CHAPTER – 1

INTRODUCTION

1.1. GENERAL:

Lakes are a body of relatively still fresh or salt water of considerable size, localized in a basin that is surrounded by land. Lakes are inland and not part of the ocean and therefore are distinct from lagoons, and are larger and deeper than ponds. The word lake comes from Middle English lake ("lake, pond, waterway"), from Old English lacu ("pond, pool, stream"), from Proto-Germanic *lakō ("pond, ditch, slow moving stream"), from the Proto-Indo-European root *leg'- ("to leak, drain"). Cognates include Dutch laak ("lake, pond, ditch"), Middle Low German lâke ("water pooled in a riverbed, puddle"), German Lache ("pool, puddle"), and Icelandic lækur ("slow flowing stream"). Also related are the English words leak and leach.

Natural lakes, which abound on the earth, were formed by tectonic, volcanic, glacial, or other phenomena. The Pleistocene glaciations were by far the most important of the lake-producing processes. In more recent times, however, man has created numerous impoundments and reservoirs for a variety of purposes. A reservoir is defined as an impoundment with a mean annual minimum pool of 202 ha (500 a). Lakes are complex ecosystems with many species of animals and plants interacting with each other and their environment. Every lake is a unique body of water, reflecting many of the characteristics of the surrounding watershed and the climate, as well as the shape and volume of the lake basin. Water chemistry, physical characteristics, and biological communities in lakes vary seasonally, as well as by water depth, throughout the year. External factors such as sunshine, wind, air temperature and water inflows combine with internal forces such as
evaporation rates, currents, nutrient release from sediments, nutrient uptake by algae, and plant-animal interactions to produce an intricate web of relationships.

1.2. LIMNOLOGY:

The term limnology was coined by François-Alphonse Forel (1841–1912) who established the field with his studies of Lake Geneva. Interest in the discipline rapidly expanded, and in 1922 August Thienemann (a German zoologist) and Einar Naumann (a Swedish botanist) co-founded the International Society of Limnology (SIL, for originally Societas Internationalis Limnologiae). Forel's original definition of limnology, "the oceanography of lakes", was expanded to encompass the study of all inland waters.

Limnology is the study of inland bodies of water and related ecosystems. Limnology divides lakes into three zones: the littoral zone, a sloped area close to land; the photic or open-water zone, where sunlight is abundant; and the deep-water profundal or benthic zone, where little sunlight can reach. The depth to which light can reach in lakes depends on turbidity, determined by the density and size of suspended particles. A particle is in suspension if its weight is less than the random turbidity forces acting upon it. These particles can be sedimentary or biological in origin and are responsible for the color of the water. Decaying plant matter, for instance, may be responsible for a yellow or brown color, while algae may cause greenish water. In very shallow water bodies, iron oxides make water reddish brown. Biological particles include algae and detritus. Bottom-dwelling detritivorous fish can be responsible for turbid waters, because they stir the mud in search of food. A lake moderates the surrounding region's temperature and climate because water has a very high specific heat capacity (4,186 J·kg$^{-1}$·K$^{-1}$). In the daytime a
lake can cool the land beside it with local winds, resulting in a sea breeze; in the night it can warm it with a land breeze.

1.3. EUTROPHICATION IN LAKES:

Lakes can be classified by measurements of potential and actual biological activity, also known as "trophic state." Lakes with high concentrations of nutrients and algae, generally accompanied by low transparencies, are termed eutrophic or highly productive, because the algae grow and reproduce at a high rate. Lakes with low concentrations of nutrients and algae, most often accompanied by high transparencies, are categorized as oligotrophic or low in productivity. Lakes intermediate between eutrophic and oligotrophic are termed mesotrophic, or in the middle.

Each lake's productivity is influenced by a variety of natural factors, including watershed size and geology, lake depth and surface area, climate, catastrophic events such as earthquakes and volcanic eruptions, and the quality and quantity of water entering and leaving the lake. Lakes may be naturally eutrophic, mesotrophic, or oligotrophic based on the original character and stability of the surrounding watershed.

Increases in a lake's biological activity ("eutrophication") may occur naturally in some lakes, but can be hastened by human activities in others. At any particular time, lakes in a region may exhibit a wide range in algae levels without being impacted by human activity. Natural eutrophication is almost never observed in the scale of a human lifetime. However, effects of human-induced eutrophication can be seen in as little as a decade.
Land use activities, including home building, commercial and industrial development, agriculture, forestry, resource extraction, landscaping, gardening, and animal keeping all have the potential to contribute nutrients to surface and ground waters as well as cause change in sediment movement. Increases in impervious surfaces associated with land development also result in distinct changes in surface water runoff patterns. This surface water, as it enters lakes and streams, can increase biological productivity by increasing concentrations of nutrients that stimulate plant growth. Additional sediment input associated with increased surface water runoff can also impact lakes in various other ways.

Lakes in various trophic states are sometimes separated by the frequency of algal blooms and the type of algae present. Large amounts of algae can affect swimming, fishing, boating, wildlife, aesthetics, and other uses. Eutrophic lakes, for example, may have frequent nuisance algal blooms dominated by bluegreen algae (cyanobacteria). These blooms can form surface scums, give off noxious odors, and may occasionally produce toxins that have direct health impacts on animals as well as people.

Vigorous growth of rooted aquatic plants can also impact boating, fishing, and swimming. A lake need not be eutrophic to support a large amount of aquatic plant life. Many aquatic plants are rooted in the sediments, from which they draw nutrients. One very important factor is the depth to which light can penetrate in the lake, as well as how much of the lake bottom is within that depth range. Clear lakes with large areas of shallow water can support more aquatic plant growth than steep-sided or colored-water lakes.
1.4. TYPES OF LAKES:

Many lakes can have tremendous cultural importance. The West Lake of Hangzhou has inspired romantic poets throughout the ages, and has been an important influence on garden designs in China, Japan and Korea (UNESCO’s World Heritage List). The different types of lakes are defined and listed below;

A. Periglacial lake: Part of the lake's margin is formed by an ice sheet, ice cap or glacier, the ice having obstructed the natural drainage of the land.

B. Subglacial lake: A lake which is permanently covered by ice. They can occur under glaciers, ice caps or ice sheets. There are many such lakes, but Lake Vostok in Antarctica is by far the largest. They are kept liquid because the overlying ice acts as a thermal insulator retaining energy introduced to its underside by friction, by water percolating through crevasses, by the pressure from the mass of the ice sheet above or by geothermal heating below.

C. Glacial lake: a lake with origins in a melted glacier, such as a kettle lake.

D. Artificial lake: A lake created by flooding land behind a dam, called an impoundment or reservoir, by deliberate human excavation, or by the flooding of an excavation incident to a mineral-extraction operation such as an open pit mine or quarry. Some of the world's largest lakes are reservoirs like Hirakud Dam in India.

E. Endorheic lake, terminal or closed: A lake which has no significant outflow, either through rivers or underground diffusion. Any water within an endorheic
basin leaves the system only through evaporation or seepage. These lakes, such as Lake Eyre in central Australia or the Aral Sea in central Asia, are most common in desert locations.

F. Meromictic lake: A lake which has layers of water which do not intermix. The deepest layer of water in such a lake does not contain any dissolved oxygen. The layers of sediment at the bottom of a meromictic lake remain relatively undisturbed because there are no living aerobic organisms.

G. Fjord lake: A lake in a glacially eroded valley that has been eroded below sea level.

H. Oxbow lake: A lake which is formed when a wide meander from a stream or a river is cut off to form a lake. They are called "oxbow" lakes due to the distinctive curved shape that results from this process.

I. Rift lake or sag pond: A lake which forms as a result of subsidence along a geological fault in the Earth's tectonic plates. Examples include the Rift Valley lakes of eastern Africa and Lake Baikal in Siberia.

J. Underground lake: A lake which is formed under the surface of the Earth's crust. Such a lake may be associated with caves, aquifers or springs.

K. Crater lake: A lake which forms in a volcanic caldera or crater after the volcano has been inactive for some time. Water in this type of lake may be fresh or highly
acidic, and may contain various dissolved minerals. Some also have geothermal activity, especially if the volcano is merely dormant rather than extinct.

L. Lava lake: A pool of molten lava contained in a volcanic crater or other depression. Lava lakes that have partly or completely solidified are also referred to as lava lakes.

M. Former: A lake which is no longer in existence. Such lakes include prehistoric lakes and lakes which have permanently dried up through evaporation or human intervention. Owens Lake in California, USA, is an example of a former lake. Former lakes are a common feature of the Basin and Range area of southwestern North America.

N. Ephemeral lake, intermittent lake, or seasonal lake: A seasonal lake that exists as a body of water during only part of the year.

O. Shrunken: Closely related to former lakes, a shrunken lake is one which has drastically decreased in size over geological time. Lake Agassiz, which once covered much of central North America, is a good example of a shrunken lake. Two notable remnants of this lake are Lake Winnipeg and Lake Winnipegosis.

P. Eolic lake: A lake which forms in a depression created by the activity of the winds.

Q. Vlei, in South Africa, shallow lakes which vary considerably with seasons.
1.5. DISTRIBUTION OF LAKES:

There are about 500,000 lakes on Earth, storing volume of water equaling 103,000 cu. km. Most of the world's water lakes are found in North America (25%), Africa (30%) and Asia (20%).

1.5.1. WORLD LAKES:

Fresh water is an important natural resource necessary for the survival of all ecosystems. Fresh and unpolluted water accounts for 0.003% of total water availability in global scale (Nitti, Gianfranco; 2011). The world's total water supply about 332.5 million cubic miles of water, over 96% is saline (fig.1.1). And of the total freshwater, over 68% is locked up in ice and glaciers. Another 30% of freshwater is in ground. Fresh surface water sources, such as rivers and lakes only constitute about 93,100 cubic kilometers (22,300 cubic miles), which is about 1/150th of 1% of total water. Yet, rivers and lakes are the sources of most of the water consumed by the people everyday.

Globally, lakes are greatly outnumbered by ponds: of an estimated 304-million standing water bodies worldwide, 91 percent are 1 hectare (2.5 acres) or less in area (Downing JA et al; 2006). Small lakes are also much more numerous than large lakes: in terms of area, one-third of the world's standing water is represented by lakes and ponds of 10 hectares (25 acres) or less. However, large lakes contribute disproportionately to the area of standing water with 122 large lakes of 1,000 square kilometres (390 sq mi, 100,000 ha, 247,000 acres) or more representing about 29 percent of the total global area of standing inland water.
Introduction

Fig. 1.1. Distribution of total water available on Earth.

The majorities of lakes on Earth are fresh water, and most lie in the Northern Hemisphere at higher latitudes. More than 60 percent of the world's lakes are in Canada; this is because of the deranged drainage system that dominates the country. Finland is known as The Land of the Thousand Lakes, (actually there are 187,888 lakes in Finland, of which 60,000 are large) (Statistics Finland), and the U.S. state of Minnesota is known as The Land of Ten Thousand Lakes.

Most lakes have at least one natural outflow in the form of a river or stream, which maintain a lake's average level by allowing the drainage of excess water (Carreck, Rosalind, ed; 1982). Some lakes do not have a natural outflow and lose water solely by evaporation or underground seepage or both and they are termed as endorheic lakes. Many lakes are artificial and are constructed for hydro-electric power generation, aesthetic purposes, recreational purposes, industrial use, agricultural use or domestic water supply.

A. WORLD’S REMARKABLE LAKES:

a) Lake Michigan-Huron is the largest lake by surface area: 117,350 km². It also has the longest lake coastline in the world: 8,790 km. If Huron and Michigan are considered two lakes, Lake Superior is the largest lake, with 82,414 km². However, Huron still has the longest coastline at 6,157 km (2980 km excluding the coastlines of its many inner islands). The world's smallest geological ocean, the Caspian Sea, at 394,299 km² has a surface area greater than the six largest freshwater lakes combined, and it's frequently cited as the world's largest lake.
b) Lake Baikal and Lake Tanganyika that lie along continental rift zones and are created by the crust's subsidence as two plates are pulled apart. These lakes are the oldest and deepest in the world. Lake Baikal, which is 25-30 million years old, is deepening at a faster rate than it is being filled by erosion and may be destined over millions of years to become attached to the global ocean. The **deepest** lake is Lake Baikal in Siberia, with a bottom at 1,637 m. Its **mean depth** is also the greatest in the world (749 m). It is also the world's **largest lake by volume** (23,600 km³, though smaller than the Caspian Sea at 78,200 km³), and the second longest (about 630 km from tip to tip).

c) The **longest** lake is Lake Tanganyika, with a length of about 660 km (measured along the lake's center line). It is also the second largest by volume and second deepest (1,470 m) in the world, after Lake Baikal.

d) The world's **oldest** lake is Lake Baikal, followed by Lake Tanganyika (Tanzania).

e) The world's **highest** lake is the crater lake of Ojos del Salado, at 6,390 metres (20,965 ft) (Andes Website). The Lhagba Pool in Tibet at 6,368 m (20,892 ft) comes second.

f) The **highest large** freshwater lake in the world is Lake Manasarovar in Tibet Autonomous Region of China.

g) The world's **highest** commercially navigable lake is Lake Titicaca in Peru and Bolivia at 3,812 m (12,507 ft). It is also the largest freshwater (and second largest overall) lake in South America.

h) The world's **lowest** lake is the Dead Sea, bordering Israel and Jordan at 418 m (1,371 ft) below sea level. It is also one of the lakes with highest salt concentration.
i) The largest island in a freshwater lake is Manitoulin Island in Lake Huron, with a surface area of 2,766 km².

j) The largest lake located on an island is Nettilling Lake on Baffin Island, with an area of 5,542 km² and a maximum length of 123 km.

k) The largest lake in the world that drains naturally in two directions is Wollaston Lake.

l) Lake Toba on the island of Sumatra is located in what is probably the largest resurgent caldera on Earth.

m) The largest lake located completely within the boundaries of a single city is Lake Wanapitei in the city of Sudbury, Ontario, Canada. Before the current city boundaries came into effect in 2001, this status was held by Lake Ramsey, also in Sudbury.

n) Lake Enriquillo in Dominican Republic is the only saltwater lake in the world inhabited by crocodiles.

o) Lake Bernard, Ontario, Canada, is the largest freshwater lake in the world with no islands.

p) The largest lake in one country is Lake Michigan, in the U.S.A. However, it is sometimes considered part of Lake Michigan-Huron, making the record go to Great Bear Lake, Northwest Territories, in Canada, the largest lake within one jurisdiction.

q) The **largest lake on an island** is Crater Lake on Vulcano Island in Lake Taal on the island of Luzon, The Philippines.

r) The **northernmost named lake** on Earth is Upper Dumbell Lake in the Qikiqtaaluk Region of Nunavut, Canada at a latitude of 82°28’N. It is located only 5.2 kilometers southwest of Alert, the northernmost settlement in the world. There
are also several small lakes located north of Upper Dumbell Lake, but they are all unnamed and only appear on very detailed maps.

B. DISTRIBUTION OF LAKE BY CONTINENT:
The largest lakes (surface area) by continent are:

a) **Australia** – Lake Eyre (salt lake).

b) **Africa** – Lake Victoria, also the third-largest freshwater lake on Earth. It is one of the Great Lakes of Africa.

c) **Antarctica** – Lake Vostok (subglacial).

d) **Asia** – Lake Baikal (if the Caspian Sea is considered a lake, it is the largest in Eurasia, but is divided between the two geographic continents).

e) **Oceania** – Lake Eyre when filled; the largest permanent (and freshwater) lake in Oceania is Lake Taupo.

f) **Europe** – Lake Ladoga, followed by Lake Onega, both located in northwestern Russia.

g) **North America** – Lake Michigan-Huron, which is hydrologically a single lake. However, lakes Huron and Michigan are often considered separate lakes, in which case Lake Superior would be the largest.

h) **South America** – Lake Titicaca, which is also the highest navigable body of water on Earth at 3,821m above sea level. The much larger Lake Maracaibo is considered by some to be the second-oldest lake on Earth, but since it lies at sea
level and nowadays is a contiguous body of water with the sea, others consider that it has turned into a bay.

**1.5.2. LAKES IN INDIA:**

Important lakes of India are:

**a) Dal Lake:**

The Kashmir valley is gifted with exotic natural scenic beauty of its landscape and water bodies, which have given it the sobriquet “paradise on the earth”. These water bodies are of great ecological and socio-economic significance. The Dal Lake with its multi-faceted eco-system and grandeur has been inviting the attention of national and international tourists.

Dal Lake is one of the most beautiful lakes of India and is the second largest in the Jammu and Kashmir (J&K) state. Being located in the heart of the Srinagar City (latitude 34°18'N, longitude 74°91'E, average altitude of 1,583m), Dal can be considered to be an urban lake. Srinagar is the summer capital of J&K state. During winters when the temperature may fall to as low as -11°C, the top crust of the lake freezes. Early spring and summers are the wet periods when large rainfall occurs; the average annual rainfall at this place is 655mm. It is in this season that the snow melts in the higher catchment which results in high discharge in Dachigam and Dara Nallah which feed water into the lake. The maximum depth of the lake is reported to be in the range of 6 to 9m. The maximum area of the Dal Lake has been estimated to be 24sq.km out of which open water area is around 15.42sq.km. The Dal Lake basin can be classified into five basins, namely, 1. Nehru Park Basin, 2. Nishat Basin, 3. Hazratbal Basin, 4. Nagin Basin, and 5. Brari
Nambal Basin. All the basins are interconnected with navigation routes in the shape of intertwined waterways.

b) Surinsar Lake:
The Surinsar Lake is situated about 40 km to the north east of Jammu city at an elevation of 605 m above mean sea level and lies at 75° 02’ 30’’ E longitude and 32° 46’ 30 N latitude. It is a fine picturesque sweet water lake with a circumference of 2.496 km. The maximum length, breadth and depth of the lake are 888 m, 444 m and 24.05 m respectively. The water spread of the lake varies from 27.92 to 29.14 hectares. The water level of the lake oscillates by about 1.20 m and touches its peak during August. The excess water flows towards the western side of the lake and goes into a channel lying by its side.

c) Mansar Lake:
The Mansar Lake is located 55km east of Jammu at a latitude of 32° 41’ N and longitude of 75° 05’ E, 666 m above mean sea level with basin area of the lake is 1.67km². The maximum length and width of the lake is 1,204m and 645m respectively. The annual average rainfall in the catchment area of the lake is 1,500mm. The total volume of lake water is 12.37Mm³. The maximum depth of water in the lake is 38.25m. The slope of the lake varies with respect to depth, in between 0.0-5.75m depth slope is 0.21m/m, 5.57-10.75m depth is 0.30m/m (maximum) and 35.75-38.25m depth is 0.04m/m The Lake is fed by rainfall and groundwater.
d) Khajjiar Lake:
Khajjiar Lake and its surroundings are one of the most picturesque saucer shaped plateaus and a tourist attraction. The watershed is located at a height of 1,940 m in a valley between Dhauladhar and Pir Panjal ranges of the Himalayas. The watershed lies at latitude of 32.5° N and longitude of 76.1° E. The size of the lake is not large and is more or less like a pond of about 60 to 80m radius. The green pastures surrounding the lake are approximately 1.5km long and 1.0km wide. The lake region experiences a moist temperature climate. Precipitation is in the form of snow during January to March and rain during the south-west monsoon with annual average precipitation of 1.2m.

e) Nainital Lake:
The Nainital Lake is situated at an altitude of 1,937 m above sea level and is 1,433 m long and 423 m broad at its widest. The total surface area is about 4.65 ha and the volume is approximately 8.33 MCM. The catchment area of the lake is 3.6 km² ranging in height from 1,937 m to 2,600 m. The mean hillslope of the area is 19° where large part being confined to the slope group of 20° to 25° and the maximum slope reaching 47° to 49°. The average slope of the snow view Sherka Danda ridge is 18°, varying between 5° to 35°. At many places, the slopes exhibit convex bulges resulting from continuing creep movement. The slopes are locally broken by scarps and fringed at the base by a succession of debris cones and fans.

f) Harirke Lake:
A barrage was constructed in 1952 at Harike, at the confluence of Beas and Sutlej rivers at about 60km from Ferozpur, Punjab. Harike Lake came into being as a result of the construction of this barrage. The lake is located at latitude of 31° 10’ N and longitude of
74° 56' E, 210 m above mean sea level. In the beginning, the lake had water spread area of 41sq.km. It is one of the six most important wetlands in the country. Over the time, this lake began attracting migratory birds and became one of the famous birds sanctuary. However, later on, the fast spreading hyacinth plants have reduced the open water area to a mere 28sq.km, leaving little space for migratory birds. Growth of hyacinths in the Harike wetland has pushed it to the brink of an ecological disaster. About 70% of the lake water surface is covered with water hyacinth. The major problems, which are facing by the lake is acute soil erosion and silting.

**g) Loktak Lake:**

Loktak Lake had vast area of 2,000 km$^2$ in 1950 that reduced to 495 km$^2$ in 1971 and 289 km$^2$ in 1995. The maximum depth of lake has reduced from 29 m in 1950 to about 20 m in 1980. The lake is located between longitudes 93° 46' & 93° 55' E and latitudes 24° 25' &, 24° 42' N. It is a shallow water lake, the depth of which during dry season ranges between 0.5 m to 1.5 m. Main water body of the lake is surrounded by shallow water stagnating over marshy/swampy land on all sides. About 40% of the lake surface area is covered by different types of weeds both floating and submerged. Southern portion of Loktak Lake (south of Thanga, Ithing and Sendra islands/hills) forms the Keibul Lamjao National Park and is the only floating wildlife sanctuary in the world. It is composed of a continuous mass of floating *phumdi* occupying an area of 40 sq. km. The park is the only natural habitat of the most endangered mammal, the brow-antlered deer (*Cervus eldi eldi*).
Chilika Lake:

Chilika is the largest brackish water lagoon that sprawls along the east coast of India in the Mahanadi delta. It is a tidal lagoon created by a beach barrier berm that developed by the accretion of the coastal sediments following the stabilization of sea levels about 3,000 to 4,000 years ago. The pear shaped lagoon has a maximum length of 64 km and an average width of 20 km. The water depth generally fluctuates between 50 cm and 3.7 m. The water-spread area of the Lagoon varies between 906 and 1,105 sq. km. A 35 km long, narrow outer channel connects the main lagoon to the Bay of Bengal, near the village Motto. The mouth connecting the channel to the sea is close to the northeastern end of the Lagoon. High tide near this inlet mouth drives in salt water through the channel during the dry months from December to June. With the onset of the rains, the rivers falling into the northern zone bring in fresh water currents that gradually push the seawater out. As a result of these, the inlet mouth constantly changes its position. The inlet channel is connected with Chilika at Magarmukh. The other connection with the Bay of Bengal is through Palur Canal on the southeastern side. Several islands are located in the Lagoon covering an area of 223 sq. km, which include hills situated both inside and around the lagoon.

Pushkar Lake

Pushkar is a famous pilgrimage center of Rajasthan. It is one of the few places on the Earth where Lord Brahma (the creator of the universe) is worshipped. The city has lent its name to the lake that lies inside it. In ancient times, the lake had a waterspread of over 71 bighas. However, of late, the Pushkar Lake is dying due to a variety of reasons. On an average the lake attracts 5,000 pilgrims daily. People from all over the country converge here to wash off their sins and immerse the ashes of their dead. The depth of water has
plunged to just 1.5 m from a depth of 9 m observed in the late nineteen eighties. The condition of the depth lake is so bad that it can no longer sustain life. In the recent past, fish, weighing five to twenty kilograms, have died in the viscous brown depths of the lake due to the lack of oxygen.

**Kolleru Lake**

The scenic Kolleru Lake, situated in the Krishna and West Godavari districts of Andhra Pradesh, 50 km east of Vijaywada at latitude of 16° 30’ N and longitude of 81° 15’ E, 0 to 5 m above mean sea level, is spread over an area of more than 900 sq. km. The lake area is about 1090 km² at the time of maximum flooding. The lake has a maximum depth of more than 3.5 m when full during the rainy season and a minimum depth of 1 m during summer. Kolleru Lake is one of the largest freshwater inland lakes in the world and is one of the largest bird sanctuaries, home to nearly 188 species of birds. It is also the world's largest natural freshwater fish producer and it produces about 30,000 tonnes per year.

**Udhagamandalam and Kodaikanal Lakes**

Due to growing human activity in the hilly regions and associated functions, such as intensive agriculture, animal husbandry and opening of commercial establishments, the Udhagamandalam (Ooty) and the Kodaikanal (Kodai) Lakes of Tamil Nadu have come under enormous pressure. The Ooty Lake is an artificial lake which was constructed by John Sullivan, the first collector of Ooty. Originally it was intended to be an irrigation tank but during the years 1823-1825, it was dredged and enlarged. This lake is a big tourist attraction and supports water-based recreation. Over the years, increasing siltation and eutrophication have inflicted enormous damage to these lakes.
1.5.3. EXTRA-TERRESTRIAL LAKES:
At present the surface of the planet Mars is too cold and has too little atmospheric pressure to permit the pooling of liquid water on the surface. Geologic evidence appears to confirm, however, that ancient lakes once formed on the surface. It is also possible that volcanic activity on Mars will occasionally melt subsurface ice, creating large lakes. Under current conditions this water would quickly freeze and sublimate unless insulated in some manner, such as by a coating of volcanic ash.

Only one world other than Earth is known to harbor lakes, Saturn's largest moon, Titan. Photographs and spectroscopic analysis by the Cassini–Huygens spacecraft show liquid ethane on the surface, which is thought to be mixed with liquid methane.

Jupiter's small moon Io is volcanically active due to tidal stresses, and as a result sulfur deposits have accumulated on the surface. Some photographs taken during the Galileo mission appear to show lakes of liquid sulfur on the surface (The Nine Planets Solar System Tour.).

There are dark basaltic plains on the Moon, similar to lunar maria but smaller, and are called lacus (singular lacus, Latin for "lake") because they were thought by early astronomers to be lakes of water.

1.6. SCOPE AND SIGNIFICANCE OF THE PRESENT STUDY:
Extensive surveillance, monitoring, and research activities are required to assess the extent and severity of sediment contamination, to evaluate the effects of contaminated
Introduction

sediments on freshwater environment, and to prepare a plan for appropriate remedial action. Analysis of sediments provides environmentally significant information and their chemical characterization is needed to understand the natural and anthropogenic influence on the bodies of water. Many different sources and processes influence the patterns of metal deposition in a sediment core, making it a challenge to interpret the historical records. The multi-element approach, which includes the analysis of more elements than just those of anthropogenic concern, will help to provide insight into the history of the lake and assists in the interpretation of natural versus anthropogenic inputs.

The history of the impact of man on the environment is apparent in many places the greatest impact has been affected within the last 150 years (Krishnamoorthy, 2003). Lakes and estuaries sediments provide a basis for reconstructing many aspects of this impact, for estimating rate of sedimentation change and for estimating a baseline in environmental monitoring programme (Eakins, 1983; Walling and He, 1993). In such studies, the establishment of accurate chronologies of sedimentation is of very importance not only for dating events but also for determining sediment accumulation rates. Furthermore, sedimentation rates based on palynological or stratigraphical methods often provide historical averages involving many meters of the sediment. Such measures may not reflect adequately the rates within upper 20 to 40 cm where significant sediment–water exchange occurs. Isotopic study will also assist in the understanding of geochemical sequestration of quantities of pollutant species and to compute the rate of sedimentation.

The results to be generated from this study will provide benefits to the Veeranam lake area and to the larger scientific community. This study will determine the sedimentation
rates in Veeranam Lake and reconstructs the sedimentation history of the lake over the past 100 years, including temporal variability and disturbances. Locally this study will provide data for educators and help managers to implement management strategies to reduce sedimentation, understand the environmental history of Veeranam lake and provide an estimate on the amount and characteristics of fine-grained sediment. It will also aids to understand how the Veeranam lake will affect downstream water quality by estimated amount of sediments trapped from upstream sources. The roles of limnological and hydrological properties of the lakes, external loading, as well as the land use of the catchment area and their importance to lake management activities are to be understood. In a broader context, this study will help further to understand the spatial distribution of sediments in this lake, which will help to understand sedimentation related issues in Veeranam lake. Additionally the uses of lake sediments are acts as environmental indicators and as a way to understand the environmental history of a lake. Hence, the following objectives are formulated;

1.7. OBJECTIVES OF THE PRESENT STUDY:
The broader objectives of the present study are outlined below:

1. To identify the morphological characteristics of the lake.
2. To determine the Textural characteristics of the sediment and comprehend the depositional environment.
3. To determine the rate of sedimentation.
4. To determine the chemical characteristics of sediments and to asses the changes in sediment contaminant levels over time.
5. To create geo-spatial distribution pattern of the sediment geochemistry.
6. To identify the relationship between land use pattern and its relation to the sediment chemistry.

1.8. STUDY AREA:

Veeranam Lake was created during Chola period in the tenth century, built from 1011 to 1037AD and is an 16-kilometre (9.9 mi) long dam in northern Tamil Nadu. Veeranam Lake gets water from Coleroon (Cauvery) via Vadavar River. Water released from the Mettur dam through Coleroon and Lower Anicut would also bring in sufficient inflow into the Veeranam Lake. With heavy rain in Western Ghats, the lake almost got its storage capacity as it received inflow from the Cauvery tributaries Bhavani and Amaravathi. The Veeranam Lake formerly known as Veeranaaraayanapuram Lake and in the opening chapter of the book Ponniyin Selvan is set on the banks of the Veera Narayanar Lake, the author Kalki gives an elaborate description of the features of the lake and the way multiple rivers flow into the lake. He also makes a reference to the fact, that Ramanujacharya decided on the number of peetas based on the number of openings in the lake.

1.8.1. GEOGRAPHIC EXTENT:

Veeranam Lake is located 14 km (8.7 mi) SSW of Chidamabaram in Cuddalore district in the state of Tamil Nadu in South India. The lake falls between north latitudes 11° 15 to 11° 15 N and east longitudes 79° 30 to 79° 35 E (fig.1.2). It falls in the geological survey of India toposheet no. 58 M/11. The lake is bounded by Vellar River in the north and Coleroon River in the south. It has good network of roads and railways.
Fig. 1.2. Geographic location of Veeranam Lake.
1.8.2. PHYSIOGRAPHY:
The general slope of the study area is towards southeast. The study area is almost a plain coastal area and river alluviums exist on most of its part with slightly high ground of Tertiary sediments. The alluvium consists of materials, which might have been deposited due to weathering action of wind, river etc. The Tertiary formation includes lateritic sandstone, sand (variegated), clayey sands, clay etc.

The maximum elevations of ground surface are marked by 125 feet contour lines, and the minimum elevation of ground surface in the adjoining area is below 50 feet. Generally, in the Tertiary area, the elevation is between 25 and 50 feet. In the alluvial area, the elevation is below 50 feet. The two major physiographic units are generally observed namely, 1. Coastal plain and 2. Alluvial plain.

1.8.3. METEOROLOGY:

Climate: The Lake Veeranam enjoys tropical climate. The maximum and minimum temperature for the study area is 37.2 °C and 20.6°C in June and January respectively. The highest and lowest temperature recorded is 43.3 °C and 11.1°C respectively.

Humidity: Relative humidity of region is 87% on higher end and 67% on the lower end. The relative humidity during April and June is higher than other months. Higher rates of relative humidity are observed during the North East Monsoon period and low in summer.

Wind: Wind prevailing in the region is generally moderate in strength with mean velocity variation from 6 to 14 Km/hr. Wind speed is higher in May and lowers in
October. South westerly wind prevails over 33% of days in a year and North easterly wind over 32% of the days.

**Rainfall:** The study area is benefited by the influence of SouthWest monsoon stretching from June to September and the North East monsoon from October to December. The winter and hot seasons (January to May) form the transition period and the rainfall is scanty. The long-term average rainfall is 1160.36mm. A perusal of the data reveled that the northeast monsoon is more effective and contributing 53.01% and is usually associated with storms from the Bay of Bengal, while the southeast monsoon is moderate contributing 32.66% of total Rainfall.

**1.8.4. GEOLOGY:**
Detailed mapping of Cretaceous and Tertiary deposits in and around Lake Veeranam area was initiated by Arokyasamy, 1967; Sundaram, 1979. The exploratory work carried out by oil and natural gas corporation (ONGC) and agencies like, Neyveli Lignite Corporation (NLC) etc., was also significant. In the study area, the basement Archean rock consist predominantly of bluish grey granite and gneiss, this older formation are overlined by Cretaceous and Tertiary sediments towards east. Eastern part of study area is underlined by recent alluvium of 50 m thick (fig.1.3). Cuddalore formation of Mio-Pliocene age consist chiefly of sandstone and extensive clay layer with a thick band of lignite seam crops out in western part of the study area, striking NE and SW and dipping towards the SE.

The area is broadly divided into five geological domains,

1. Younger sedimentaries of Mio-Pliocene age,
Fig. 1.3. Geology map of study area.
2. Lateritic soil cover over Mio-Pliocene sediments in the western part,
3. Coastal plains in the east fringing with Bay of Bengal and

**A) Tertiary:**

The Tertiary rocks comprise the Cuddalore formation, consisting of cobble and pebbly sandstone, mottled sandstone, ferruginous sandstone with bands and lenses of clay, besides lignite seams. The Cuddalore sandstone is gritty, consisting of quartz cemented in clay matrix and is inter-bedded with thin, lenticular bodies of white clay. The sandstone is characterized by ferruginous materials and is of yellowish red, pink and purple in colours. The alternate formations of sandstone and clay dip towards east with low angle and creating an artesian condition in the Tertiary formations. A small patch of lateritic soil is demarcated on the top of Cuddalore Formation in the central part of the area. Krishnan (1982) has suggested a Mid-Pliocene age for the laterisation of the Cuddalore sandstone. Elsewhere in other parts of the Coramandal coast especially based on artifacts, the lateritic surface has been assigned a Mid-Pleistocene age (Subramanian, 1979). These are over lined by the Quaternary (fluvial, marine, and aeolian) formations along the coast as well as the river course.

The Cuddalore sandstone is named after the town Cuddalore where it has a good exposure. It has a length of 56 km in ENE – WSW and 26 km in NNE – SSW direction. Outcrops of Cuddalore series commence as far North as Midnapur in West Bengal from where they are noticed in a number of more or less discontinued inliers. In the study area, it is hidden under ferruginous, argillaceous and gritty alluvium of Coleroon and Vellar riverbed.
It comprises the fossils like *Terebra, Conus, Cencellaria, Oliva, Mitra, Fusus, Buccinum, Nassa, Murex, Triton (Gastropod), Ostrea* and *Foraminifera* of several species (Wadia, 1985). In Neyveli and Jayankondam it is inter-bedded with the valuable lignite deposits.

**B) Quaternary:**

The river Vellar and Colleroon have built up extensive alluvium consisting of admixtures of sand and silt in the delta portions in and around Chidambaram. The extent of alluvium and its depth varies greatly as there are number of exposures in the river almost in the eastern part of the study area and sea shore. They are fine to medium-grained sands with or without consolidation. The thickness varies from 10 to 15m below ground level in the river courses. Several abandoned channel and buried courses are also indicated in the delta portion that consists of medium to coarse-grained sand and silt with appreciable porosity and permeability. The borehole data of Central Ground Water Board clearly indicate that the alluvium, stretched over the older flood plain sediments are of Tertiary formations.

A greater part of the study area is covered by alluvial formations belonging to the Quaternary age comprising of grey, brown, black clays and sands under fluvial regime, black clay and medium sands under fluvio-marine regime, grey brown sand, black clay and sands under marine regime and medium to fine grained sand under aeolian regime.

**C) Structure:**

The Cuddalore sandstone is dipping $2^0$ to $5^0$ E (Subramanian, 1969). The recent alluviums are horizontal in nature. The alluvial sands show cross bedding, the beddings
are of low angle. The prominent mega lineament identified in the western part and confirmed as fault zone includes NE – SW trending boundary fault of crystalline – sedimentary contact.

1.8.5. SOILS:
Soils of the study region are classified as the black, red, ferruginous and arenaceous. They are again subdivided into clays, loam and sands. The soils derived from the Cuddalore sandstones, laterites and lateritic gravels are of red sandy type. Younger alluvial soils are found in small patches along the river and stream courses.

1.8.6. NEW VEERANAM PROJECT:
The Veeranam project, to supply water to Chennai, was conceived in 1967 by the then Chief Minister of Tamil Nadu, Dr.C. N. Annadurai, and executed under his successor, Dr.M. Karunanidhi. The project was subject to stagnation and has been completed in 2004 by chief minister of Tamilnadu Miss.J.Jayalalitha. Ironically it was impossible to use any water from the lake since it had run dry, and the face-saving proposal adopted by the authorities was to dig 45 deep borewells around the area and pump the resulting water 235 km to Chennai via the pipeline. While the new direction the project took was heavily criticized by local farmers and conservationists fearing depletion of the ground water resulting from the borewells, the fears have been unfounded and for the most part the lake and the surrounding borewells have been able to provide between 50 - 180 mld (million litres daily). The lake has a capacity to store about 1,465 mcft of water. Though the level in the Veeranam Lake has dipped to 323 million cubic feet (mcft), the same amount of 180 mld (million litres a day) was being drawn for chennai city supply.
1.9. ORGANISATION OF THE THESIS:

The thesis is organized into eight chapters;

1. The **first chapter** is the introductory part dealing with the importance, objective, significance and scope of the study.
2. The **second chapter** is literature review related to our study.
3. The **third chapter** elaborates the method of sample collection and laboratory techniques involved, flow diagram and the methodology for each analysis.
4. The **fourth chapter** elaborates detailed analysis of morphometric parameters of both, surface and subsurface dimensions of the Veeranam Lake.
5. The **fifth chapter** elaborates the grain size distribution, textural characteristics and sedimentary depositional environment of Veeranam lake sediments.
6. The **sixth chapter** deals with the rate of sedimentation in Veeranam Lake.
7. The **seventh chapter** deals with the spatial and temporal variation in geochemical characteristics of lake sediments.
8. The **eighth chapter** deals with the summary and conclusion of the study.