyta* throughout the seasons at most of the stations.

Wani (1998) reported about 89 species of phytoplankton in *Trigamsar* Lake, Kashmir and the species structure described is comparable to that of *Periyar* Lake. The Compound Quotient (Naganandini and Hosmani, 1998) i.e., total number of species of Blue greens + Diatoms + *Chlorococcales* + *Euglenophyta* divided by the number of Desmids for *Periyar* Lake was 4.9 which were close to upper limit of weak eutrophic system.

Station wise comparison of seasonal changes in diversity of different groups revealed that the changes at the different stations were random. This agrees with the

observations of Naselli-Flores (2000) that environments of different trophic states may share very similar phytoplankton assemblages and conversely environments which were ranked in the same trophic category may differ strongly in the structure of their assemblages. However, the presence and dominance of certain groups and species at different stations throughout the period of study showed certain significant ecological tendencies of the Lake. Seasonal changes may favor particular species and such species may dominate the ecosystem at a specific time of the year (Patrick, 1970).

5. 12. 4. Chlorophyta in the Lake

Annual average density of *Chlorophyta* in the Lake was 48%; seasonal average also did not vary much and remained 48-49% throughout the seasons. Among *Chlorophyta*, density percentage of Desmids was always slightly higher than that of *Chlorococcales* at most of the stations; in the pre-monsoon the percentage of *Chlorococcales* and Desmids were 23% and 25%, and during the southwest monsoon the percentage of them were 22% and 27%. But there was a significant increase in density percentage of Desmids (29%) over *Chlorococcales* (20%) during the northeast monsoon.

Desmids are hardly or not to be expected in polluted waters and the reason for the absence of Desmids in polluted waters is attributed to the fact that under nutrient-rich conditions they cannot grow as fast as other algae, so lose in competition. However, station-wise analysis showed exceptional variations in density percentage of the two groups of *Chlorophyta* at station-4B where the Desmids were just 11%, whereas the *Chlorococcales* were around 20%. This may be due to consistently low water level in the station which contributed more access to nutrients in the bottom sediments. *Chlorococcalean* algae are known to prefer inorganic nutrients providing alkaline pH and moderately high temperature (Sharma *et al.*, 1999). Philipose (1967) found that *Chlorococcales* thrived well in water rich in NO₃ than phosphates. Sharma *et al.* (1999) reported that *Chlorococcales* were dominating plankton of the lake *Jai Mahal*, Jaipur, Rajasthan, where they are found mixed with Desmids, Diatoms and Blue-greens and according to the author *Chlorococcales* thrive well in hard water and rich growth of *Chlorococcalean* genera is a sign of pollution. Species of *Scenedesmus* (Busing, 1998) are well known for their adaptability to organic pollution. Large number of species and

the greater quantities of *Chlorococcal* green algae present in summer are indicative of eutrophic ecosystems (Rott, 1984). Seasonal and station wise fluctuations in *Chlorophyta* revealed that developing tendencies of trophic changes in the Lake require further long term specific monitoring of the same.

There were fluctuations in the seasonal average density of *Chlorophyta* at stations-3 and 4A; at station-3 the highest density percentage of *Chlorophyta* (63%) was noticed in the southwest monsoon, followed by the northeast monsoon (61%) and the pre-monsoon (43%). At station-4A the density percentage of *Chlorophyta* was found maximum (65%) during the northeast monsoon followed by the pre-monsoon (54%) and the southwest monsoon (31%). At station-5 the highest *Chlorophyta* density percentage noticed was (60%) during the pre-monsoon followed by the southwest monsoon (51%) and the northeast monsoon (48%). Density percentage of *Chlorophyta* was lowest at station-4B during all the three seasons. The maximum of *Chlorophyta* was 41 % during the southwest monsoon followed by 38 % during the pre-monsoon and 26% during the northeast monsoon. The highest *Chlorophyta* density percentage noticed in the Lake was (65%) at station-4A during the northeast monsoon and the lowest noticed was (26%) at station-4B during the northeast monsoon.

Among the seasons, the pre-monsoon showed highest diversity of *Chlorophyta* (21 species), whereas during the northeast and the southwest monsoons there were 18 species of *Chlorophyta* and 17 species during northeast monsoon in the Lake. *Closteriopsis longissima* (of the order *Chlorococcales*) was one of the species of *Chlorophyta* found at all the stations of the Lake throughout the three seasons. *Closterium parvulum* was found at all the stations during the southwest monsoon, but the species was found absent at station-4B during the northeast monsoon season, and also found absent at station-1 and 5 during the pre-monsoon. *Staurastrum leptocladium* and *Staurastrum paradoxum* were the Desmids found at all stations during the pre-monsoon and southwest monsoons. *Staurastrum paradoxum* was absent during northeast monsoon at all the stations. However, certain other species of the same genus—*Staurastrum chaetoceras* was observed in the Lake at all stations except at station-4B during the season. *Selenastrum westii* was found only at station-4B during the pre-monsoon whereas it was found at stations-1 and 2 during the northeast monsoon.

The dominance of *Chlorophyta*, both density wise and diversity wise suggested organic pollution because certain authors suggested that in cold climates an increase in organic load commonly leads to a shift in the ecosystem from Diatom-dominated flora to green algae-dominated flora (Patrick, 1970). Hutchinson (1967) also had the view that the nutrient increase in a lake due to human activities in the catchments lead to change of lake flora from Diatom assemblage to those of greens and blue greens. However, Rojo and Rodriguez (1994) were of the view that while Diatoms are important in temperate rivers; tropical rivers were mainly dominated by *Chlorophyceae*. *Pediastrum*, *Staurastrum*, *Cosmarium*, *Euastrum* were all species of *Chlorophyceae* found in the Lake, also reported in other south Indian lakes. However, typical species of nutrient rich waters such as *Mougeotia*, *Oocystis*, *Ulothrix*, *Spirogyra*, *Micractinium* (Sreenivasan *et al.*, 1997) were not found in most part of the *Periyar* Lake. The algal community structure thus suggested that the system is still under natural control as was evidenced by the dominance of sensitive species. However, the general occurrence of certain pollution tolerant species such as *Selenestrum* (Alam *et al.*, 1996) and *Scenedesmus* (Tewari and Srivastava, 2004), and the rare occurrence of *Spirogyra*, *Ulothrix*, *Oedogonium* at some parts of the Lake is a tendency to be monitored intensively.

Dominance of Desmids in the Lake was a good sign, but this observation needs further verifications and continuous monitoring. Study of Desmid flora would be useful in managing the pristine quality of this Lake. Sufficient literature exists towards this reason. Desmids in general indicate good quality of water (Hosmani *et al.*, 2002). The establishment of the Diatom-Desmid assemblage is typical for mesotrophic ecosystems (Reynolds, 1980) and absence of Desmids is an indication of heavy pollution of water (Hosmani *et al.*, 2002). Among aquatic microbes, Desmids lend themselves particularly well for the assessment of water quality and nature conservation value and the algae indicate a tendency of oligotrophication and acidification of aquatic habitat (Coesel, 2003). Low nutrient contents, low EC and a slightly acid pH are known to promote an optimal development of the Desmid flora (Coesel, 2001). According to Coesel (1997) Desmids are ecologically highly sensitive microorganisms and is a useful tool in aquatic conservation management especially in those cases where macro-organisms fail.

Traditionally Desmids are associated with oligotrophic fresh waters (Hutchinson, 1967). But when the biomass is taken into account, Desmids play only a minor role in the composition of plankton (Rawson, 1956; Rosen, 1981). Desmids of oligotrophic waters may be an important food source for herbivorous fish. The food chain relations of endemic and endangered species of fishes may include specific phytoplankton species. Therefore, it is important to work out the food chain relations of such endemic and endangered species in *Periyar* Lake. The Lake with sufficient representation of *Cosmarium*, *Closterium*, and *Staurasturm*, offers a typical system for depth study of Desmids and their interrelationships with endemic fish fauna. Moreover, the dominance of Desmids over *Chlorococcales* in the Lake may be considered as a positive biological sign to suggest that the trophic characteristics of the system are still within control. **(Plate-7 & 8)**

5. 12. 5. Bacillariophyta (Diatoms) in the Lake

It is well known that a combination of physical, chemical and biological factors determine the distribution of the Diatom communities in Lakes (Fabricus *et al.*, 2003). *Bacillariophyta* is the major algae with the highest density at station-4B during all the seasons, whereas it was the second major algal species at other stations during all the seasons. At station-1 the Diatom density percentage was 36% during the pre-monsoon and 37 during the northeast monsoon, and it was 34% during the southwest monsoon. At station-2 the Diatom density percentage was 43% during the southwest monsoon followed by 38% during the pre-monsoon, and 32% in the northeast monsoon. At station-3 the Diatom density percentage was highest (43%) during the pre-monsoon followed by 34% during the southwest monsoon, and 18% during the northeast monsoon. At station-4A there was an extra ordinary increase of Diatom density percentage (to about 61%) during the southwest monsoon, followed by 34% during the pre-monsoon, and an extra ordinary decline in Diatom percentage to about 18% during the northeast monsoon. Density percentage of Diatoms was 38% (southwest monsoon), 23% (pre-monsoon) and 32% (northeast monsoon) at station-5. Compared to the other stations, the Diatom density percentage in general remained very high at station-4B—70% during the northeast monsoon, 58 % during the pre-monsoon and 56 % during the southwest monsoon. These observations agree with the findings of Burton *et al.* (1990) who found that the higher

Diatom densities were detected in the river system with the low N and P levels in the stream water combined with alkaline pH. In *Periyar* Lake the pH tended to be alkaline throughout the study period indicating the existence of a buffer system. According to Owen *et al.* (2004) pH, EC and NO₃ appear to be particularly closely related to Diatom development and some species show good potential as indicators of habitat, pH, EC, and temperature. Diatoms need at least 2 micro mol. silicate/L for successful development (Escavara and Prins, 2002). Diatoms have high tolerance capacity to varied changes in the water (Hosmani *et al.*, 2002). Medium nutrient content perhaps may be the factor that limits the growth and the slightly alkaline pH might be one of the factors which favored the species of Diatoms in *Periyar* Lake.

The highest density percentage of Diatoms noticed in the lake was 70% at station-4B during the northeast monsoon and the lowest of Diatom reported (17%) was at station-4A during the same season. Diatoms are stationary and are therefore less able to avoid harmful conditions, and therefore the fluctuations in Diatom percentage at various stations during the different seasons indicated the local and seasonal impact of significant changes in water quality conditions in the Lake.

Diatoms are ecologically diverse and colonize virtually all microhabitats in marine and freshwater. Dixit *et al.* (1992) considered Diatoms as a good tool for environmental monitoring because indices based on Diatom composition give more accurate and valid predictions as they react directly to pollutants. A variety of indices like, Commission for Economical Community Index–CEC (Descy and Coste, 1991), Overall Practical Index (Lenoir and Coste, 1996), Diatom Assemblage Index for organic pollution –D Alpo (Watanabe *et al.*, 1986) and Trophic Diatom Index (Kelly and Whitton, 1995) use Diatoms as bio-indicators. Diatoms can provide valuable information for monitoring rivers, particularly on organic pollution (Sladeczek, 1986).

Bacillariophyta (Diatoms) was the second most diverse group of algae in the Lake with a total of about 26 species belonging to 11 genera representing 38% of the total phytoplankton diversity of the Lake. Among the seasons, pre-monsoon showed the maximum species diversity of 19 whereas during the southwest and the northeast monsoons there were 14 species each. During the pre-monsoon the highest diversity of

Bacillariophyta was at station-3 with 11 species, but during the northeast monsoon this station showed low diversity. During the southwest and the northeast monsoon periods the diversity of station-2 and 1 was 8-9 species, which was higher than that at other stations. *Melosira granulata* was the Diatom found at all the stations in all the seasons throughout the period of study. Anand (2000) reported the dominance of species of *Melosira varians* in a stream in Jammu and Kashmir, India, and noticed its affinity towards clear, fast moving water with low water temperature.

Cyclotella meneghiniana, one of the universally known pollution tolerant Diatom (Unni and Pawar, 2000) was present at all the stations during the northeast and in the southwest monsoon also it was found at all the stations, except at station-4B. However during the pre-monsoon it was found at station-2 and 3 alone. Another species of *Cyclotella* and *Melosira* were found at all stations during the southwest monsoon. *Cocconies placentula* was found at station-3 alone during the pre-monsoon and at station-5 alone during the southwest monsoon. *Stauronies anceps* was found at stations-4A and 4B alone during the southwest monsoon, but at stations-1 and 2 alone during northeast monsoon. *Nitzschia palea*, which is also universally considered as pollution tolerant species (Unni and Pawar, 2000) was found in the southwest monsoon at station-2 alone. According to Sladeczek (1973), *Nitzschia palea* is an indicator Diatom taxon of alpha mesosaprobic system. *Navicula* and *Pinnularia* were the species mostly found at stations-1 and 5 during all the seasons throughout the study. (Plate-6)

5. 12. 6. Cyanophyta (Blue-green Algae) in the Lake

Specific investigation of *Cyanophyta* in Lake waters is very significant because many authors have pointed out that toxin producing *Cyanobacteria* in lakes and reservoirs form a threat to humans (Carmichael, 1996; Chorus and Bartram, 1999; Codd *et al.*, 1999; Chorus 2001), bird and fish as well as various other forms of aquatic life (Lampert, 1981; Kotak *et al.*, 1996; Pflugmacher *et al.*, 1998). ‘Microcystins’ are potent liver toxins and tumor promoters from *Cyanobacteria*. They are produced by several common freshwater *Cyanobacteria* including *Microcystis*, *Anabaena* and *Planktothrix*. Toxic *Cyanobacteria* are very abundant in large number of Lakes, causing a potential threat to humans and animals (Chorus and Bartram, 1999).

Density wise, *Cyanophyta* formed a minor group of phytoplankton in the Lake. Annual average density of *Cyanophyta* in the Lake was 9% and there was marked fluctuations in the percentage of *Cyanophyta* during different seasons. The maximum percentage density of *Cyanophyta* was noticed during northeast monsoon in the Lake and the minimum was during the southwest monsoon. The percentage of density of *Cyanophyta* was quite low (3-8%) at all the stations during the southwest monsoon. The density percentage of *Cyanophyta* during the pre-monsoon was 10%. There were fluctuations in the percentage of this group between the different stations during all the three seasons. In general, during most of the seasons, station-5 (outlet) showed a higher percentage density of Blue-greens than at the other stations and station-4B (the major inlet) showed a lower percentage density than the others. The highest density percentage of Blue-greens (15 %) noticed was at station-5 and the lowest percentage (2%) noticed was at station-4B during the pre-monsoon. Water turbulence - different degree, magnitudes and durations - is a determining factor in phytoplankton growth, especially in *Cyanophyceae* dominance (Reynolds and Walsby, 1975). Lakes that become eutrophied primarily because of an excess of P are typically characterized by a shift towards the dominance of phytoplankton by *Cyanobacteria* including noxious forms several of which are toxin producers. Since the influence of *Cyanobacteria* in *Periyar* Lake was not much, the role of P may be ignored as a growth stimulator in it.

In *Periyar* Lake, *Cyanophyta* group was represented by only 7 species belonging to 4 genera representing 10 % of total diversity. All throughout the seasons the species diversity was 4 or 5. During the pre-monsoon and northeast monsoon, *Microcystis aeruginosa* was found at all the stations except at station-4B. According to Reynolds (1988), *Microcystis aeruginosa* is an S-strategist, which is stress tolerant having low growth rate, low metabolic activity, high nutrient storage capacity with enhanced resistance to sinking and grazing losses and apparently characteristic of waters with phosphate oscillations, is a specialist in phosphate storage and efficient in regulating its density. According to Kilham and Hecky 1988, and Kromkamp *et al.* (1992) this species requires high temperatures, tolerates low light intensity and is not subject to predation by herbivores. According to Brunberg and Blomqvist (2002) *Microcystis* is a widely distributed organism, which dominates the phytoplankton community in nutrient rich

lakes. *Microcystis aeruginosa* is one of the main microcystin producers of lakes (Lindholm *et al.*, 2003). Hence presence of this alga in the lake poses a threat to the wildlife in the sanctuary; the degree to which they may be affected by this alga must therefore be well monitored.

Station wise analysis showed that the lowest species diversity and density of *Cyanophyta* was observed at station-4B (the inlet), whereas the maximum diversity and density of the group was found at stations-1, 2, 3 and 5. Blooms of *Cyanobacteria* in fresh water ecosystems are attributed to nutrients, particularly to phosphorus enrichment. Increased detection of 'cyano-toxins' in water bodies generates a complex challenge for water resource managers all over the world (Johnston and Jacoby, 2003). Other factors are high water temperature, stable water column, low light availability, high pH, low dissolved CO₂, and low total N to P ratio - TN: P ratio (Welch, 1992; Pearl, 1998; Hyenstrand *et al.*, 1998). Impact of *Cyanophyceae* are unsightly surface scum, decreased water column transparency, unpalatable drinking water with noxious odour and some produce toxins (Carmichael, 1996, Chorus, 2001) and 'cyanotoxins' in general are hepato-toxins which are known tumor promoters and have been associated with high rates of primary liver cancer in people drinking water with high concentrations of microcystins (Yu, 1989). Hence, though density wise insignificant, the presence of the species such as *Microcystis* in *Periyar* Lake is a definite pollution signal. **(Plate-5)**

5. 12. 7. Euglenophyta in the Lake

Euglenophyta was the group represented in the lowest density percentage in the Lake. No member of this group was observed at stations-4B during the southwest and the northeast monsoons, at station-3 during the pre-monsoon and the southwest monsoon, and at station-2 during the southwest monsoon. The annual average density percentage of this group in the Lake was just 4%. The highest percentage of *Euglenophyta* noticed in the Lake was 7% at station-1 during the southwest monsoon and at station-3 during the northeast monsoon. Though temperature conditions and pH of the Lake, in general, are slightly favorable to *Euglenophyta*, an excess growth of this group could not be observed in any part of the Lake during the study period.

There were only 6 species of *Euglenophyta* belonging to 4 genera representing just 9% of the total diversity of species in the Lake. Three species of *Euglena* were found in the Lake of which *Euglena viridis* and *Euglena acus* were the most common in the three seasons. One or both of these species was always present at stations-1 and 5 during the entire seasons throughout the study period. *Dinobryon* was found at station-5 in the pre-monsoon alone, whereas it was observed at station-1 during the southwest and the northeast monsoon periods. *Phacus acuminatus* was found in the pre-monsoon at station-1 and 5 alone. *Trachelomonas armata* was found at stations-2 and 4A during the pre-monsoon, but found at station-1 alone during the southwest monsoon. It was found at stations-4A and 5 during the northeast monsoon.

However, presence of *Euglena* and *Phacus*, especially at station-5 and station-1 was a simple and direct indication of higher pollution load at these sites in the system, because both these species, in general, are considered to be dominant tolerant genera of polluted ponds (Alam *et al.*, 1996). However, Tiwari and Srivastava (2004) found *Euglena* and *Phacus* in industrially polluted and non polluted waters in North India and also observed that they are species with greater ecological amplitude to their occurrence in aquatic systems exhibiting varying levels of pollution load. Sreenivasan *et al.* (1997) reported these genera in a shallow polluted lake in TN. **(Plate-4)**

5.13. Periphyton

The periphyton is a thin bio-derm in the interface between aquatic substrata and the surrounding water, which are important autotrophic component of aquatic ecosystems (Moschini-Carlos *et al.*, 2001). Accounting of periphyton in aquatic ecosystems is done for understanding complex biological chain of events in them (Chellappa, 1989). Diatoms form the bulk of the periphytic communities in most of the streams (Patrick *et al.*, 1954). Periphyton forms a dominant ecological feature of oligotrophic lakes. It provides habitat and food for invertebrates and fishes, and changes in the structure and function of this assemblage may affect several other processes in wetlands. Periphyton provides one of the earliest reliable indicators of eutrophication (Browder *et al.*, 1994; McCormick *et al.*, 1998). Species diversity of periphyton increases with increased nutrient content and diversity of chemical environment and decrease of its number in winter over that of

summer is attributed to decreased sunlight and low water temperature of the season (Ennis and Albright, 1982). The rate of activity and growth of periphytic algae depends on substrata as well as physico-chemical conditions of water and on morphometric characteristics of aquatic systems (Wetzel, 1983). The substrate characteristics play a key role in periphyton development, and the living organisms in the sediment represent a substantial nutrient source for them (Kahlert and Pettersson, 2002). In tropical waters many organic and inorganic nutrients originate from anthropogenic activities known to contribute high or low diversity of micro algal species (Chellappa, 1990). In aquatic systems periphytic community is known to be a significant contributor to primary productivity, but is also a controller of the nutrient fluxes (Wetzel, 1990; Engle and Melack, 1993).

Periphyton plays key role in nutrient storage (McCormick *et al.*, 1998) in lakes. Loss of periphyton assemblage provides an early indication that P assimilative capacity of wetlands has been exceeded and that the integrity of ecosystem is being degraded (McCormick *et al.*, 2001). Water quality and light determine periphyton bio-film development in rivers and organic or inorganic toxicants are likely show a widely different interaction with such bio-films (Guasch *et al.*, 2003). The biomass and productivity of the periphytic community are controlled mainly by hydrological regime (fluctuation in water level) or physical parameters such as water transparency and conductivity or chemical variables such as alkalinity, ammonium and silica (Moschini-Carlos, 2001). Among physico-chemical parameters TDS and temperature mostly control spatial and temporal pattern of periphyton, but in general, the periphyton distribution is controlled by complex of factors including shading, current velocity and biotic interactions (Chessman, 1985).

In order to make the present investigation holistic, the periphyton characteristics of *Periyar* Lake, preliminary investigation of them were also carried out at two sites—station-4A (one of the major inlets) and station-1 (the only outlet). This study was carried out during all the seasons of the year 2004 only. Altogether 15 species of periphyton algae were recorded in the Lake of which 6 were *Chlorophyceae*, 5 were Diatoms, 2 were *Cyanophyta* and 2 were *Euglenophyta*. Moore (1980) reported about 48 species of attached plankton in *Great Bear* Lake, compared to which the species diversity of

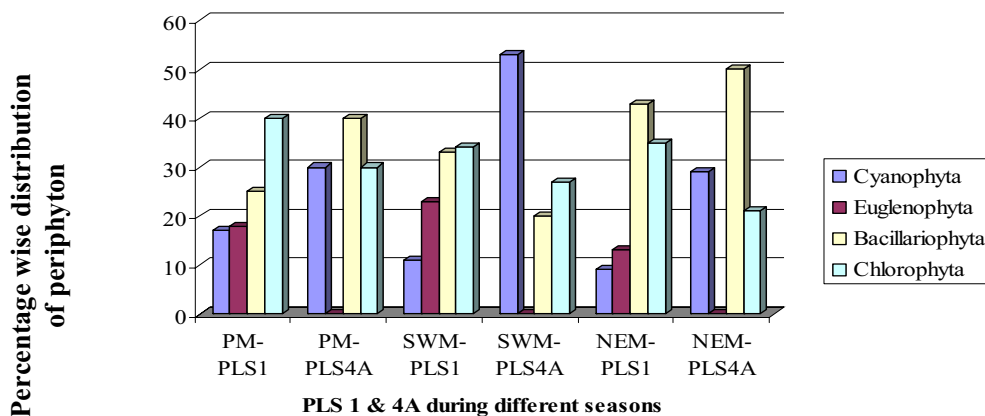
periphyton community at *Periyar* Lake was very low. In the literature there are diverse views on the interrelationships of periphyton community and nutrient status of lakes. Many studies indicate that the relationship between diversity and environmental quality is very complex (Podani, 1992). Maznah and Mansor (2002) observed more diversity at polluted sites than clean sites in a river basin in Malaysia. According to Ho and Peng (1997) high diversity indices cannot be interpreted as being a reflection of high quality habitat. Archibald (1990) stated that to accurately estimate water quality using species diversity, it is necessary to define precisely the species that compose the community. Cox (1988) is of the view that to explain such relationships, thorough knowledge of the autecologies of the algal species is essential. According to (Chellappa, 2001) the main effect of nutrient enrichment on aquatic epiphytic algae is generally a decrease in overall species richness. Morgan (1987) observed that with increase in nitrate some species tend to dominate the community or an increase in species richness occurs in aquatic systems.

Quantitative analysis of Periphyton community in the lake (**Chart-6**) showed that *Chlorophyta* dominated at station-1 (46% density) during the pre-monsoon, but during the southwest and northeast monsoons, Diatoms was the dominant group of periphyton community at this station. At station 4-A, Diatoms were the dominant group during the pre-monsoon and the northeast monsoon, whereas in the southwest monsoon Diatoms and *Chlorophyta* were almost equal (20-27%) and *Cyanophyta* was the most dominant group (53%). *Euglenophyta* were found at station-1 throughout the seasons where as it was absent at station-4A. In station-4A, Diatoms were higher than *Chlorophyta* during all the seasons. But at station-1, except in the northeast monsoon season, *Chlorophyta* dominated the benthic community. In the northeast monsoon, Diatoms dominated this station as well. The relative abundance and differences in specific sensitivity of certain Diatom species to pollution are reliable and useful means in assessing the degree of pollution in river systems, but diversity of diatom associations is not directly related to water quality (Maznah and Mansor, 2002).

Among *Chlorophyta* filamentous species such as *Oedogonium* and *Spirogyra* were found at station-1 only. *Melosira granulata* was the Diatom found at both stations during all the seasons. *Staurostrum paradoxum*, *Cosmarium contractum* and *Closterium* sp. was the species of green algae found at both the stations throughout the seasons. Most

of the Diatoms such as *Navicula* sp. *Pinnularia* sp and *Cyclotella* sp. were found at both the stations throughout the seasons. *Cyclotella* sp are characteristic species of oligotrophic waters (Hutchinson, 1967, Moore 1978). *Synedra* sp. was found at station-1 alone, especially during the pre-monsoon and the southwest monsoon alone. Ecologist generally accepts the view that certain groups of species can be used as bio-indicators when their precise autecologies are known. Taxonomic indicators based on Diatom assemblages provide a useful estimate of ecosystem change and were recommended as a standard mean in biological monitoring (McCormick and Cairns, 1994). *Nitzschia palea* one of most tolerant species and a strong indicator of polluted water (Lange-Bertalot, 1979) are dominant at polluted sites (Maznah and Mansor, 2002). In *Periyar* Lake, *Nitzschia palea* was found among phytoplankton, but they were not encountered among the periphytic community, which indicated that the species did not favor periphytic habitat in the Lake.

Chart-6. Percentage distribution of different groups of periphyton in PLS-1 & 4A during three different seasons (pre-monsoon, southwest monsoon and northeast monsoon)- 2004.



Pollution tolerant species thrive at sites with high levels of nutrients and organic pollution (Kelly *et al.*, 1995). They can live at low oxygen levels and are resistant to putrescent substances (Mason, 1996). Thus in general the periphytic community also explains the oligotrophic nature of the Lake. However, the presence of some pollution tolerant species belonging to *Chlorophyta*, Diatoms, *Cyanophyta* and Blue-greens among periphytic component of the alga suggested the necessity of a detailed and long term

monitoring of the hydrobiology of the Lake as a means to protect it from catastrophic degeneration due to anthropogenic impacts.

5. 14. Benthon

Benthic algae play an important role in lake ecosystems (Wetzel, 1983). The trophic level of water plays an important role in governing the structure of benthic algal assemblages (Vilbaste and Tru, 2003). Benthic flora may form a buffer for the surface populations and the mechanism by which these algae survive in the anaerobic zone of the sediment is not yet understood, and it is assumed that the survival properties depend on depressed metabolic activity (Hunding, 1971). Hakanson and Boulion (2004) emphasized the urgent need of researches on benthic algae in lake ecosystems. Therefore we included the preliminaries of the benthic community structure also in our investigations. Benthic species were identified monthly and the three seasonal characteristics of the community structure at three different stations—station-1, station-4A and 4B were calculated for the year 2004.

In the pre-monsoon, altogether 41 species of algae (17 species of diatoms, 15 species of *Chlorophyceae*, 7 species of *Cyanophyceae* and 2 species of *Euglenophyceae*) were identified in station-1. The diversity of benthic algae got reduced to 32 species (18 species of Diatoms, 12 species of *Chlorophyceae* and 1 species each of *Cyanophyceae* and *Euglenophyceae*) at station-4A. At station 4B, only 29 species of algae (18 species of Diatoms and 11 species of *Chlorophyceae*) were noticed. *Cyanophyceae* and *Euglenophyceae* were completely absent (**Chart-7**).

In the southwest monsoon also there were 41 species of benthic algae at station-1, but only 30 species at station- 4A and 22 species at station-4B. In the northeast monsoon the total algal species at station-1 were 31, at station-4A 21 and at station-4B only 15 species. Thus there was a visible reduction in the diversity of benthic algae during the northeast monsoon in the Lake (**Chart-8**).

During the pre-monsoon and southwest monsoon the percentage content of Diatom species at station-4B was much higher than at other stations (41% at station-1, 53-57% at station-4A and 62- 63% at station-4B). The percentage of *Chlorophyta* at all the three stations was 33-39% during the pre-monsoon and the southwest monsoon.

Percentage of *Cyanophyta* was 15-18% at station-1, 3-7% at station-4A and 0 at station-4B during the pre-monsoon and northeast monsoon and 1% during the southwest monsoon (**Chart-9**). Percentage of *Euglenophyta* was 5-10% at station 1, 3-6 % at station-4A and 1 at station-4B during southwest monsoon and 0 during the other seasons. In the northeast monsoon the species diversity noticed was the lowest at all stations. At station-1, only 31 species of algae were observed (39% of Diatoms, 29% of *Chlorophyta* and 22% of *Cyanophyta* and 10% of *Euglenophyta*). At station-4A there were only 21 species of algae (52% Diatoms, 38% *Chlorophyta* and 4% each of *Cyanophyta* and *Euglenophyta*). At station-4B there were only 15 species of algae (67% Diatoms and 33% *Chlorophyta*; *Cyanophyta* and *Euglenophyta* were totally absent). Thus it was clear that as we moved towards the inlet in the Lake the benthic algal diversity decreased with an increasing trend in the percentage content of Diatoms over other groups and extreme decline of *Cyanophyta* and *Euglenophyta*.

In *Periyar* Lake, *Microcystis aeruginosa* was an alga found among benthic algae at station-1 and 4A, throughout the year 2004. *Microcystis* is a typical species of nutrient rich lakes, the life cycle of which include both pelagic and benthic stages (Brunberg and Blomqvist, 2002). They may remain in substantial numbers in the sediment depth of several years of age (Bostrom *et al.*, 1989) and are capable of restart of growth after extended periods of 'resting' (Reynolds *et al.*, 1981). Considering its potentials to cause toxic blooms, the various factors related to such an outbreak of this species must be well monitored; otherwise it would become catastrophic to the precious wildlife which always depends on the waters of this Lake.

Chart-7. Percentage density of benthic algae during pre-monsoon-2004

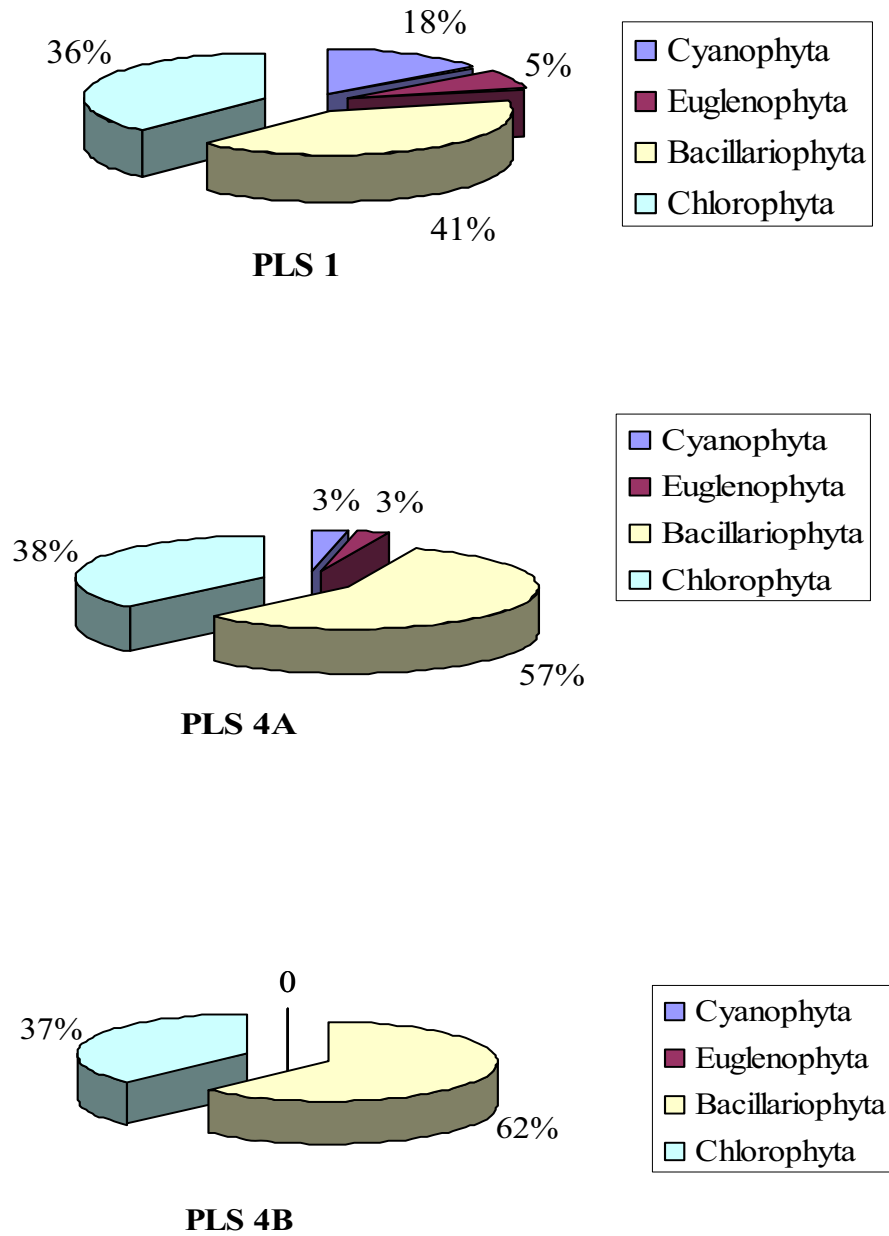


Chart-8. Percentage density of benthic algae during southwest monsoon - 2004

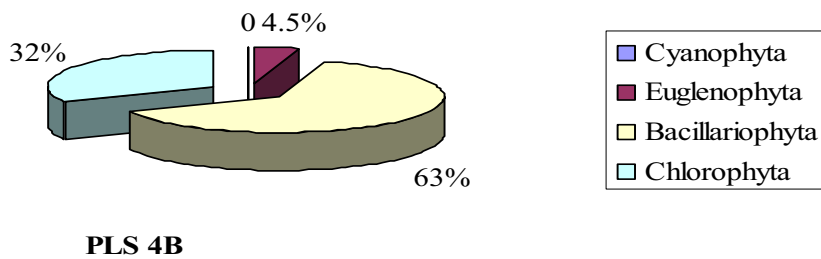
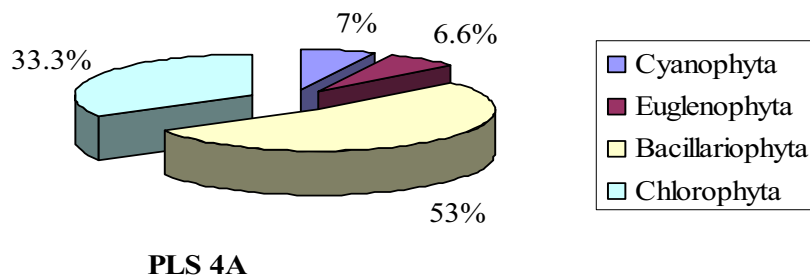
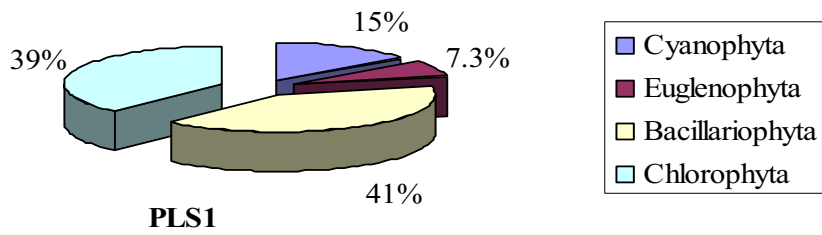
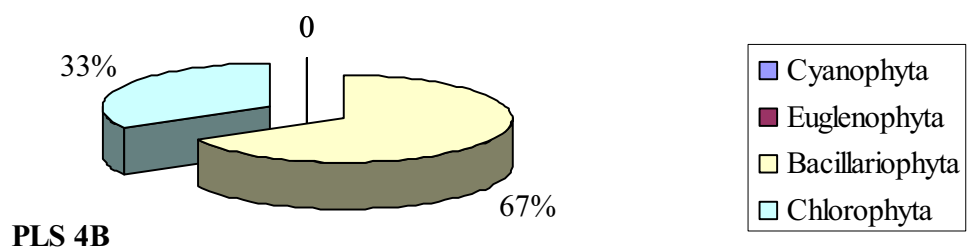
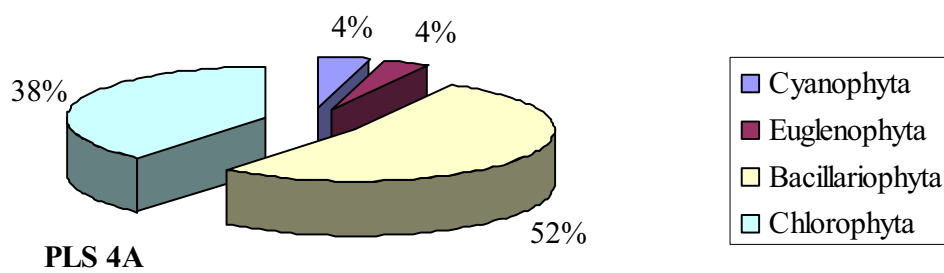
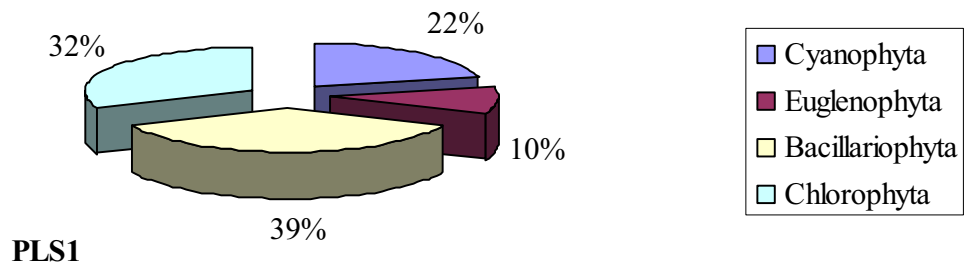


Chart-9. Percentage density of benthic algae during northeast monsoon - 2004



5.15. Correlations- phytoplankton density and water quality parameters

Physical factors within all the natural biological systems interact among themselves and with the biotic factors resulting in the formation of a complex relationship which is usually called as the environmental complex. Species and their natural assemblages called communities are quite inseparable from this complex of interacting factors. Therefore, analyses of environmental factors individually are insufficient to trace the exact role of each factor affecting the existence of species population or communities. In such circumstances correlation analyses would be much more fruitful. Correlation analyses of physical environmental factors with community characteristics are important to identify certain key relationships crucial to the sustainable management of natural ecosystems. However, correlations of different factors may appear quite contradictory at different situations in highly complex natural systems. But such observations of interactions may reveal certain important trends as well.

Quite naturally, correlations of phytoplankton density and the density of different algal groups with the different physico-chemical parameters in the *Periyar* Lake showed certain contradictory relations at different stations. However, certain general trends were also visible in these correlations (**Table-184 and 185**).

5.15.1. Correlation of phytoplankton density with water temperature, TS, pH and transparency

Significant positive correlations were noticed between surface water temperature and total plankton density at all stations in the Lake except at station-4A. Total plankton density at station 4A showed a negative correlation with water temperature. Many reports on positive correlations between density of specific groups of phytoplankton and temperature are available (Sarojini, 1996; Unni and Pawar, 2000). However, the negative correlations of phytoplankton density observed at station-4A might be due to the unidentified interactions of certain factors operating in the region. Correlation analysis of density of different algal classes and temperature at different stations revealed that the relationship of such groups with temperature was positive at certain stations but negative

at certain other stations. It may be noted that at station-4A, where *Bacillariophyta* was the dominant group, it showed a positive correlation with temperature. But, Bhatt *et al.* (1999) observed negative correlations of *Cyanophyceae* and *Bacillariophyceae* with temperature. According to Palmer (1980) various classes as well as individual species of algae have minimum, optimum and maximum temperatures for growth. The author has reported optimum temperature for Diatoms as 18-30⁰C, for Green-algae 30-35⁰C and for Blue-green algae 35-40⁰C. Since the surface water temperature fluctuations in *Periyar* Lake varied from 24 to 29⁰C, temperature regime in the Lake is not very favorable for *Cyanophycean* and *Chlorophycean* growth.

In the Lake significant correlations between total solids and algal densities were observed at different stations. However, this observation does not agree with the fact that the Lake is dominated in general by *Chlorophyceae* and *Bacillariophyceae*, which usually show a negative correlation with TS (Bhatt *et al.*, 1999). According to An and Jones (2000) *Cyanophyceae* dominate phytoplankton communities under reduced light environment. Contrary to these observations *Cyanophyta* showed positive correlations with transparency at stations 3 and 4A in *Periyar* Lake. Bhatt *et al.* (1999) reported a positive correlation of *Bacillariophyceae* and *Chlorophyceae* with transparency. However, *Periyar* Lake with dominating populations of *Bacillariophyceae* and *Chlorophyceae*, no positive correlations of density of these groups with transparency was observed. These contradictions also might be due to unidentified interactions of different environmental factors.

Correlation coefficient for pH was found negative with *Cyanophyceae* and *Chlorophyceae* and positive with *Bacillariophyceae* (Bhatt *et al.*, 1999). However, such a clear tendency in correlations of total phytoplankton density or density of different algal groups and pH was not observed in different stations of the Lake. According to Palmer (1980) majority of algae grow best in water at or near neutral point of pH, but some Blue-greens grow best at high pH. The neutral or slightly alkaline pH observed in *Periyar*

waters is therefore suitable for the community structure dominated by *Bacillariophyta* and *Chlorophyta* as was revealed in the present investigations of the Lake.

5.15.2. Correlation of phytoplankton density with hardness, alkalinity, salinity and EC

In general, phytoplankton density was found correlated only positively with hardness in the Lake. However, such positive correlations were observed at stations 1, 4B and 5. Group wise correlation analysis showed varied trends with different algal groups at different stations. In station-1 *Cyanophyta* and *Bacillariophyta* correlated with total hardness. In station-2 and 3 *Bacillariophyta* and *Chlorophyta* showed positive relations. In station-4A *Bacillariophyta* only showed a positive correlation with hardness. Significant positive correlations were noticed between *Euglenophyta*, *Bacillariophyta* and *Chlorophyta* and total hardness at station 4B. Many authors have (Iqbal and Katariya, 1995; Bhade *et al.*, 2001) observed positive correlations of *Cyanophyta* and total hardness of freshwater systems.

Total alkalinity showed a very significant positive correlation with the total plankton density of the lake in all the stations and seasons except at station-3. At station-3 there was a significant negative correlation of plankton density and total alkalinity, the reason of which of course might be due to an unidentified interaction of different factors. At many stations (1, 2, and 5) *Cyanophyta* showed a significant positive correlation with total alkalinity. At stations 3, 4A, 4B and 5 there were significant positive correlations of *Chlorophyta* and total alkalinity. Bhatt *et al.* (1999) observed similar positive correlation of *Chlorophyta* and *Cyanophyta* in *Taudaha* Lake, Katmandu. Correlations of *Bacillariophyta* and alkalinity at station-1 and 4B were positive, correlations of *Euglenophyta* and alkalinity at stations 4A and 4B were found to be positive.

Plankton density showed a positive correlation with salinity in all the stations of the Lake except stations-2 and 5. As in the case of hardness different algal groups showed different trends of correlations at different stations. At station-1 density of *Cyanophyta* showed positive trend with salinity, at station-2 *Bacillariophyta* and *Chlorophyta*

exhibited such trends, but at station-3 all the four groups were positively correlated with salinity. *Euglenophyta* and *Chlorophyta* showed positive correlation with salinity at 4A. At 4B all groups except *Cyanophyta* were positively correlated with salinity. In station-5 only *Bacillariophyta* showed a positive correlation. Sarojini (1996) observed that *Bacillariophyta* in general are saline tolerant.

Positive correlations of plankton density and EC were observed at stations 1, 3, 4A, and 5. There were very good positive correlation with all plankton group except *Cyanophyta* at station-5. However, *Cyanophyta* showed positive correlations with EC at stations-2 and 3. Apart from station-5, *Bacillariophyta* showed a positive correlation at station-3; *Euglenophyta* at stations-4A and 4B and 5, whereas *Chlorophyta* at 4A and 5. Coesel (2001) is of the opinion that low EC promotes optimal development of Desmid flora. However, in *Periyar* Lake at station-4B with low EC showed a dominance of *Chlorococcales*. There are reports of positive correlations of *Bacillariophyta* and EC in the literature (Sarojini, 1996; Owen *et al.*, 2004).

5.15.3. Correlation of phytoplankton density with dissolved CO₂ and DO

Phytoplankton density showed significant correlations with dissolved CO₂ at stations-1, 2 and 4A. At stations 1, 2, and 3, *Cyanophyta* showed significant positive correlations with dissolved CO₂. Johnston and Jacoby (2003) are of the opinion that low dissolved CO₂ favours growth of *Cyanophyta*. However, significant difference in this factor was not observed in the surface waters at stations 1, 2 or 4A from that of other stations. Therefore, the factors contributing to the positive correlations of dissolved CO₂ and *Cyanophyta* might be some others. *Euglenophyta* showed a positive correlation with dissolved CO₂ at stations 2, 3 and 4A.

No significant positive correlations were noticed between plankton density of the lake and DO at any station. However, group wise correlation studies showed different trends. At stations-1 and 3 positive correlations between *Euglenophyta* and DO were observed positive which was contradictory to the report of Heide (1982), who found a

low DO highly favorable to the growth of *Euglenophyta*. At station-5 the positive correlation was between *Bacillariophyta* and DO. Sarojini (1996) observed positive correlation between *Bacillariophyta* and DO. At other stations no definite trend was observed. Bhatt *et al.* (1999) observed a positive correlation of *Chlorophyceae* and *Bacillariophyceae* with DO whereas a negative correlation of *Cyanophyceae* with DO in *Taudaha* Lake. However, in *Periyar* Lake *Chlorophyceae* and *Cyanophyceae* did not show such a trend. Since DO and temperature are interrelated factors, their interaction with each other and with other factors contribute greatly to the growth of phytoplankton species in general, the exact role of DO on phytoplankton density may not be easily identified.

5.15.4. Correlation of phytoplankton density with minerals

At all stations except at stations-1 and 3, there were positive correlations between total plankton density and Cl ion in *Periyar* waters. *Cyanophyta* showed a positive correlation with Cl at stations 2, 4A and 5. However *Euglenophyta* showed a positive correlation with Cl at all stations except at station-1. *Bacillariophyta* showed positive correlations at station-1 and 4B whereas *Chlorophyta* showed positive correlations with Cl at stations 1, 4A and 5. One of the interesting observations was that at stations-4A and 5 the three algal groups *Cyanophyta*, *Euglenophyta* and *Chlorophyta* showed positive correlations with Cl.

Total phytoplankton density and Ca were found negatively correlated at most of the stations whereas at stations-4B and 5 the correlations were positive. Group wise analysis showed that *Chlorophyta* and Ca were positively correlated at stations 1, 3, 4B and 5 and negative correlations at station-4A. Other algal groups and Ca showed positive trend at certain stations but negative trends at other stations. Observation of Heide (1982) that Ca above 1 mgL⁻¹ inhibits multiplication of most species of algae in Indian ponds might have been the reason for negative correlations between algal density and Ca observed at many stations in *Periyar* Lake, where the content of Ca was above 2 mgL⁻¹ in general. Correlations between Mg and plankton density were positive at most of the

stations except at stations-2 and 4A. In general, correlations between *Cyanophyta* and Mg were negative but positive for *Euglenophyta*. Correlations of *Bacillariophyta* with Mg were always positive whereas that of *Chlorophyta* with Mg was mostly neutral.

Highly significant positive correlations were observed between plankton density and Na at all stations. At stations-1, 3 and 5 *Cyanophyta* showed positive correlations with Na. *Euglenophyta* showed a positive trend at stations-4A, 4B and 5, but a negative trend at 3. *Bacillariophyta* showed positive trend with Na at stations-1, 2, 3 and 4B. Correlations of *Chlorophyta* with Na was positive at stations-2, 4A, 4B, and 5 but neutral at stations-1 and 3. Correlations of phytoplankton density with K were either negative or neutral in the Lake. Group wise analyses showed positive trend of *Euglenophyta* at stations-1, 2 and 4B; *Bacillariophyta* at stations-1,4A and 5, *Chlorophyta* at stations 1, 3, 4B and 5. Unlike the observations of Izaguirre *et al.* (2004) no positive correlation of *Cyanophyta* with K was observed in *Periyar* Lake, but the case of diatoms were similar to the author's observations.

5.15.5. Correlation of phytoplankton density with nutrients

Correlations of phytoplankton density and P were significantly positive at stations-1,4B and 5 but neutral at other stations. Significant positive correlations between *Bacillariophyta* and P was observed at stations 1, 3, 4A and 4B, *Chlorophyta* and P at station-2, 3, 4B and 5; all groups and P at station 4B; *Cyanophyta* and P at station-5. Since positive correlation between *Cyanobacteria* and P was observed at station 5 alone, the belief that P highly stimulates *Cyanophyceae* growth (Iqbal and Katariya, 1995; Sarojini, 1996; Gulati and Donk, 2002; Calijuri *et al.*, 2002; Johnston and Jacoby, 2003; Izaguirre *et al.*, 2004) appears relative to other factors as well.

Phytoplankton density and total N showed very good positive correlation at all stations in the Lake. This observation agrees with the observations of Gulati and Donk (2002) that N has the greatest impact on algal growth in freshwaters. *Chlorophyta* showed positive correlation with total N at stations 4A, 4B and 5 but *Bacillariophyta* showed positive correlation with total N at station-4B only. *Cyanophyta* showed positive

correlations with total N at all the stations, whereas *Euglenophyta* showed positive correlations at stations-2, 4A, 4B and 5. The positive correlation of *Cyanophyta* with N observed in *Periyar* Lake does not agree with the report of Johnston and Jacoby (2003) that low total N favours *Cyanobacterial* growth. However, the range of total N content of the Lake in general was very low and hence at such levels the positive influence is quite reasonable.

Phytoplankton and higher plants utilize different forms of Nitrogen and may differentially influence phytoplankton growth, size structure and community composition (Rabalais, 2002). Therefore, correlations of NO₃N with phytoplankton characteristics also were interesting. Correlations of phytoplankton density and NO₃N were also positive or neutral; positive at most of the stations such as 2, 3, 4A and 5. As in the case of total N, relationship between *Cyanophyta* and NO₃N was positive at stations 3, 4A and 5.

Euglenophyta showed a positive correlation with NO₃N at stations 2, 3, 4B and 5 but *Bacillariophyta* showed positive correlations at 1 and 2 only. Relationship of *Chlorophyta* and NO₃N was positive at stations 1, 2 and 5. It was interesting to note that except *Cyanophyta*, all the other groups showed negative correlations with NO₃N at one or many stations. Bandela *et al.* (1999) reported a positive correlation between NO₃N and *Cyanophyta* in *Barul* dam. Similar positive correlations of other algal groups such as *Bacillariophyta* and NO₃N (Sarojini, 1996; Bhatt *et al.*, 1999; Owen *et al.*, 2004) *Chlorophyta* and NO₃N (Sarojini, 1996; Bhatt *et al.*, 1999) are found in the literature.

There were no positive correlation between total phytoplankton density and Silica. *Cyanophyta* and *Euglenophyta* never showed a positive relationship with Silica in the Lake. However, *Bacillariophyta* exhibited significant positive correlations with Silica at stations-1, 2, 3, 4A, 5, and at other stations the relations were insignificant. This observation of positive correlation between Diatoms and Silica agrees with the finding of Escavara and Prins (2002) that Diatom development is strictly controlled by silicate availability. *Chlorophyta* also showed a positive relationship with Silica at stations-1, 2, 3, 4B, but showed negative correlation at station-4A.

5.15. 6. Correlation of phytoplankton density with COD and BOD

Correlations of COD and total phytoplankton density were found positively correlated at stations 1,4B and 5; at other stations the relationships were either neutral or negative. Positive correlations of *Bacillariophyta* and COD were observed at stations 1, 3,4A and 4B; *Cyanophyta* and COD at stations 1 and 5; *Euglenophyta* and COD at stations 4A, 4B and 5; *Chlorophyta* at stations 3, 4B and 5. Correlations of BOD and total density were positive at all stations, except station-2. BOD showed positive trends for *Cyanophyta* at stations 3, 4A and 5; *Euglenophyta* at stations 4A, 4B and 5; *Bacillariophyta* at stations 3, and 4B; *Chlorophyta* at stations 4A, 4B and 5.

5.15.7. Correlation of phytoplankton density with Oil and Grease

Plankton density showed a significant positive relationship with oil and grease at stations 1, 3, 4B and 5 but at other stations the relationships were neutral. *Cyanophyta* showed only significant negative correlations with oil and grease in Lake at stations 3 and 4A; but at other stations the relationships were neutral. *Euglenophyta* showed positive correlations with oil and grease at stations-3 and 5. But the group showed negative correlations at other stations. One of the interesting observations was that correlations between *Bacillariophyta* and, oil and grease were always positive at all stations. Correlations of *Chlorophyta* with oil grease were positive at stations 1, 2, 4B, and 5 but neutral at other stations.

5.16. Conclusion - Phytoplankton density and water quality parameters

The three-year average phytoplankton density of the Lake and that at different stations suggested that the nutrient impact on the system in general was quite low, characteristic to oligotrophic systems. In general, algal density fluctuations across different stations were significant during the pre-monsoon and northeast monsoon but insignificant during the southwest monsoon. Throughout the seasons *Chlorophyta* dominated at all stations except at station 4A and 4B in the Lake; at station 4B the dominant group was always the *Bacillariophyta*. Another significant tendency noticed

was the dominance of *Desmids* over *Chlorococcales* among *Chlorophyta* throughout the seasons at most of the stations which suggested a normal trophic structure expected of a typical unpolluted freshwater system. The Lake is famous for its endemic fish fauna. The system therefore offers a typical system for depth study of *Desmids* and their interrelationships with endemic fish fauna.

Correlation studies of hydrobiology with physico-chemical parameters revealed that the relationship between phytoplankton density in general and that of the specific groups are highly complex and often controlled by interactions of different factors, some of which are unidentified. However, certain groups were found to be positively correlated with certain parameter, while certain other groups were found negatively correlated with certain parameters. In developing definite and clear trends of interaction between different factors and hydrobiology of water body three-year monitoring is minimal. In developing such trends a long term monitoring is essential.

Chapter-VI

GENERAL CONCLUSION

6. 1. Introduction

Mullaperiyar Reservoir/ the *Periyar* Lake was formed after the construction of the Dam (1886-95) during the British Rule. The Dam and the water in the Lake are owned and managed by the TN Government as per the provisions of the Lease agreement known as '*Periyar* Lease'. At present the Dam and the Lake water are objects of conflicts and disputes between the States of Kerala and TN. The present investigation enabled a comprehensive and systematic analysis of the climatic, hydrologic, physico-chemical and biological characteristics as well as the seasonal variations of all in the Lake. In the absence of prior knowledge of environmental conditions, this monitoring established a baseline for future comparisons. The following are the major conclusions derived by the investigation.

6. 2. Climate and hydrology

Narrow fluctuations in air temperature across seasons revealed that the dominant climatic factor in this tropical high altitude Lake system is not air temperature. A comparison of rainfall between different seasons clearly proved that precipitation is the major climatic factor dominating in the system. Southwest monsoon season was the season of maximum fluctuations in precipitation over the years followed by the northeast monsoons, and the least fluctuation was in the pre-monsoon throughout the study period. The major management concern at present in this Lake was to extract as much water as possible as and when the inflow increases. Consequently the water level continuously fluctuates diurnally and seasonally, and the fluctuations were found unpredictable. A constant water level is very essential for the sustainable existence of the Lake as a natural biological system supporting the wildlife sanctuary, its economic use as water body supporting international

tourism, as a water reservoir for irrigation and power generation purpose in TN, and as the water resource to sustain the viability of *Periyar* River down the Dam.

6. 3. Physico-chemical parameters

The seasons of the lowest and highest temperature in surface water are similar to that of the other aquatic systems elsewhere in Kerala, but the range of fluctuation in this Lake was found less than that of the other systems in the State. Moreover, the maximum surface water temperature in the Lake was lower than that of the other fresh water systems here. This is on account of the high altitude location, as well as the presence of thick evergreen forests around it. Both the surface and bottom waters exhibited a seasonal trend in temperature with a slight increase in the pre-monsoon, a decrease during northeast monsoon and moderate values during the southwest monsoon.

Unlike the observations in different tropical freshwaters by many authors, the transparency of waters in this Lake was found increased only during the monsoon seasons. This is owing to excessive inflow which is not muddy due to the undisturbed watershed which keeps the soil system intact during monsoon. Boat activity combined with lesser water level was the reason for decreased transparency during pre-monsoon. In general the secchi depth was found least during the pre-monsoon, highest during the northeast monsoon and moderate during the southwest monsoon at all stations.

The water in *Periyar* Lake in general showed a neutral or slightly alkaline pH, and is in the safe range. This water showed a very low EC. Low ionic content in natural waters is generally attributed to slow chemical weathering in the catchment area. Moreover, apart from slightly random spatial and yearly fluctuations, water in this Lake did not express any definite seasonal trends in the EC value. Since no significant difference in the EC of both surface and bottom waters, it may be concluded that there exists quite a good vertical mixing of waters up to the depth examined in the Lake.

There was no significant difference in salinity between the surface and the bottom waters of the lake. These results suggested that in general the salinity range of the Lake is normal. The fluctuation in TS over the years was found much more

pronounced than that between the seasons during the entire period of study. TDS in the surface and bottom waters were found very low at most stations. However, the trend of increased salinity and TDS at station-1 and 5 were clear evidence of the negative influence of the growing Kumily township on the *Periyar* Lake.

Total alkalinity of the *Periyar* Lake remained within safe level at all stations during the entire period of study. No prominent fluctuation in alkalinity between the seasons or the years was prevalent in the Lake. The Lake water at its inlet zones were nutrient poor, whereas that at the outlet was moderately nutrient rich. Since sewage water from the near by township joins the Lake at station-5, the slight increase in hardness in surface water at this site was a sign of anthropogenic impact on the system just as in the case of other parameters. The absence of such a tendency of higher hardness in bottom-waters at all the stations underlined this assumption.

Even though pollution trends were observed at station-5; in general the free CO₂ in *Periyar* Lake waters remained quite normal for an oligotrophic freshwater system and never exceeded the standard values during the entire period of study. The water remained stable with only meager fluctuations in DO throughout the period of study. The fluctuation in DO observed in the Lake was random. There were no visible seasonal trends in the average DO of surface and bottom waters at all the stations in the Lake.

6. 4. Major cations and anions in the Lake

There were not much difference in Ca, Mg, K and Na ions in both surface and bottom waters. In general there was a slight increase in Ca in waters at station-5 (the outlet) from that at the Dam site (the site of culmination of all inlets). However, unlike the mineral composition of other lakes, the amount of Mg ions in the Lake was found higher than Ca ions. Both Ca and Mg were found higher in water at station-5 than that at all the other stations during the entire period of study. In general, there was a slight increase in Na ions during pre-monsoon over that of the monsoons. Spatial comparison revealed that the water at station-5 showed a higher amount of Na at all seasons during the entire period of study. Moreover, Na was found higher than that of K in the Lake. Spatial comparison revealed that water at the outlet in general has a higher amount of Cl than that at the inlet during all the

seasons of the entire period of study. A slight increase in the amount of major cations in the outlet region of the Lake is definitely the result of the sewage water.

6. 5. Major nutrients in the Lake

N concentration was low and normal at all the stations during the study, in spite of the increasing anthropogenic influences. In general, the N contents (both the total Kjeldal form and the NO_3 form) at station-5 remained slightly higher than that at the other stations during all the seasons throughout the study period. The maximum P content (50-100 micro grams L^{-1}) was noticed at station-5 followed by station -1 (30 to 70 micro grams L^{-1}). The inlet zones showed minimum P content of 10 to 60 micro grams L^{-1} . The amount of dissolved Silica in the water was very low.

6. 6. Primary production

The seasonal average of GPP varied from 0.17 to 0.36 mg L^{-1} of Oxygen/hr and Respiration varied from 0.08 to 0.24 mg L^{-1} of Oxygen/hr. During the three-year monthly study, respiration never exceeded the GPP. The seasonal average of NPP in the Lake varied from 0.03 to 0.19 mg L^{-1} of Oxygen/hr.

6. 7. Pollution in the Lake

Compared to the reports of BOD from lakes in different parts of India the *Periyar* Lake is found unique with lowest BOD values in all seasons throughout the entire period of study. However, a higher level of BOD was always visible at station-1 and 5 over that of the other stations. The COD at stations-1 and 5 also were found higher than that of the other stations; COD at the inlet (station-4A and 4B) and stations up to 2 remained very low.

Oil and grease were found on surface waters, all over the Lake, as broken films during the entire period of study. Among different stations, the highest oil content (930 – 2282 mg L^{-1}) was found at stations 1 and 5 throughout the study, whereas the lowest oil content was (110-650 mg L^{-1}) at stations 4A and 4B. At all stations the highest oil content was observed during the pre-monsoon, the lowest amount was found during the northeast monsoon and moderate oil content was found during the southwest monsoon. These impacts of the oil load on the system need a thorough monitoring, because it affects the endemic fish life in general and

the wildlife in the sanctuary in particular. Such studies should look into the impact of oil on the general health and reproductive biology of endangered wildlife including that of elephants, which heavily depend on the Lake.

6.7.1. Fecal contamination

The main sources of fecal *Coli form* bacteria in the Lake are sewage inflow from Kumily township at station-5, direct human sources (tribal fishermen and officials living inside the systems) and wild animals. Animal fecal sources can be ignored because such *Coli form* bacteria in general are not hazardous (Mubiru *et al.*, 2000). But the fecal bacteria of human origin are dangerous to wild animals. Since the MPN count was found quite high at most stations in the Lake, danger of spreading human disease to precious wildlife in the system cannot be overlooked. Therefore, an intensive monitoring of fecal *Coli form* based on more water samples is very essential in the Lake.

6. 8. Diversity and dynamics of phytoplankton

Station wise monthly analysis of total phytoplankton density and density of different species of algae were carried out. From the monthly results, seasonal and yearly averages of the whole plankton and individual species of them were derived, and compared station wise and year wise.

6. 8. 1. Seasonal dynamics of phytoplankton

Average phytoplankton density in the Lake during the three-year study period varied from 250 cells L⁻¹ (southwest monsoon of 2003) to 496 cells L⁻¹ (pre-monsoon of 2004). This suggested that in general nutrient impact is much more pronounced during the low water level season than the high water level seasons. The monthly and yearly average phytoplankton density at different stations of the Lake and the general average phytoplankton density for the whole Lake suggested that the nutrient impact on the system is quite low, characteristic of oligotrophic system, which is quite similar to previous observations in other regions in the Western Ghats. Since rainfall schedule fluctuate quite random during different years, pronounced seasonal tendencies cannot be expected in systems like *Periyar*.

6. 9. Phytoplankton community structure in the Lake

Periyar Lake with annual phytoplankton diversity of 69 species may be considered as a sufficiently complex community, characteristic to systems of less pollution. The fluctuations in diversity of species at certain stations may be attributed to the impact of anthropogenic influence. The phytoplankton community of the Lake was found dominated by *Chlorophyta*, followed by *Bacillariophyta* (Diatoms), *Cyanophyta* and *Euglenophyta*. In general, station wise comparison of the seasonal changes in the diversity of different groups revealed that the changes at different stations were random.

6. 9. 1. Chlorophyta

Annual average density of *Chlorophyta* in the Lake was 48%; seasonal average also did not vary much and remained 48-49% throughout the seasons. Among *Chlorophyta*, density percentage of Desmids was always slightly higher than that of *Chlorococcales* at most stations. The dominance of Desmids over *Chlorococcales* in the Lake may be considered as a positive biological sign to suggest that the trophic characteristics of the system are still within control.

6. 9. 2. Diatoms

Bacillariophyta (Diatoms) was the second most diverse group of algae in the Lake with a total of about 26 species belonging to 11 genera representing 38% of the total phytoplankton diversity. Among the seasons, pre-monsoon showed the maximum species diversity of 19, whereas during the southwest and northeast monsoons there were 14 species each. The highest density percentage of Diatoms noticed in the Lake was 70% at station4B during northeast monsoon and the lowest reported (17%) was at station-4A during the same season. *Melosira granulata* was the Diatom found at all stations in all seasons throughout the period of study.

6. 9. 3. Cyanophyta (Blue-green algae)

Density wise, *Cyanophyta* formed a minor group of phytoplankton in the Lake. Annual average density of this group in the Lake was 9%, and there was marked fluctuations in the percentage of *Cyanophyta* during different seasons. The maximum percentage density of the group was noticed (12%) during northeast

monsoon in the Lake and the minimum was 5% during the southwest monsoon. Station-wise analysis showed that the lowest species diversity and density of *Cyanophyta* was at station-4B (the inlet), whereas the maximum diversity and density of the group was found at stations-1, 2, 3 and 5.

6. 9. 4. Euglenophyta

Euglenophyta was the group represented in the lowest density percentage in the Lake. No member of this group was observed at station-4B during southwest and northeast monsoons. There were only 6 species of *Euglenophyta* belonging to 4 genera representing just 9% of the total diversity of species in the Lake. Presence of *Euglena* and *Phacus*, especially at station-5 and station-1 is a simple and direct symptom of pollution load at these sites in the system, because *Euglena* and *Phacus* in general are considered to be dominant tolerant genera of polluted ponds.

6.9.5. Correlation of phytoplankton density with physico-chemical parameters

Correlation studies of phytoplankton density with physico-chemical parameters revealed that the relationship between algal density in general and that of the specific groups are highly complex and often controlled by unidentified interactions of different factors. Certain groups were found to be positively correlated with certain parameters and certain other groups were found negatively correlated, hence those may be utilized as indicator species or groups for identifying the ecological status of aquatic systems in general. However, in developing such definite trends, many decades of monitoring studies are essential.

6. 10. Periphyton

In order to make the present investigation holistic, the periphyton characteristics of *Periyar* Lake, were also carried out at two sites– station-4A (the major inlet) and station-1 (the only outlet from the Lake). Altogether 15 species of periphyton algae were recorded in the Lake of which 6 were *Chlorophyceae*, 5 were Diatoms, 2 were *Cyanophyta* and 2 were *Euglenophyta*. The periphytic community explains the oligotrophic nature of the Lake. However, the presence of some pollution tolerant species of *Chlorophyta*, Diatoms, *Cyanophyta* among periphytic component suggests the necessity of a detailed and long term monitoring of the

hydrobiology of the Lake as a means to protect it from catastrophic degeneration due to anthropogenic impacts.

6. 11. Benthon

Forty one species of phytoplankton were found in the benthic community. Towards the inlet of the Lake, the benthic algal diversity was found decreased. An increasing trend in the percentage content of Diatoms over other groups, and extreme decline of *Cyanophyta* and *Euglenophyta* were observed towards the inlet stations. *Microcystis aeruginosa* was a benthic alga found at station-1 and station-4A.

6.12. Conclusion

The present investigation has thus revealed the oligotrophic status of the Lake. The investigation generated some important baseline data on the pollution status and phytoplankton community structure of the Lake. These data would be helpful in planning for future policy decisions on using the reservoir as an eco-tourist center as well as in the better conservation and management of the precious wildlife in the world-famous sanctuary. Analysis and interpretation of the data on phytoplankton and water quality parameters provided the necessary information to assess the impact of tourism related activities on the hydrobiology of the Lake.

Anthropogenic impacts from tourism were evident especially in the oil and grease content and nutrient status in *Periyar* Lake. Water bodies situated inside wildlife sanctuaries representing undisturbed watersheds are safe from disturbances such as leaching of nutrients and wastes. Therefore, formation of wildlife sanctuaries in the watershed of reservoirs in general is helpful in the sustainable economic and ecologic management of reservoirs in general. However, conservation efforts in wildlife reserves around reservoirs should include not only the wild flora and fauna of the land but also of the aquatic systems because both the watersheds and reservoir in such places represent one integrated system. Careless management of aquatic resources and tourism activities of water bodies in such places may ultimately collapse the stability of the precious wildlife in the terrestrial system as well.

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Figures and Plates

Figure-1. Area wise distribution of fresh water reservoirs in India after Sugunan (1997)

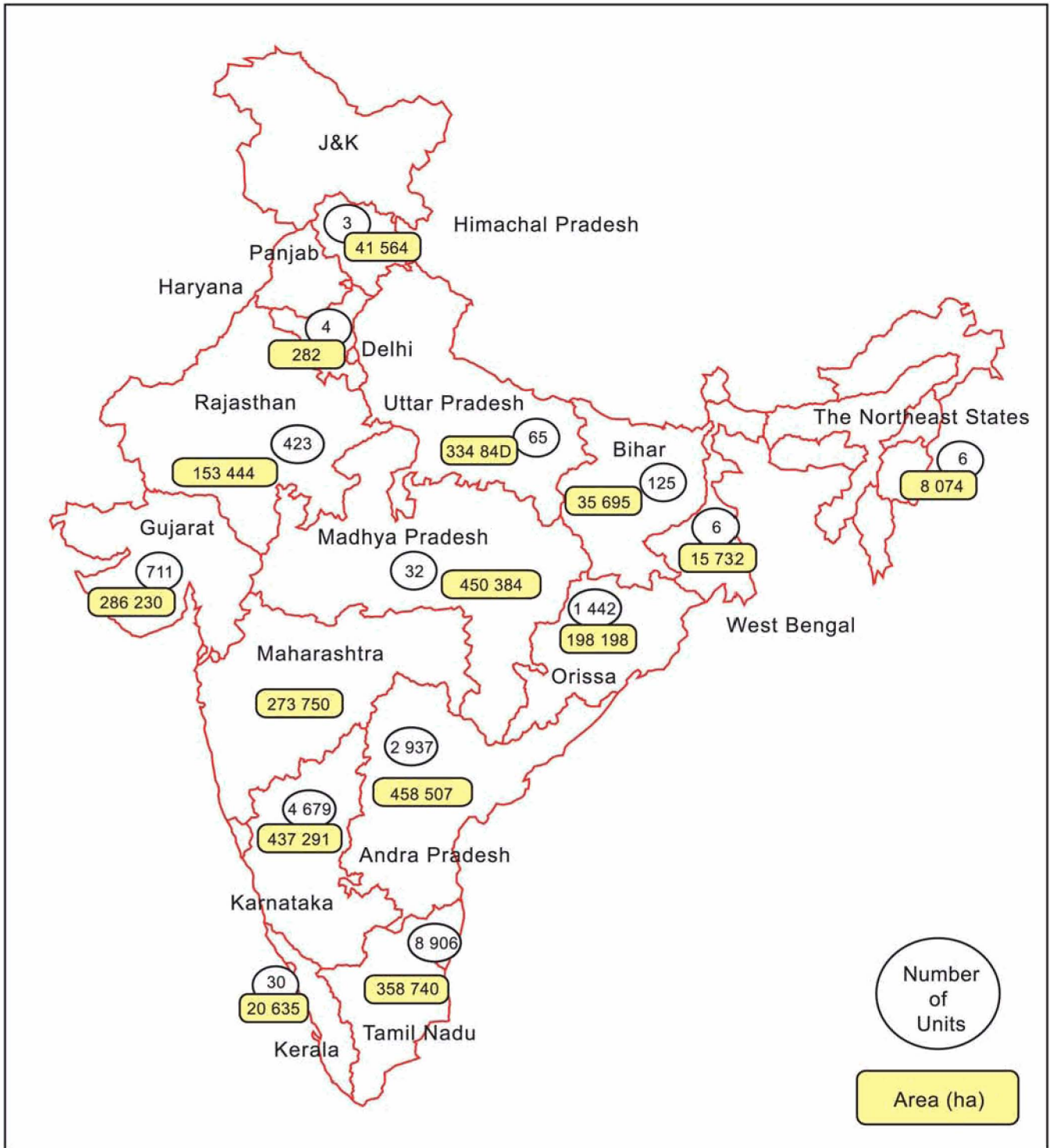


Figure -2 : Western Ghats region of India after National Atlas Organisation Physiographic Map adapted from State Gazetteer (1986)

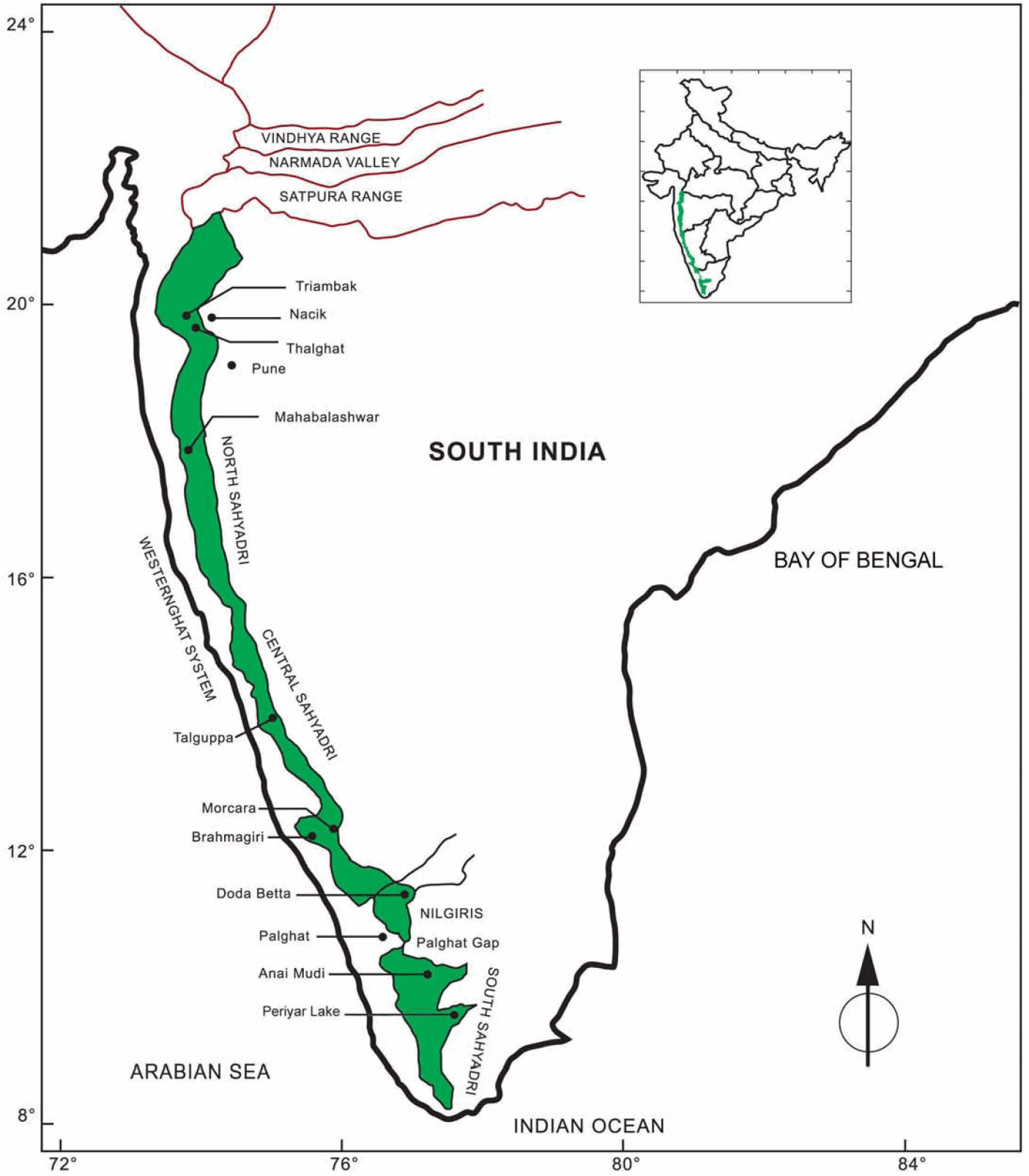


Figure-3: Different study stations in Periyar Lake

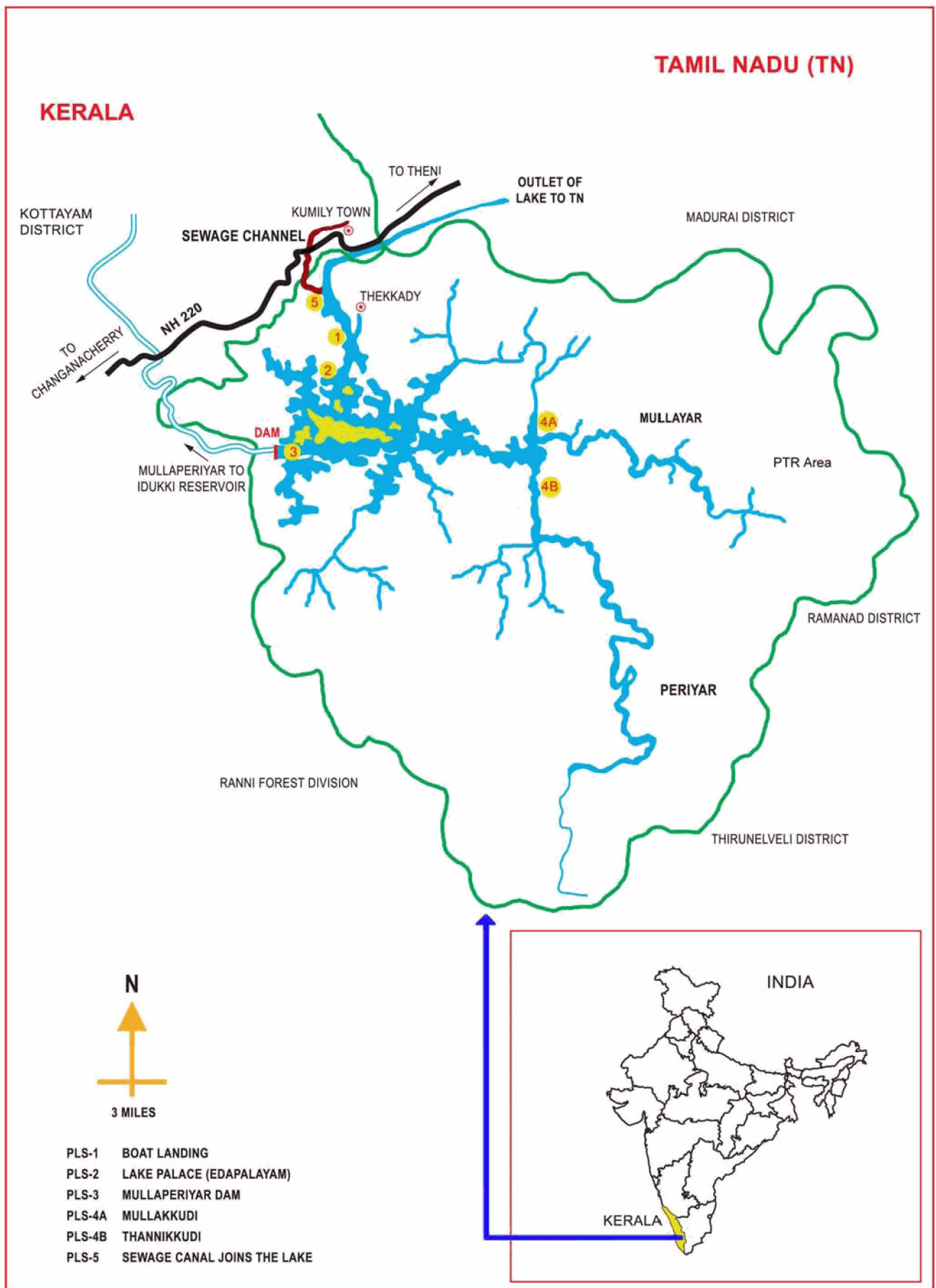


Plate - 1: Boat landing site - the PLS-1 : Seasonal views of three - years
(southwest monsoon 2002 to pre-monsoon 2005)



Pre-monsoon 2003



Pre-monsoon 2004



Pre-monsoon 2005



Southwest monsoon 02



Southwest monsoon 03



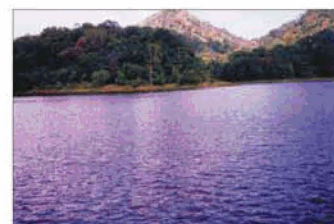
Southwest monsoon 04



Northeast monsoon 03



Northeast monsoon 04



Northeast monsoon 05

Plate -2 Tourist impacts at the PLS -1

Morning to evening there is a huge crowd, especially in the season



At every trip all boats are full and some will have to wait for another trip ...



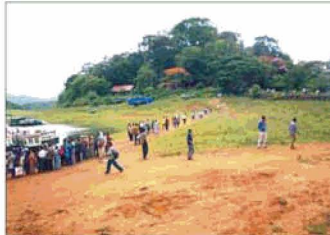
Visitors are in the open sky for an hour sometimes waiting for the boat...



Year after year the crowd is increasing



After a trip this natural call is usual ...



Open urinal ...



Forest Department is Careful but waste is left behind...



Tadpoles found dead in the water..



People are left, now the place is lonely for the wild to visit the polluted and disturbed waters



Plate -3 : Field stations in the Lake

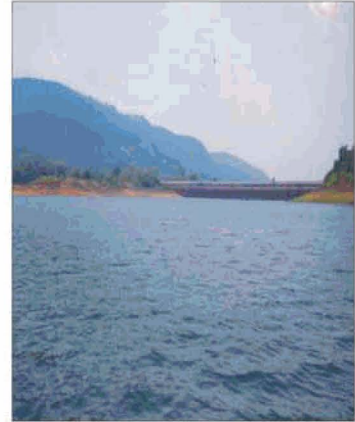
PLS - 2



PLS - 2



PLS - 3



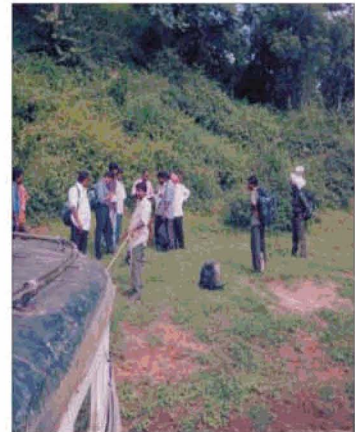
PLS - 4A



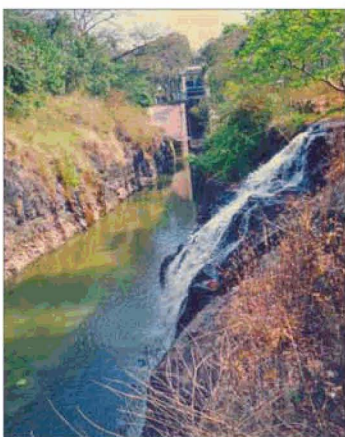
PLS - 4A



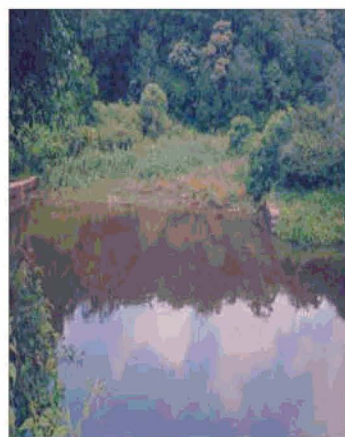
PLS - 4B



PLS - 5



PLS - 5



PLS - 5

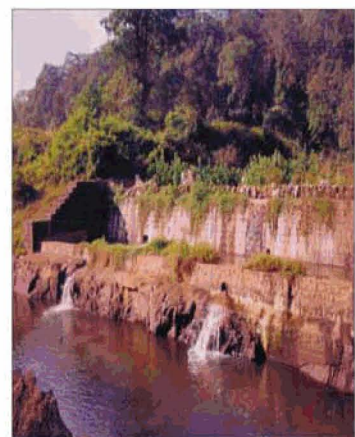


Plate - 4 : *Eugleophyta* of the Lake

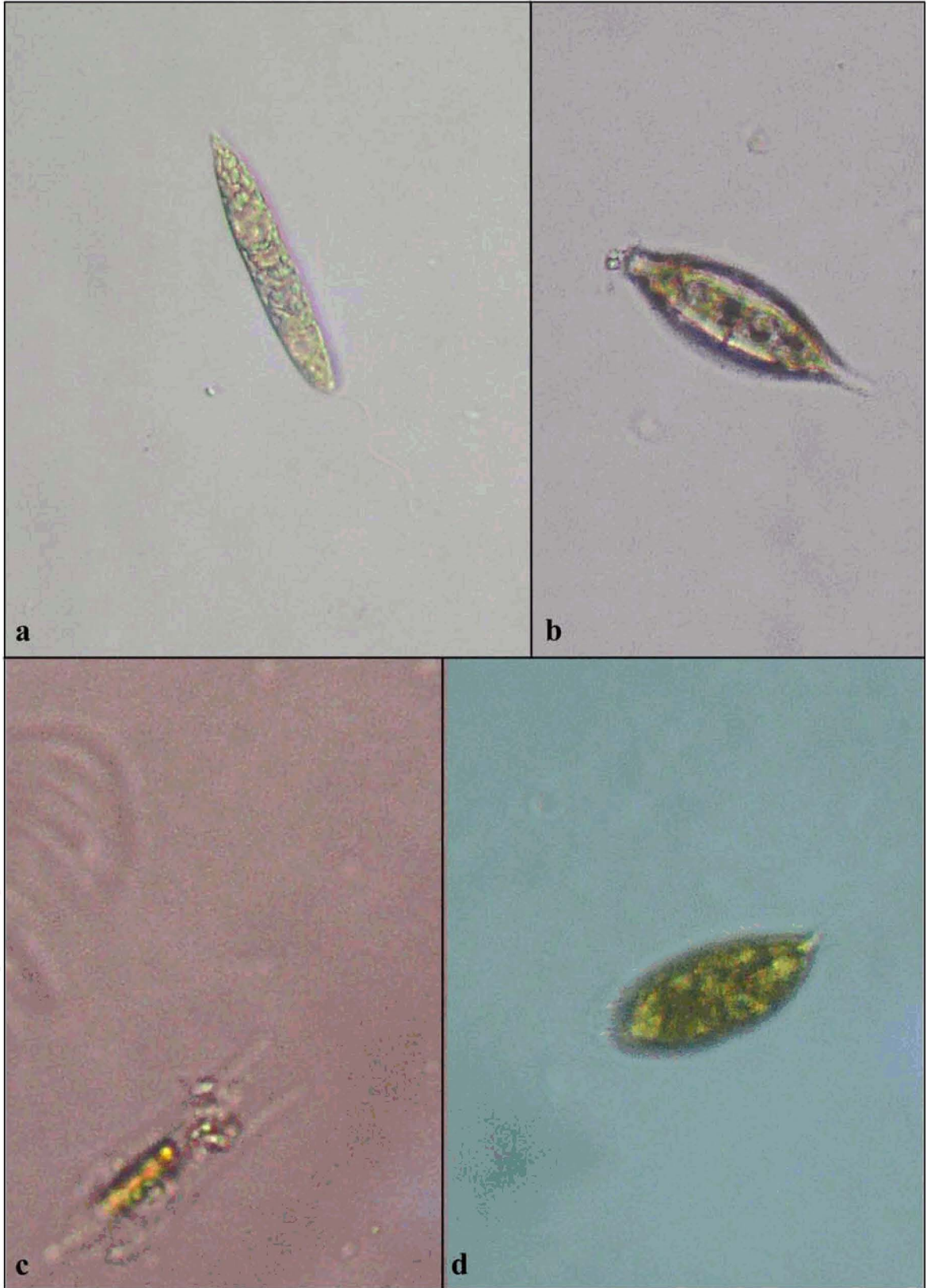


Plate - 5 : *Cyanophyta* (Blue-Green algae) of the Lake

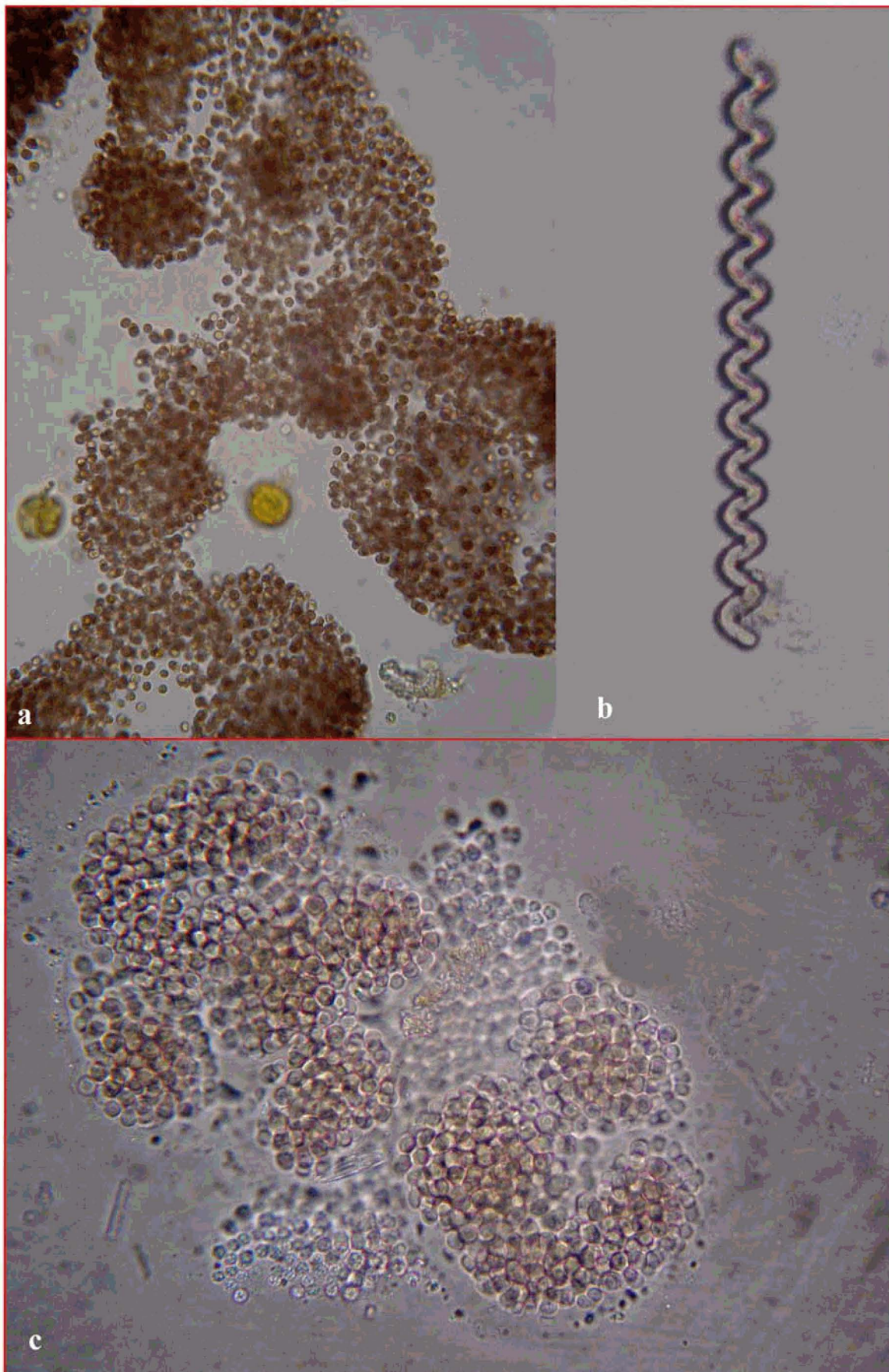


Plate - 6 : Bacillariophyta (Diatoms) of the Lake

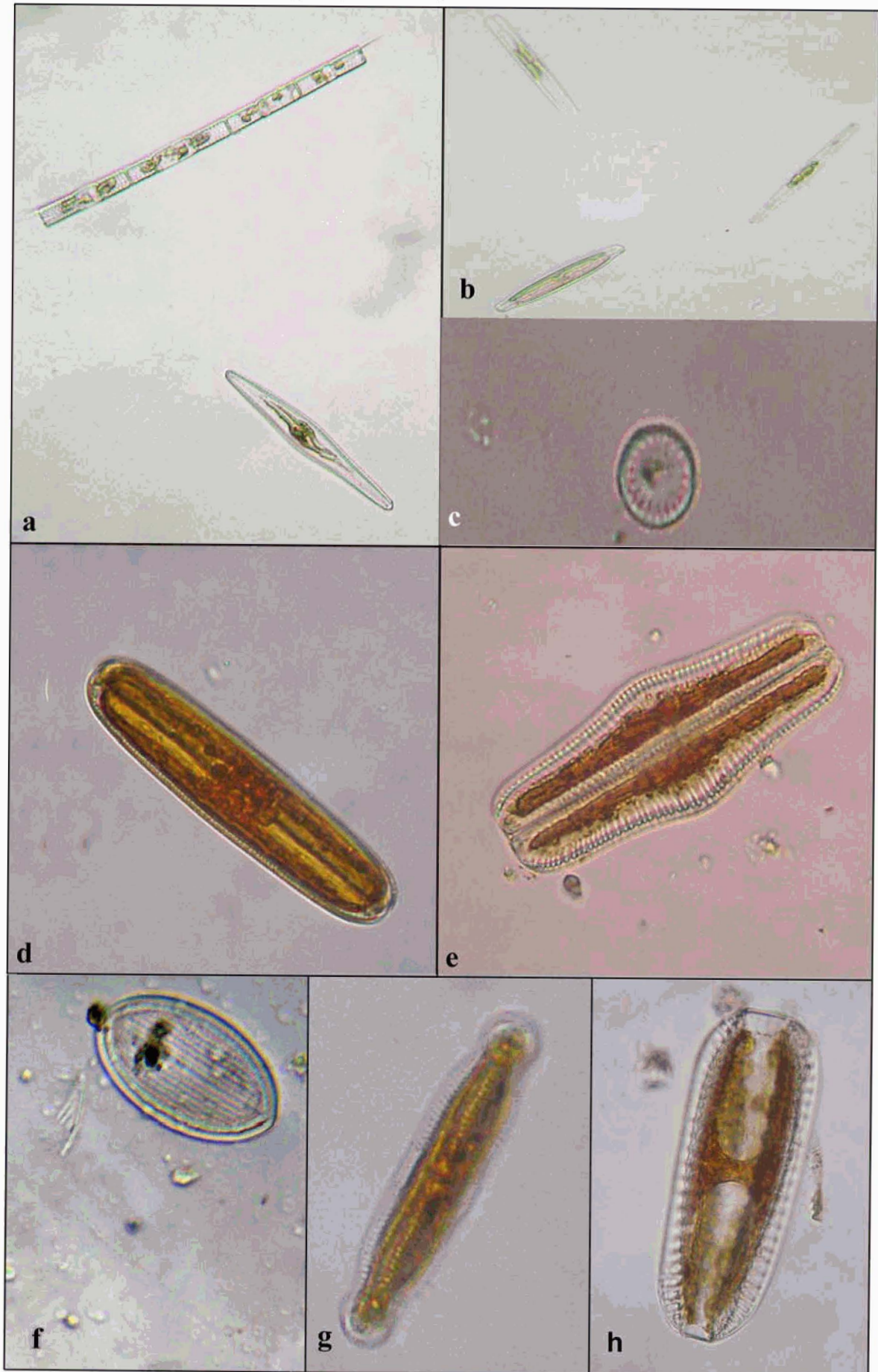


Plate - 7 : Chlorophyta - Chlorococcales of the Lake

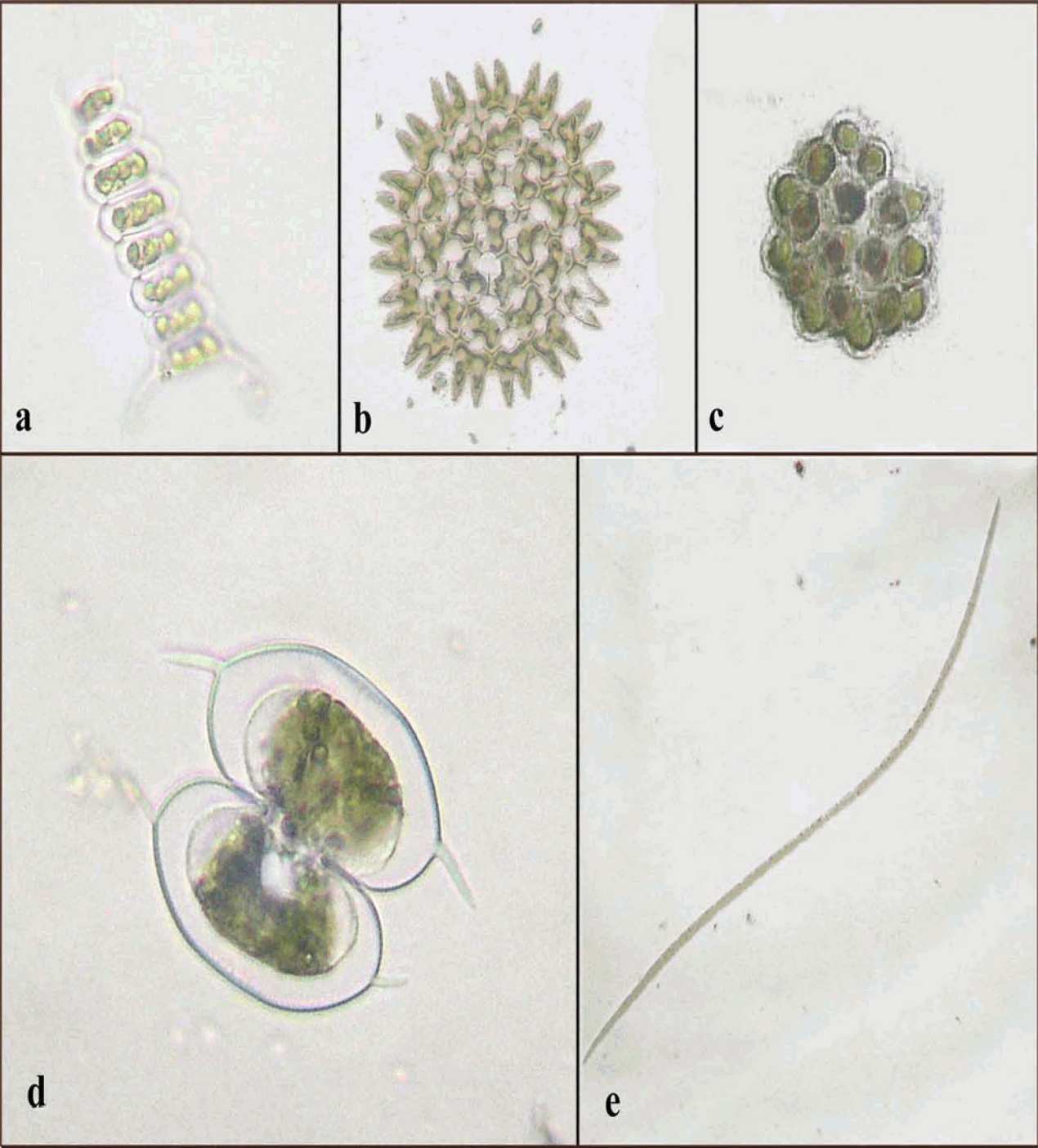


Plate - 8 : Chlorophyta - Zygnematales (Desmids) of the Lake

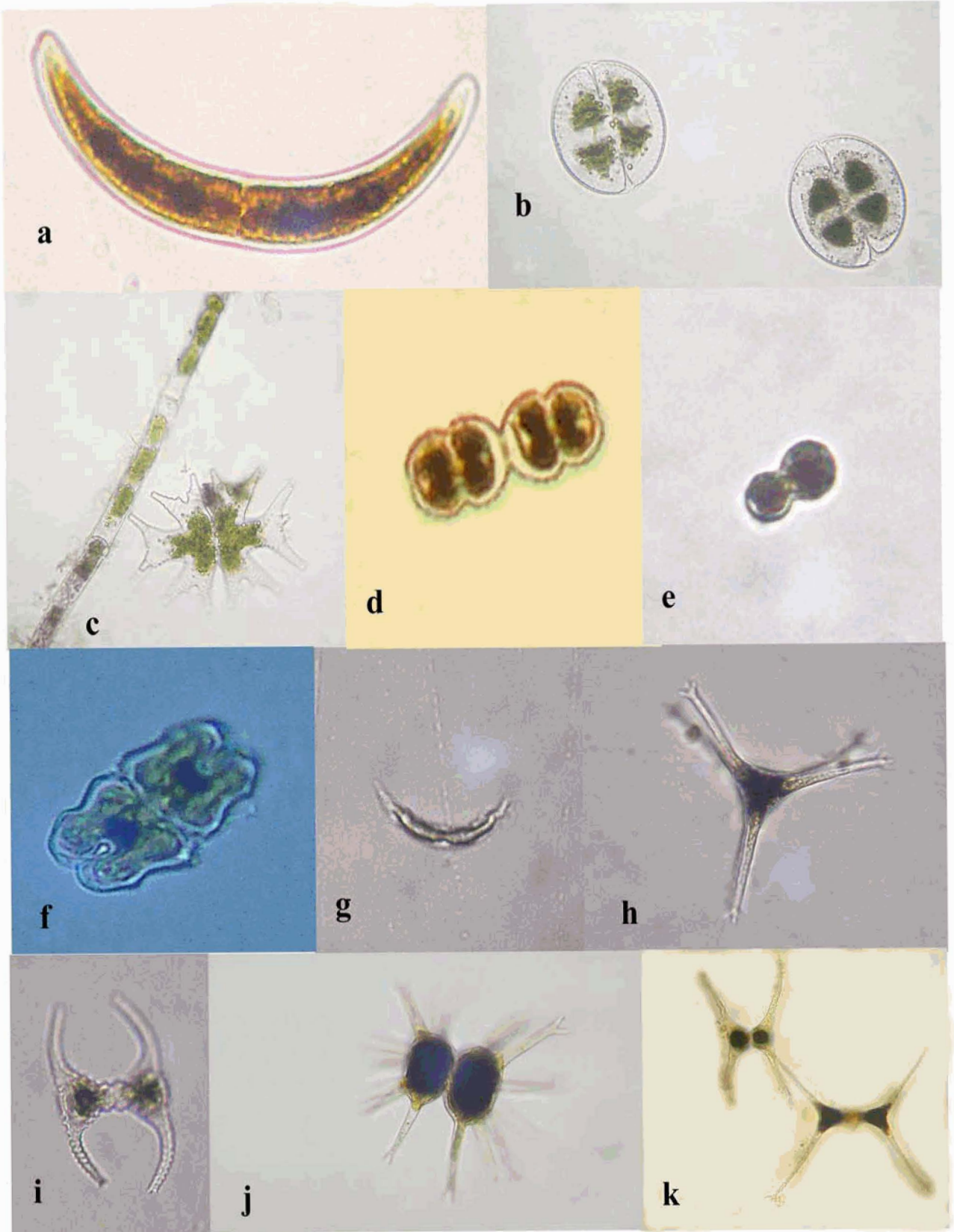


Plate - 9 : Pollution in the Lake

Plastic waste at the landing site



Tourists leave waste everyday



Plastic waste in water as well



Solid waste & Wild Boar link to tiger



Oil is everywhere



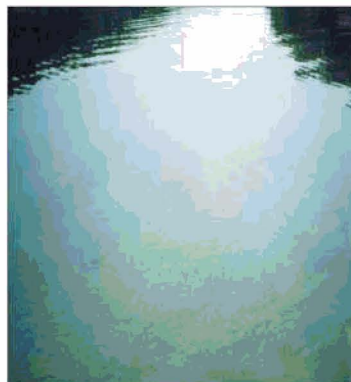
Oil show is very common



More of oil show



Oil flow in to the canal



Oil coming aside getting into wildlife

