CHAPTER I
INTRODUCTION

1. 1 Introduction

Diatoms are one of the prominent and ecologically most significant groups of organisms on the earth. Diatoms are unicellular, eukaryotic, photosynthesizing algae having siliceous skeleton and are found in all aquatic environments. Diatoms can be found in the oceans, freshwater, soils and on damp surfaces. They live pelagically in open water, although some live as surface films at the water-sediment interface (Benthic) or even under moist atmospheric conditions. There are species which can live in either salt or brackish water, some are common to brackish and fresh water and a few can live either in the sea or in fresh water.

Diatom's cell wall is made of SiO_2 or glass frustules ranging in size between 20-200 microns in diameter or length, although sometimes they can be up to 2 millimeters long. These frustules show a wide diversity in form, but are usually almost bilaterally symmetrical, hence the group name. The symmetry is not perfect since one of the valves is slightly larger than the other allowing one valve to fit inside the edge of the other. The cell may be solitary or colonial. They are non-motile or capable of only limited movement along a substrate and play ecological roles in producing diatomaceous earth and toxic blooms in surface waters. Diatoms multiply rapidly, maintaining a dynamic population of varying size. Among unicellular microalgae, diatoms probably represent one of the most diverse groups with the number of species estimated to be between 10,000 and 100,000. Diatoms may occur in such large numbers and be well preserved enough to form sediments composed almost entirely of diatom frustules called as *diatomite* or *diatomaceous earth*. These deposits are of economic benefit being used in abrasives, filters, paints, toothpaste, and many other applications.

Diatoms are especially important in oceans, where they are estimated to contribute up to 45% of the total oceanic primary productions. They are at the beginning of a food chain which ultimately is a very major factor in the welfare of the human race. They are used as food by lower animal forms and crustaceans in the oceans which in turn support fish and other larger marine life. Gran (1930) says that "These enormous quantities of diatoms, without doubt, are the most important food for the pelagic

copepods adds indirectly for the fish larvae which develop after the great spring spawning period".

In recent years, early monitoring studies relied primarily on diatom diversity as a general indicator of surface waters because species composition of assemblages varied seasonally and species diversity varied less. These approaches address two important environmental assessments, one inferring pollution levels and the other determining biodiversity, a more valued ecological attribute (Stevenson, 2006). According to Stevenson et al. 2004, two fundamental questions need to be answered in almost all ecological assessments: “Is there a problem?” and “What is causing the problem?” Understanding the meaning of these questions and how they will be asked and answered by government agencies or other scientists is important for determining how diatoms can help answer both of these questions. Problems can usually be defined relative to the uses of water bodies and their ecosystem services.

In the 21st century, discussions of diatoms are everywhere, regarding the roles they play in global nutrient, oxygen and silica cycling, their utility in understanding the status and trends of aquatic ecosystem health, harmful algal blooms and also in their potential as a possible source of renewable fuels. Diatoms often have narrow windows of tolerance to pH, nutrients or salinity which have been widely studied and defined. Diatoms have proven to be extremely powerful indicators with which to explore and interpret many ecological and practical problems related to health sciences, forensic sciences, nanotechnology and global environmental changes (Smol and Stoermer, 2010).

Today, diatoms are being used to assess ecological conditions in surface water bodies around the world. As diatoms occur in almost all the environmental niches, the same group of organisms can be used for comparison of lakes, streams, wetlands, oceans, estuaries, and even some ephemeral aquatic habitats. Diatoms can be found on the substrata in streams, even when the stream is dry, so they can be sampled throughout the year. Diatoms are ideal for biomonitoring purposes as they occur in very high numbers, are sensitive to changes in water chemistry, are easily collected from the field site and transported to the laboratory and can be readily identified to species level.

1. 2 Application of Diatoms

Water is the most precious resource on earth. It plays a predominant role in distribution of organisms. Fresh water contains various micro-organisms. The quality of

water through parameters (Physico-Chemical) affects the species composition, their abundance and productivity of water. Some organisms can survive in a wide range of conditions and some are more tolerant to pollution while others are very sensitive to changes in conditions and intolerant to pollution.

Freshwater ecosystems are considered as one of the most important natural resources for the survivability of all the living organisms of the biosphere. Fresh water habitats are of much importance to mankind but they occupy a relatively small portion of the earth's surface as compared to the marine and terrestrial habitats (Santra, 2001). The disturbing rate of decline of water quality of fresh water resources like lakes, ponds, rivers, etc. are now a global problem. Over-exploitation, misuse and pollution of water are responsible for making it scarce and unfit for consumption.

Diatoms are being used increasingly to assess short and long-term environmental change, because they are informative, versatile, flexible and powerful ecological indicators. Diatoms respond rapidly to changes in many ecological characteristics. Diatoms are key components of nearly all fresh and saline environments. All species are good indicators for a range of water quality variables, because they have narrow optima and tolerances for many environmental variables: habitat, salinity, pH of the water, nutrient, temperature, saprobity, etc. Diatoms respond quickly to environmental change because they immigrate and replicate rapidly.

During the earlier part of the 19^{th} century diatom study in India was mainly diverted towards taxonomy. The current knowledge of diatom ecology and their importance as bio-indicators in Indian lake ecosystems is meager, although a few studies on river ecosystems have been done. Diatoms now constitute one of the most powerful indicators of water quality and the environmental effects of water chemistry parameters. A sudden change in one or many of the chemical factors causes the appearance of algal blooms which further degrades the water. Physical and chemical methods of detection of water quality have proved to be non-satisfactory. Benthic diatoms are advantageous, particularly in shallow lakes where present and past water chemistry are unexplored.

Biological indicators of water quality monitoring developed during the recent years have served as excellent tools in the area of water pollution studies. Among all the algae, fresh water diatoms are the most commonly used indicators of the conditions of water. Several diatom indices are tested for rivers and lakes in other countries. However,

the diatom studies respect to rivers, lakes and scanty. The present study aims to record the diatom species to assess the environmental conditions in the fresh water Lake of Yercaud.

1. 3 Diatoms as Environmental Indicators

Diatoms occur in all types of aquatic environments; the essential conditions for the growth of diatoms are moisture and light. They also depend upon temperature and chemical conditions in their environment and are found in all parts of the world at all latitudes, from the lower regions of the oceans to high altitude locations in mountains. Diatoms are collectively showing a broad range of tolerance along a gradient of aquatic productivity, individual species have specific water chemistry requirements (Werner, 1977; Round et al. 1991). Diatoms have one of the shortest generation times of all biological indicators (Rott, 1991).

Diatoms are sensitive to change in nutrient concentrations, supply rates and silica/phosphate ratios (Tilman, 1977; Tilman et al. 1982). Each taxon has a specific optimum and tolerance for nutrients such as phosphate (Hall and Smoll, 1992; Reavie et al. 1995; Fritz et al. 1993; Bennion, 1994, Bennion et al. 1996) and nitrogen (Christie and Smol, 1993), which can usually be quantified, to high degree of certainty. Diatoms assemblages are typically species rich. Considerable ecological information may be gained from this diversity of ecological tolerances. Diatoms are responding rapidly to eutrophication and recovery (Zeeb et al. 1994). Because diatoms are primarily photoautotrophic organisms, they are directly affected by changes in nutrient and light availability (Tilman et al. 1982).

Round (1993) lists numerous reasons why diatoms are useful tools of biomonitoring, amongst which the following bear especial relevance to the South African situation; methods are cost effective, data is comparable, techniques are rapid and accurate and identifications and counts can be done by non-specialists with a biological background if they are provided with illustrated guides.

1.4 Purpose and Objectives of the Study

Water pollution is one of the most serious problems faced by man today. Diatoms play significant ecological role and are being extensively used as indicator of water pollution because they are natural inhabitants of water. The Distribution of Diatom species in surface water bodies are mainly governed by the physico-chemical

composition of the water. It is important to understand which environmental variable can affect the diatom growth, assemblage and distribution. Diatoms provide advantages over direct chemical monitoring in that they respond over periods of days avoiding unrepresentative sampling. Also, as an important component of the biota, they represent the chemical/biological interface.

In India, Diatom studies especially for monitoring the environment is yet to gain momentum. The investigations on Lake Diatoms are scanty. The present work is an attempt, first of its kind in the study area, to record the diatom species, study of diatom assemblage, geochemistry of lake water, diatom indices and water quality index for assessment of environmental conditions in Yercaud Lake (Fig.1), Salem District, Tamil Nadu, India. As diatoms provide interpretable indications of specific changes in water quality, diatom indices were tested in this study for its application in the Yercaud Lake.

The objectives of the study are as follows:

- To record the diatom fauna present in the study area
- To study the diatom assemblages and distribution
- To assess the quality of water in Yercaud Lake
- To determine the diatom indices and water quality index
- To determine the environment of Yercaud Lake and their correlation

1. 5 Study Area

The study area "Yercaud Lake" is situated in Yercaud hill station in Salem District, Tamil Nadu located in the Shevaroys range of hills in the Eastern Ghats. Yercaud derives its name from "*Yeri*" means Lake; "*Kadu*" means forest in Tamil language owing to the abundance of trees, "*categorized as a forest near the lake"*, the name signifying "*Lake Forest"*. Yercaud is affectionately known as the poor man's Ooty. The climate of Yercaud is neither too cold nor too hot. Bauxite the ore of aluminum is widely reported and excavated from Yercaud.

The Shevaroy hills is a detached hill range, covering an area of 400 sq. km., and the Yercaud hill station is situated at an altitude of 1515 metres (4970 feet) above sea level and the highest point in Yercaud is the Servarayan temple, at 1,623 metres (5,326 feet). Yercaud Lake is located between longitude 78°12' 28" to 78°12' 40" E and latitude from 11°46' 56" to 11°47' 08" N in of Salem District, Tamil Nadu, India (Fig. 1.1).

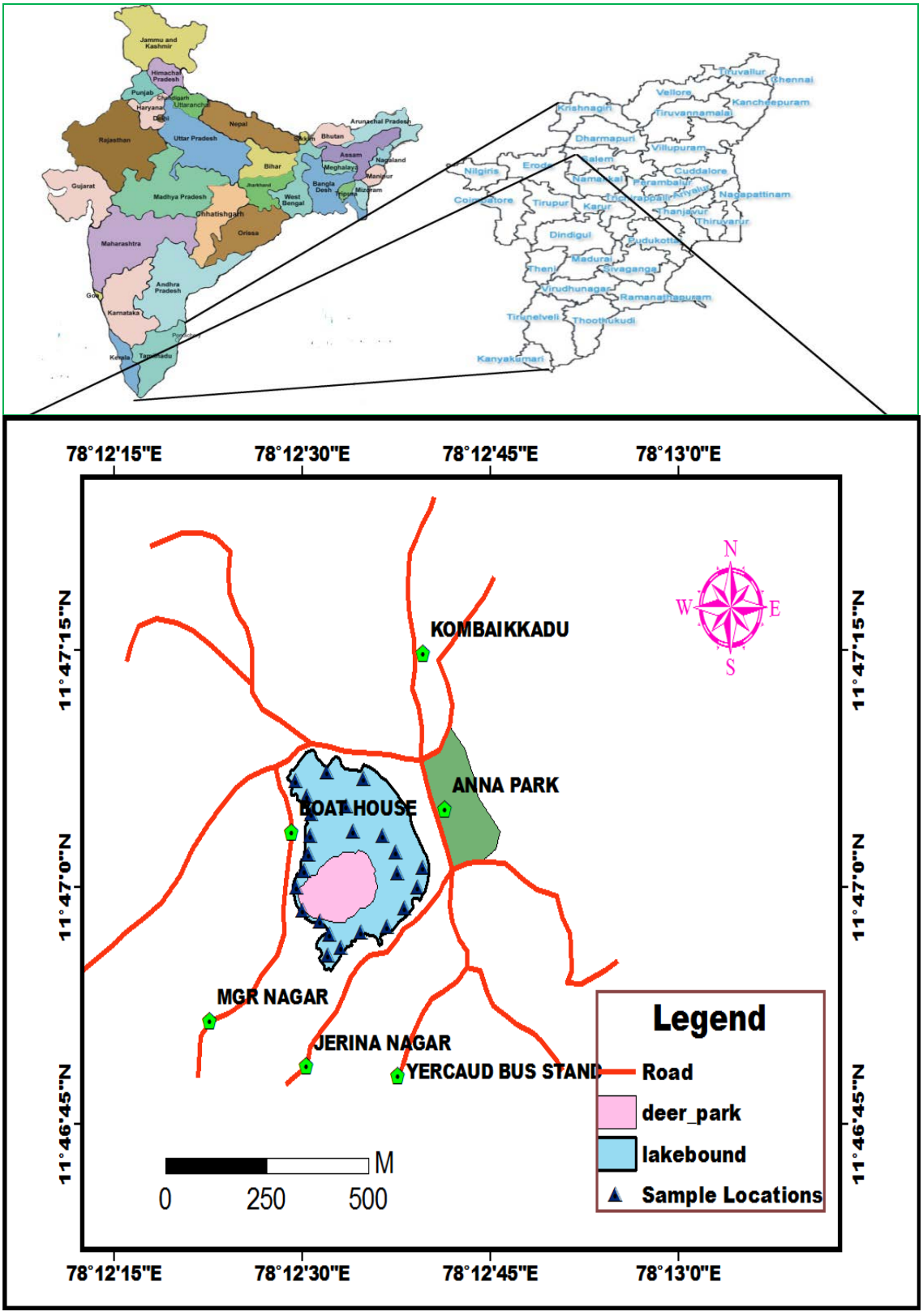

Fig. 1.1 Location of the Study Area

1.6 Physiography

Yercaud Lake is situated in a low lying area of Yercaud Township surrounded by sloping elevated hills on all sides. It is fed by small streams. The overflow from Lake forms a major stream called "*Periya Aru*" means big river which creates the beautiful "*Kiliyur falls*" at Kiliyur village situated five kilometers south of Yercaud Lake.

The Shevaroys is the largest mountain in Salem district. It is an outlier of the Eastern Ghats lying between the Mallapuram Ghats and the Manjavadi Valley. An outlier of the Shevaroys is the Kavaramalai hill in the south-western corner of the Harur taluk in Dharmapuri district. South-west of the Shevaroys is another outlier, the Nagavamalai in Salem taluk. East and north-east of the Shevaroys are the Thendamalai range. It consists of the Theerthamalai in the north, the Chiterimalai in the center and the Aranoothumalai in the south.

The topography is undulating and the slopes range from 20 per cent to 70 per cent. The forest reserves on the slopes are under the supervision of the Shevaroyan South Range and Shevaroyan North Range of the Tamilnadu Forest Department.

A park located opposite Yercaud Lake is popularly known as "*Anna Park*" which is named after C. N. Annadurai, former Chief Minister of Tamil Nadu State. It has lovely gardens with lawns, paths and sports facilities for children. A flower show and a horticultural show during the annual carnival of Yercaud called 'summer festival' is usually held during the month May.

1. 6.1 General Geology of Yercaud Hill

Yercaud town is considered as irregular plateau situated on the southwestern side of Shevaroyan hills. Yercaud is cut off from the view of the plains by a circle of hills range in height from 1371 to 1463 meters. This plateau terminates to the north of the Sanyasimalai. The rock type of this hill range is bluish grey to dark grey coarse grained Charnockite. It has a generally oily sheen caused by the presence of blue quartz. The rocks have been divided into three groups namely acid, intermediate and basic depending upon the amount of blue quartz present in them. This geological feature is common to most of the hill areas in Salem district.

In the Shevaroys hill, granetiferous, lueocratic rocks called leptynities are found to occur. The rocks of alterations have given rise to bauxite deposits on the Shevaroys. Bauxite which is the raw materials for the manufacture of aluminum occurs in Shevaroys

as cappings over altered leptynities. The total quantity is estimated at 6.7 million tons and its quality is as good as any other deposits in India. The main prevailing soil type in the Shevaroys hills is ‘Red Loam’ with one to one point five meters in depth.

1. 6.2 Stream

The ‘Thoppar River’ rises in the Shevaroys and flows along the southern border of Harur and Dharmapuri taluks (Dharmapuri district). The ‘Sarbhanganadi’ formed by the union of the two streams rising in the Shevaroys flows across Omalur taluk (Salem) and Tiruchengode taluk (Namakkal). The river ‘Vaniyar’ rises near Senkadu in the south Shevaroys Mountain and runs through a twelve miles long valley. It joins the ‘Pennar’ below its confluence with the Pambar. The valley of the Vaniyar River divides the mountain from south to north into two large sections. East of this valley is Thalaisolai and Maramangalam plateau. On the west are the plateaus of Nagalur and Yercaud.

1. 6.3 Climate and Weather

The Shevaroys in Yercaud taluk have a very pleasant climate with a mild temperature all trough the year. The salubrious climate of Yercaud made it a popular summer resort of the British even before the Nilgiris Mountains became the popular summer resort of south India. The hottest months in the district are March, April and May. The heat declines to some extent on the outbreak of the south-west monsoon from June. But, owing to the stillness of the atmosphere in September and October, the temperature is oppressive. The winter is from the middle of November to the middle of February, when the climate is chill but enjoyable.

Temperature varies with altitude and aspect. Even on this count, the hills have an annual mean temperature of about 22° C. The average annual range of temperature is about 1.5°C. Annual mean relative humidity is 85 per cent. The annual mean daily minimum is around 70 per cent and the maximum 98 per cent. Given this general context of climatic elements, it is clear the area has high potential of production in terms of conditions favoring plant growth.

Summer Season (From March to May)

The temperature starts rising from February in India. By April, the northern plains of India experience daily temperatures exceeding 40° C while in the south temperature reaches around 35° C but humidity is more. In summer heat is so relentless and tiring in India. It is always extremely hot, sunny and dry.

Monsoon Season (From June to October)

In India there are two types of monsoons - the southwest monsoon and the northeast monsoon. The southwest monsoon, which is the main monsoon, comes in from the sea and starts making its way up India’s west coast in early June. By mid July, most of the country is covered in rain. This gradually starts clearing from most places in northwest India by October.

The northeast monsoon affects India’s east coast during November and December. It’s a short but intense monsoon. The states of Karnataka, Tamil Nadu and Kerala receive most of their rainfall from the northeast monsoon, while the rest of the country receives most of its rainfall from the southwest monsoon.

During the monsoon, India doesn't receive rain all the time, although it usually rains for a heavy period every day, followed by pleasant sunshine. The rain brings some relief from the scorching heat. Conditions become very humid while the temperature still remains quite hot.

Winter Season (From November to February)

Once the monsoons subside, average temperatures gradually fall across India. As the Sun's vertical rays move south of the equator, most of the country experiences moderately cool weather. December and January are the coldest months, with mean temperatures of 10–15 °C (50–59 °F) in Indian Himalayas. Mean temperatures are higher in the east and south, where they reach 20–25 °C (68–77 °F). In the south, it never gets cold.

1. 6.4 Rainfall

The rainfall seasons can be grouped into three viz., the summer rains, the south-west monsoon rains and the north-east monsoon rains. The summer rains are in the months of April and May. Heavy showers accompanied by thunder occur during this period. The south-west monsoon is usually very weak in the district. About 5-6 inches of rainfall occurs during this period from the middle of June to August. The north-east monsoon occurs in the months of October and November and gives about 30-35 inches of rain in all the places of the district except in Yercaud which gets about 60 inches.

The average rainfall is about 1600 mm; the entire rainfall period is about 9 months, from March to December. However, maximum of rainfall is received in the

months of May to November. It appears that while the hills receive rainfall in both south-west and north-east monsoons periods, rainfall is high especially in the north-east monsoon periods, September to November. The period from January to April is usually dry, but occasional rains may fall in these four months. The temperature and rainfall in Yercaud will be moderate throughout the year and favors the formation of Bauxite and growth of coffee plantations.

1. 6.5 Vegetation

Primary vegetation consists of dry deciduous and evergreen trees in the higher altitudes and hill slopes. The valleys abound in trees and plants, often of great girth and height. Tamarind trees occur in large numbers and yield very good revenues. Dry mixed residues forests occur above the fuel forests. Commercially these forests are very valuable for Sandal. Bamboos also attain the best developments in these forest areas. In the higher altitudes of Shevaroys, plantations of Drevillea robeata (silver oak), Eucalyptus, Globulos, Prenella, and Rhomboidea (paper, pulp wood) have been raised.

1.7 Diatoms in Fossil record

The fossil record of diatoms has largely been established through the recovery of their siliceous frustules in marine and freshwater sediments. Although diatoms have both a marine and non-marine stratigraphic record, diatom biostratigraphy, which is based on evolutionary originations and extinctions of unique taxa, is only well developed and widely applicable in marine systems. The ranges of diatom species have been documented through the study of ocean cores and rock sequences. The diatom based biozones are well established and calibrated to the geomagnetic polarity time scale in Southern, Northern, Eastern and Equatorial Pacific oceans, where the age estimates have been resolved up to within 100,000 years.

In geology, diatoms may indicate the location of ancient lakes or seas, the contours of their beds may be indicated by the presence of pelagic or littoral forms and the climate at the time, whether temperate, tropical or arctic may be ascertained.

The fossil record of marine diatoms is still incompletely known due to dissolution and taphonomic effects (e.g. Hesse 1989; De Wever et al. 1994; Martin 1995; Schieber et al. 2000). The earliest unequivocal recorded diatom frustules are centric forms from the Early Jurassic although very few remains are known before the Campanian (Late Cretaceous). Diatoms were only moderately affected by events at the Cretaceous–

Tertiary boundary (c. 23% extinction). A major radiation took place among centric diatoms in the Paleocene when the first pennate types also appeared (Fig.1.2), expanding their numbers gradually through time.

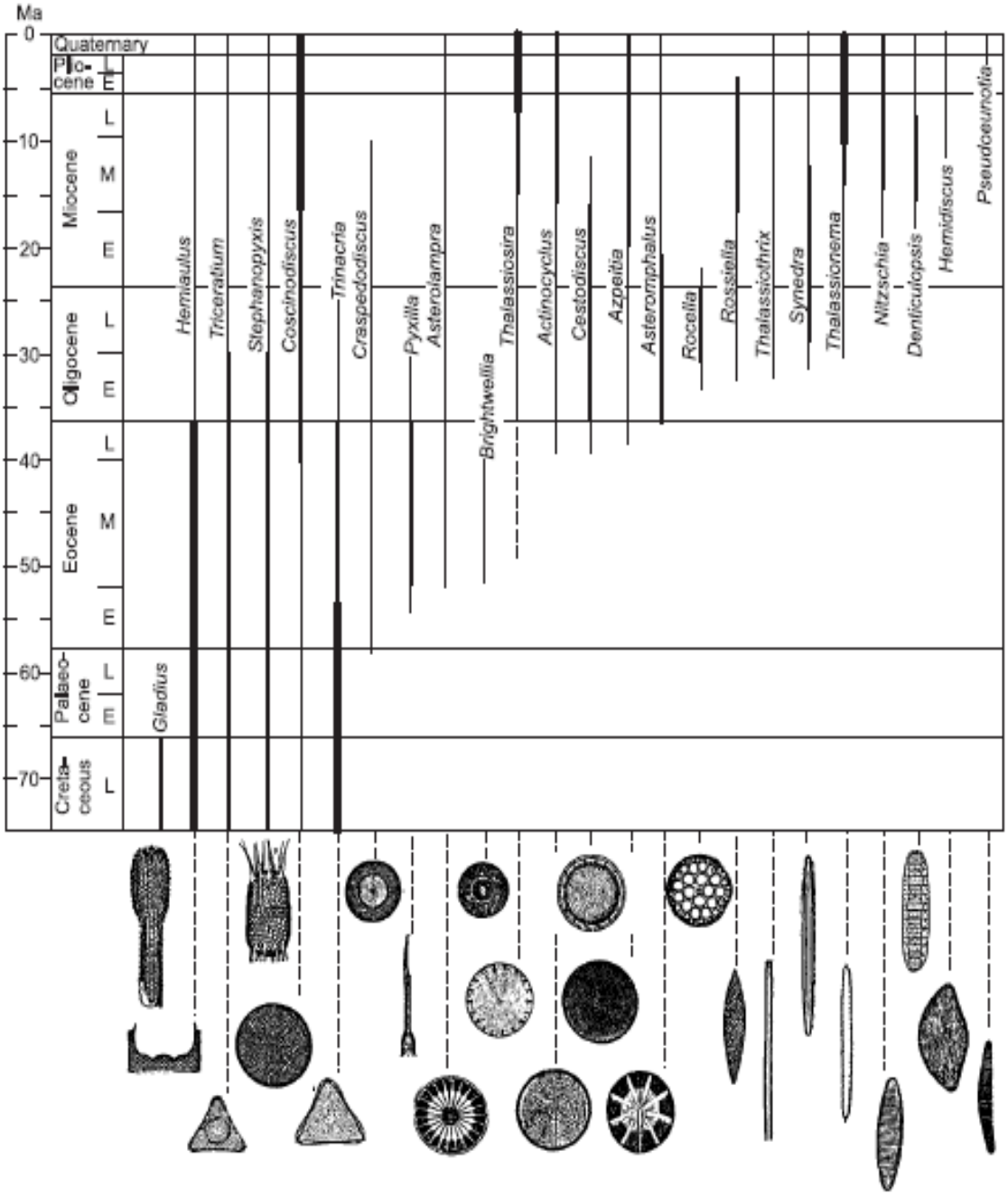

Fig. 1.2 Stratigraphical ranges of diatoms after (Armstrong and Brasier, 2005).

1. 8 Uses of Diatoms

Diatoms are very abundant, largely existing wherever there is water. Diatoms live in all aquatic and semi-aquatic habitats. Some diatoms live as free floating cells in the

plankton of rivers, streams, ponds, lakes and oceans. Planktic species often have morphological adaptations that allow them to remain suspended in water. The study of extant diatom species, and particularly their ecologies, can provide useful information for the interpretation of environmental conditions. Diatoms exhibit three major modes of existence: planktic, benthic, and macrophytic (attached to plants). Planktonic forms contain oil globules, which help to keep the diatom afloat in the water column. As a result, it is often easier to identify dead diatoms, in which the internal oil globules and chloroplasts have decayed away to reveal the valve ornamentation, than it is to identify living diatoms to species level.

In general diatoms can be used to trace a variety of environmental phenomena, from changes in sea level, (whether brought about by climate change or tectonic activity), breaches of coastal barriers, (as a result of storms and/or sea-level rise), to the evaporation of lakes, (increasing salinity determining diatom assemblages). All diatom species are highly sensitive to environmental changes, giving rise to very different assemblages under rather tight environmental constraints. For example, diatoms display varying assemblages according to pH, trophic status and pollution levels. Diatoms bloom seasonally, with different species blooming at different times of the year.

1. 9 Review of Literatures

Ecological studies give us the insight on the life, its forms and their levels of existence and immortality on earth. Ecology provides men 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 anthrop genial and techno-genial factors on fresh water resources are imperative.

1.9.1 International

With the continuous increase in human population and its constant demands on the fresh water aquatic resources of the globe, there has been a "*Compounding of the interrelationship algae and man*" (Jackson, 1964). This relation has become all the more complex and important with advances and technology and increase eutrophication of lake and stream. Problems related to taste, odor, toxicity or obnoxious growth caused by algae are common.

According to Round (1965), the diatoms take silica from water for its growth through aerobic process. He also states that the diatoms are the dominant group of organisms in many natural habitats and as such are subtle indicators of environmental conditions, whilst they themselves modify the habitats and all that is needed for any indication of pollution is the number of species in the habitats for in all and unbalanced system, a single species or a few species which remain and grow abundantly making the system unbalanced. The amount of incident light penetrating in water is an important factor which determines the growth of certain algae (Palmer 1967). Further, algae are capable of growing in nitrogen and phosphorus rich environment which is critical for habitation.

King and Tyler (1981) have studied the limnology of a lake in south-west Tasmania of Australia and found that the oxygen of the hypolimnion declines late in the stratification period resulting lower productivity environment. He also studied the seasonal changes of biomass in the lake environment. Barroin et al. (1982) described the physic-chemical and biological parameters of eutrophic Lake Lemen in France. Rai and Hill (1982) have studied the physico-chemical and microbiological parameters of Central Amazon lakes in Brazil and classified the lakes based on the pH, electrical conductivity, dissolved oxygen, silica and phosphate content into oligotrophic and eutrophic. Brown (1982) has studied the effect of pH and calcium on fish and fisheries in Brazil.

According to Wetzel (1983), the dissolve oxygen is essential for the metabolism of all aerobic aquatic organisms and oxygen distribution is important for the direct needs of many organisms, affecting the solubility and availability of many nutrients. The oxygen balance in water bodies are based on the input and output, where the input is due to the atmosphere and photosynthesis and the output is due to the respiration, decomposition and mineralization of organic matter as well as losses to the atmosphere.

Ferris and Tayler (1985) also have investigated the impact of total phosphorus in Burragorang Lake, New South Wales and some other Southern hemisphere Lake. Blouin *et al.,* (1985) have presented a comparative study of phytoplankton and zooplankton and their distribution in relation to water chemistry in the lakes of Novascotia, Canada. Chitranshi and Bilgrami (1986) have investigated the lentic (stagnant) water ecosystem and discussed the importance of physico-chemical characters of water in relation to the distribution pattern of phytoplankton. They have considered the pH, temperature, potassium, sodium, dissolved oxygen and phosphate as the chief physico-chemical characteristics which play a significant role either by increasing or decreasing certain phytoplanktonic groups in different water bodies. Kurata et al. (1987) have observed the seasonal change of temperature, transparency, salinity, nutrients and phytoplanktons in lake Notoro Hokkaido, Japan. Osborne et al. (1987) has studied the Lake Murray of Papua New Guinea and have observed that the wind induced disturbance of anaerobic sediments in the Lake enhances nutrient release from the sediment, which stimulates phytoplankton production. According to Osborne et al. (1987), the water quality in temperate lakes and tropical lakes are not stable in wet as well as dry seasons.

Schelske et al. (1987) have studied the limnological aspects such as biogenic silica and bio-geochemistry of silica in lake St. Moritz and lake Zurich, Switzerland. June and Fred (1987) has made observations on physic-chemical and biological characteristics of lake Sharpe, South Dakota, USA. Meybeck et al. (1989) have investigated the primary salinisation of lakes and streams can be attributed to processes such as the accumulation of airborne sea-salt, evaporation, and the dissolution of minerals.

Dixit et al., (1992) have conducted extensive studies on diatoms and revealed that they can be used as indicators of biological condition, used to address a wide variety of environmental issues, including Lake Acidification, Lake Eutrophication and climate changes. Pedroz et al. (1993) and Vilaclara et al. (1993) have studied the major ionic composition of six main type carter lakes, as well as pond and have found that salinity varies with natural factors and not with nutrient inputs, they also have observed that both Mg and SO_4^{-2} precipitations were found to be more dependent on pH, Photosynthesis and evaporation driven processes. Wu (1999) has reported that aquatic algae are sensitive to pollution or other events, and are therefore commonly used for monitoring environmental contamination. Dixit et al. (2000) have investigated that fossil diatoms

and pigments to assess the past trends in water quality of four prairie lakes of Canada, which were subjected to both discrete urban and diffuse agricultural human impacts. 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.

Romero et al. (2002) have stated that the knowledge of the phytoplankton productivity and algal adaptations to growth limitations are needed prior to the development of scientifically based restoration strategies for eutrophic lakes. Vilbaste and Truu (2003) have studied the distribution of benthic Diatoms in relation to environmental variables in low land streams in Estonia and have found that the trophic level of water plays an important role in governing the structure of benthic Diatom assemblages. Kamenir et al. (2004) have investigated 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. Muzaffar and Ahmed (2007) have investigated that effect of the flood cycle on the diversity and composition of phytoplankton community of a seasonally flooded Ramsar wetland in Bangladesh. Moreno-Ostos et al. (2008) have studied the spatial distribution of phytoplankton in a Mediterranean reservoir.

1.9.2 National

In India, the pioneering work on algae has been carried out by Eherberg (1851, 1854) on diatom of Bengal, Deccan and Northern India; Skovortzow (1935) on diatoms of Calcutta; Majeed (1935) on diatoms of Punjab; and Biswas (1937) on diatoms of Loktak Lake in Manipur. The diatoms of Uttar Pradesh have been worked out by Singh (1961, 1962 and 1963) and Ahmad (1972). Saxena (1968) has given the list of diatoms from Kashmir. Suxena and Venkatashwarlu (1968) and Suxena et al (1972) have worked on diatom from high altitude areas in Eastern Himalayas. Anand and Kant (1976) have described some diatom from the Jammu Manser lake in Kashmir. Comprehensive accounts of diatoms of South India have been given by Venkataraman (1939), Iyengar and Venkataraman (1951) and Krishnamurthy (1954). Subrahmanyan (1946) has given an extensive account of the marine plankton diatom of the Madras coast.

The important contribution to the science of aquatic biology in India include those of Gonzalves and Joshi (1946) who worked on the seasonal accession of algae in tank at Bandra, Bombay. Patrick (1948) has observed the factor affecting distribution of

diatoms Rao (1953) investigated on the distribution of algae in a group of six small ponds. Krishnamurthy (1954) worked on diatomic flora of south Indian Lakes; Gandhi (1955) worked on the fresh water diatoms of Pratabgarh, Rajasthan; Philipose (1960) worked on the freshwater phytoplankton of Inland fisheries; Singh (1960) recorded the phytoplankton ecology of Inland water of Uttar Pradesh; Khan and Quajjum (1966) studied the ionic composition of tropic freshwater pond of Uttar Pradesh; Zafar (1967) worked on the ecology of algae in certain fish pond of Hyderabad.

The diatom of western India have been very extensively worked on by Gonzalves and Gandhi (1952, 1953, 1954) and Gandhi (1955-1970), has worked on diatom of Bombay, Ahmedabad, Mysore, Kolhapur and adjoining areas of India. Biswas (1949) and Sreenivasan (1965) have enumerated the diatom of India. The important contribution to the science of aquatic biology in India include those of Tandon and Singh (1972) who have the studied effect of certain physico-chemical factors on phytoplanktons of the Nangal lake. Sarkar and Krishnamurthy (1977) have emphasized on biological monitoring as a method to evaluate the degree of pollution and have recommended the uses of species diversity index as an indication of pollution.

Misra and Yadav (1978) have made a comparative study of physico-chemical characteristic of rivers and lakes of central India. Mohan (1980) compared the values of organic carbon and planktonic biomass with that of dominant algal associations in two lakes of Hyderabad. The other noteworthy publications on Indian limnological studies include those of Goel el al. (1980) on the impact of sewage on the freshwater ecosystem; Purohit and Singh (1981) on the physico-chemical aspects of Nainital lake. Further, Parra et al. (1981) observed the seasonal succession of phytoplankton in some lentic water bodies of Chile and showed the complex inter-relationship between water quality limnological conditions and planktonic organisms.

The other important investigations made in India include those of Dakshini and Gupta (1984) on the ecological characteristic of three lakes in the union territory of Delhi and Singh and Rai (1984) on the ecology of Jabalpur lake (Madhyapradesh). Puttaiah and Somashekar (1985) studied the limnological aspect of Mysore city ponds and Kanungo et al. (1985) worked on the physico-chemical characteristic of some pond of Raipur city. Puttaiah and Somashekar (1987) pointed out that higher carbondioxide and lower concentration of oxygen significantly contribute to the anundance of Euglenoids in the water bodies of Mysore city. Singh and Mahajani (1987) discussed the role of

temperature, nitrate nitrogen and phosphorus for phytoplankton variations in the lakes of Himachal Pradesh.

Zutshi and Khan (1988); Anand (1988); Bhattacharya (1988); Saifullah et al. (1988) who did considerable work on the chemical composition of standing water bodies concluded that both physical and chemical characteristic of water significantly affect the algal population and they emphasized the importance of pH, total alkalinity and carbon dioxide content of water on the succession of phytoplanktons leading to eutrophication.

Goel et al. (1988) investigated the species diversity in phytoplankton communities in four freshwater bodies of south-western Maharashtra. Singh (1990) has correlated certain physico-chemical parameters and primary production of phytoplanktons in Jamalpur, Munger. The succeeding contributions to the field of freshwater bodies with special references to the distribution of phytoplanktons and water chemistry have been recorded in the publication of Sarwar and Wazir (1991) on the physicochemical characteristic of freshwater pond near Srinagar.

Swarnalatha and Narasingrao (1991) revealed the fact that cyanophyceae blooms, by and large, are common in highly polluted lakes and regarded the blooms of cyanophyceae as indicators of pollution of water. Kumar and Sharma (1991) studied the Pichola Lake, Udaipur and pointed out that the electrical conductance, pH, total alkalinity and nitrates at higher concentration increase the productivity status of lake and these parameters could serve as indicators in assessing tropic level of the water bodies.

Chatterjee (1992) has investigated the Nandan kanan lake in Orissa and has recorded that temperature with slightly alkaline pH, conductivity, chlorides, calcium and magnesium do not seem to vary much indicating the insignificant influence of organic and inorganic matter from outside to the lake. Borkar et al. (1992) from Goa, studied the diurnal variation in physico-chemical parameter of lake near Marmugoa and Goa and concluded that dissolved oxygen, free carbon dioxide, pH, chloride and total alkalinity in higher concentration could accelerate the pollution rate in the lake. Nirmal Kumar (1992) also prepared indices based on chemical properties in relation to planktons. However, there is no report on phytoplankton composition in relation to hydro chemical properties of tropical community wetland, Kanewal, Gujarat, India. Rao et al. (1993) have analyzed various physico-chemical and biological factors in the storm water channel and Ooty

Lake in Tamil Nadu and suggested that the dumping of sewage into the lake affects the lake's environment.

Sreenivas and Rana (1994) studied the ecology and tropic status of Gomti tank, Gujarat, pointing out that the tank was on the verge of attaining eutropic state. Ravikumar and Puttaiah (1996) studied the ecology of Hassan district lakes. Padhi (1995) studied the water chemistry and algal communities on the three freshwater ponds in and around Berhampur in Orissa and suggested the revival methods using algal communities as biological indicators. He recorded wide variations in pH, Biological oxygen demand (BOD), Chemical oxygen demand (COD) and Dissolved oxygen (DO), phosphate and nitrates. The seasonal variations in physico-chemical parameters like dissolved oxygen, chlorides, salinity and planktonic composition of Kurichi ponds were studied by Arivazhagan et al. (1997). Sarojini et al. (1997) have studied pollution of water resources of Kolleru area. Wani (1998) has investigated the seasonal dynamics of phytoplankton in a shallow Himalayan lake.

Pandey et al. (2000) have investigated the nutrient status and cyanobacterial diversity of tropical freshwater wet lands of Udaisagar and clearly indicated elimination of sensitive cyanobacterial species from the substations receiving urban industrial effluents. Nandan et al. (2001) have carried out the limnological studies on the Hartala Lake of Jalgaon District of Maharastra. They have found the dominant occurrence of blue-green algae when compared to other groups of algae. They have also noticed that the abundance of blue-green algae was due to the higher concentration of dissolved oxygen, carbonates, total alkalinity, phosphate and chlorides.

Rajkumar (2001) has studied seasonal distribution phytoplankton in the polluted freshwater pond of Pollachi in Tamil Nadu and has observed that the minimum number of phytoplankton occurred in the colder months than in summer and monsoon months. Tewari and Srivastava (2004) have investigated the distribution pattern of algal flora in a water body affected by the effluents form the nearby rubber factory in India. Angadi et al., (2005) studied physico-chemical and biological status of aquatic bodies and recorded 39 species of algae from four classes. In Gujarat state, Nandan (1983) studied the algal flora of polluted waters. Shaji (1989) and Jose (1990) evaluated the algae as pollution indicators in running waters. Rana and Nirmal Kumar (1992) and Nirmal Kumar et al. (2005, 2008) studied the physico-chemical characteristics of water, sediments, diversity of macrophytes and planktons of certain wetlands of Central Gujarat.

Aher and Nandan (2005) made an assessment of water quality of Mosam river of Maharashtra with relation to phytoplanktons. Senthikumar and Sivakumar (2008) studied physico-chemical parameters of Veeranam Lake in Cuddalore district of Tamil Nadu in relation to phytoplankton diversity. Pejaver et al. (2002) have carried out the ecological study on Ambegosale Lake and recorded high value of phosphates during monsoon and lower in summer months. They have reported high Carbon dioxide content during post monsoon and it was totally absent in monsoon month. Singh and Laura (2012) made an assessment of physico-chemical properties and phytoplankton density of Tilyar Lake, Rohtak (Haryana).

1. 10 Lakes and Environmental Threats to Lakes in India

International Glossary of Hydrology (UNESCO and WMO 2012) states that a lake is an "*Inland body of surface water of significant extent*". Kuusisto (1985) has described the lake as a depression or a group of depressions partly or fully filled by water, all parts of the water body have the same surface, excluding temporary variability, caused by wind or ice, the ratio between inflow and volume is small enough to let most of the suspended, inflowing material to form bottom sediments, and the surface area exceeds a given minimum value (1 hectare (ha) / 2.47 acre). The lakes with an extant less than 1 ha size can be defined as ponds though the minimum value for a pond has not been determined.

Water resources monitoring studies requires information on the natural conditions of the watershed area, pressure factors of the water bodies both in quantity and quality. The most important background information of the watershed area is as follows:

- Climate (seasons, temperature)
- Land use (for agricultural and forestry use, built environment)
- Population density of watershed area (inhabitants/km2)
- Waste water load (urban and industrial waste water etc.).

Lakes are more or less closed systems. Substances once introduced to the lake are permanently incorporated in the circulation. Only a part of them are removed (depending on water exchange rate). However, the rivers are considered as open systems with constant downstream transport of substances (Heinonen et. al. 2000).

The Indian lakes are no longer serene water bodies. Instead, they have become stinking cesspools, the result of continuous inflow of sewage and massive siltation. As

the lakes die a premature death, the question that arises is who is responsible for this sorry state of affairs and who is answerable for the health of the populace. Many lakes in India are heading towards disaster and the residents face the threat of an epidemic from water-borne diseases. Further, the lakes are facing environmental threats due to siltation and pollution. The siltation of the lakes has mainly occurred due to deforestation and disposal of sewage. Deforestation in the hills and forests washes down tons of silt into the lakes. The scale of encroachments and the level of siltation all depended on the intensity of the monsoons and the geography of the local catchments area.

The domestic sewage and wastewater from the hotels around the lakes is conveniently let into the lakes. The sewage system constructed around the lakes does not work and raw sewage is directly emptied into them. Solid domestic waste is also dumped close to the lakes. This finds its way into the lakes during the monsoons. Besides, people living around the lakes continuously attempt to extend their personal property by encroaching upon the lakes. In addition, the lakes are also used by the public for bathing and washing which includes infected linen from hospitals located near the lakes. A large amount of detergent goes into the water, increasing its phosphate content. Synthetic detergents are known to be corrosive, toxic, and slow to biodegrade and contribute to the growing levels of eutrophication in water bodies.

The lakes in India have become highly polluted primarily due to eutrophication. Their water spread too has either been replaced with silted land mass or covered with aquatic weeds which take a turn for the worse during summer. The continuing pollution has posed a serious threat to the quality and the effectively usable quantity of water from the lakes for the public water supply scheme, which is already handicapped by the absence of an alternative cost-effective water source. In addition, agriculture residues from village areas and solid waste, including construction debris from residential and commercial areas, also find their way into the lakes through the drains and streams, particularly during the rainy season. One of the serious impacts of the degradation of the lakes has been the gradual loss of a flood control system. There are frequent floods in the lakes every year and the water level remains high due to inflow from feeder drains, local drainage and springs from the lake-bed.