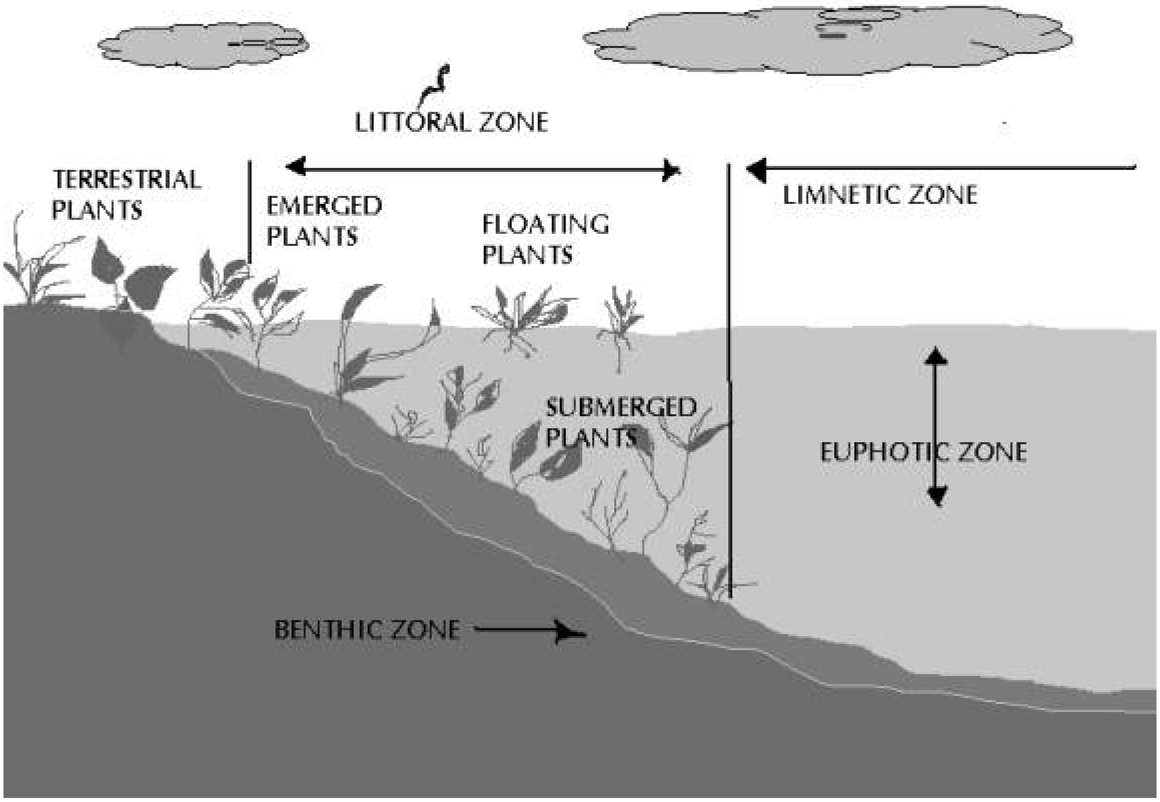
ECOLOGICAL ASSESSMENT OF LENTIC WATER BODIES OF BANGALORE

T. V. Ramachandra **Malvikaa Solanki**



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Environmental Information System [ENVIS]
Centre for Ecological Sciences,
Indian Institute of Science,
Bangalore - 560012, INDIA

Web: http://ces.iisc.ernet.in/energy/
http://ces.iisc.ernet.in/biodiversity

Email: cestvr@ces.iisc.ernet.in,
energy@ces.iisc.ernet.in

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SUMMARY:

The restoration, conservation and management of water resources require a thorough understanding of what constitutes a healthy ecosystem. Monitoring and assessment provides the basic information on the condition of our waterbodies. The present work details the study carried out at two waterbodies, namely, the Chamarajasagar reservoir and the Madiwala Lake. The waterbodies were selected on the basis of their current use and locations. Chamarajasagar reservoir serves the purpose of supplying drinking water to Bangalore city and is located on the outskirts of the city surrounded by agricultural and forest land. On the other hand, Madiwala lake is situated in the heart of Bangalore city receiving an influx of pollutants from domestic and industrial sewage. Comparative assessment of the surface water quality of both were carried out by instituting the various physico–chemical and biological parameters. The physico-chemical analyses included temperature, transparency, pH, electrical conductivity, dissolved oxygen, alkalinity, total hardness, calcium hardness, magnesium hardness, nitrates, phosphates, sodium, potassium and COD measurements of the given waterbody. The analysis was done based on the standard methods prescribed (or recommended) by (APHA) and NEERI. The biological parameter included phytoplankton analysis.

The detailed investigations of the parameters, which are well within the tolerance limits in Chamarajasagar reservoir, indicate that it is fairly unpolluted, except for the pH values, which indicate greater alkalinity. This may be attributed to the natural causes and the agricultural runoff from the catchment. On the contrary, the limnology of Madiwala lake is greatly influenced by the inflow of sewage that contributes significantly to the dissolved solids of the lake water, total hardness, alkalinity and a low DO level. Although, the two study areas differ in age, physiography, chemistry and type of inflows, they still maintain a phytoplankton distribution overwhelmingly dominated by Cyanophyceae members, specifically *Microcystis aeruginosa.* These blue green algae apparently enter the waterbodies from soil, which are known to harbour a rich diversity of blue green flora with several species common to limnoplankton, a feature reported to be unique to the south Indian lakes.

Chamarajasagar water samples revealed five classes of phytoplankton, of which Cyanophyceae (92.15 percent) that dominated other algal forms comprised of one single species of *Microcystis aeruginosa.* The next major class of algae was Chlorophyceae (3.75

percent) followed by Dinophyceae (3.51 percent), Bacillariophyceae (0.47 percent) and a sparsely available and unidentified class (0.12 percent).

Madiwala Lake phytoplankton, in addition to Cyanophyceae (26.20 percent), revealed a high density of Chlorophyceae members (73.44 percent) dominated by *Scenedesmus sp.*, *Pediastrum sp.,* and *Euglena sp.,*which are considered to be indicators of organic pollution. The domestic and industrial sewage, which finds its way into the lake, is a factor causing organic pollution. As compared to the other classes, Euglenophyceae *and* Bacillariophyceae members were the lowest in number.

Thus, the analysis of various parameters indicates that Chamarajasagar reservoir is relatively unpolluted except for the high percentage of *Microcystis aeruginosa,* and a slightly alkaline nature of water. Madiwala lake samples revealed eutrophication and high levels of pollution, which is clarified by the physico–chemical analysis, whose values are way above the tolerance limits. Also, the phytoplankton analysis in Madiwala lake reveals the dominance of Chlorophyceae members, which indicate organic pollution (sewage being the causative factor).

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

INTRODUCTION

Mismanagement of natural resources coupled with an ever increasing population has been responsible for introducing many undesirable modifications to aquatic environments. Most of the freshwater resources are under the stress of urbanisation and large-scale industrialisation. The development of new environmental problems as a result of this has given rise to new ideas in the field of monitoring and assessment of aquatic ecosystems. The overall condition or health of aquatic ecosystems is determined by the interaction of all its physical, chemical and biological components, which make up its ecosystem. Information on and understanding of environmental change is necessary to allow for the protection and remediation of ecosystems. Ecological assessment considering all components of the ecosystem helps in arriving at appropriate conservation strategies and restoration methods towards the conservation, management and sustainable use of natural resources.

1.1 WATER

Water is the most abundant substance, covering more than 70 percent of the earth's surface and existing in many places and forms: mostly in the oceans and polar ice caps, but also as clouds, rain water, rivers, freshwater aquifers, and sea ice. Water is also found in the ground and in the air we breathe and is essential to all known forms of life. It makes up two thirds of our bodies. In fact, between 50 and 90 per cent of the weight of any living being is water. Great civilisations have risen where water supplies were plentiful, such as on the banks of rivers and major waterways; Mesopotamia, the so-called cradle of civilization, was situated between two major rivers. Large metropolitans like London, Paris, New York, and Tokyo owe their success in part to their easy accessibility via water and the resultant expansion of trade. Water is used for domestic purposes for cleaning, cooking bathing, and carrying away wastes, and in agriculture for irrigation, power generation, industries, navigation, recreation and many other reasons. On the planet, water is continuously moving through the cycle involving evaporation, precipitation, and runoff to the sea, thus influencing the earth's climate.

Water is in a constant state of motion as explained in the hydrological cycle shown in figure 1.1. The very act of condensation usually requires a surface, or nuclei, water may acquire impurities at the very moment of condensation. Additional impurities are added as the liquid travels through the remainder of the hydrological cycle and comes in contact with materials in the air and on or beneath the surface of the earth. Human activities contribute further to the impurities in the form of industrial and domestic wastes, agricultural chemicals and other less obvious contaminants. However, it is the water quality in the intermediate stage, which is of greatest concern, because it is the quality at this stage that affects human usage.

With the onset of industrialisation and the green revolution, the world's oceans and other freshwater resources have been increasingly contaminated with sewage, agricultural chemicals, oils, heavy metals, radioactive materials, detergents and many other products of the human settlements. As the earth's population continues to increase rapidly, the growing human need for freshwater is leading to a global water resources crisis. There is a growing consensus that if current trends continue, water scarcity and deteriorating water quality will become critical factors limiting the future economic development, the increase of food production, the provision of basic health and hygiene services to millions of disadvantaged people in the developing countries. Although, rivers have been used to satisfy the daily needs of the living world, humankind has been exploiting this scarce resource to the hilt. The world is heading towards a freshwater crisis mainly due to the mismanagement of natural resources. This crisis is already evident in many parts of the world, varying in scale and intensity. UNESCO's World Water Development Report (WWDR, 2003) from its World Water Assessment Program indicates that, in the next 20 years, the quantity of water available to everyone is predicted to decrease by 30%. 40% of the world's inhabitants currently have insufficient freshwater for minimal hygiene. More than 2.2 million people died in 2000 from diseases related to the consumption of contaminated water or drought.

In this context, the conservation and restoration of this precious resource is gaining importance and calls for integrated management approaches. The water resources have been grossly mismanaged to accommodate the various human needs resulting in declined water quality and considerable loss of water resources. The various impacts due to anthropogenic activities need to be assessed at regular intervals for its restoration and conservation. Recognising the importance of water resources to the planet's future, the United Nations General Assembly proclaimed the year 2003 the 'International Year of Freshwater.' To understand the importance of water, the implications of its mismanagement and to facilitate strategies to manage, restore and conserve this fast degrading natural resource, it becomes essential to understand its ecological status and certain processes associated with water.

1.1.1 HYDROLOGIC CYCLE - THE SUN POWERED CYCLE

Water on the earth is in motion through the hydrological cycle. The endless circulation of water from the atmosphere to the earth and its return to the atmosphere through condensation, precipitation, evaporation and transpiration is called the hydrological cycle. The hydrological cycle depicted in Figure 1.1, illustrates the movement of water through the atmosphere to lithosphere and back into the atmosphere. As water is heated by the sun, it's surface molecules become sufficiently energised to break free of the attractive force binding them together, and then *evaporate* and rise as invisible vapour in the atmosphere.

As water vapour rises, it cools and eventually *condenses*, usually on tiny particles of dust in the air (aerosols) and forms clouds.

Precipitation in the form of rain, snow and hail comes from clouds. Clouds move around the world, propelled by air currents. The precipitation may be *intercepted* before it reaches the ground by tress and vegetation on leaves and branches, buildings, etc. which is subject to constant evaporation and part of it trickles down into the ground. Once, the water trapped in the plants is evaporated, water in the soil and saturated zone moves upward in a plant and eventually to the atmosphere through leaves. This process is known is *evapo-tranpiration*. The precipitation that reaches the soil surface may be absorbed by the soil through *infiltration* (seepage) and percolates further down. The water that enters the soil is known as *sub surface water* that increases the soil moisture and flows through the soil. Once the soil is saturated, overland flow begins and is often referred as *surface runoff*. Runoff is the visible flow of water in streams, rivers, creeks, etc. Some of the precipitation and snow melt moves downward *percolates* or *infiltrates* through cracks, joints and pores in soil and rocks until it reaches the saturated zone, where it becomes *groundwater*. Subterranean water is held in cracks and pore spaces.

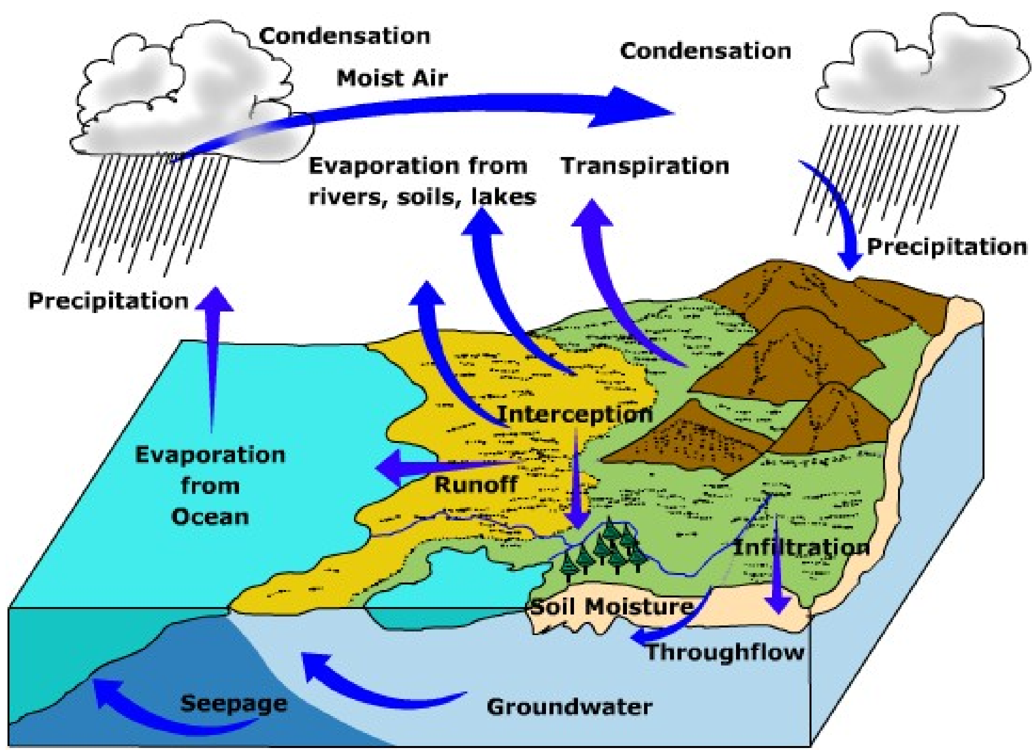
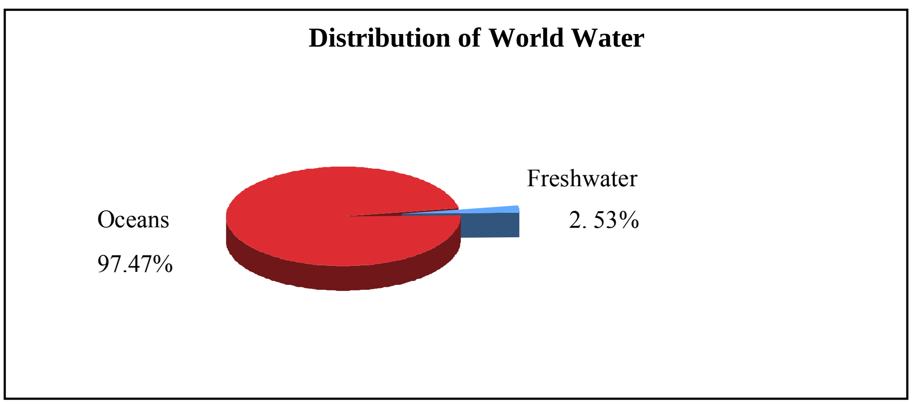


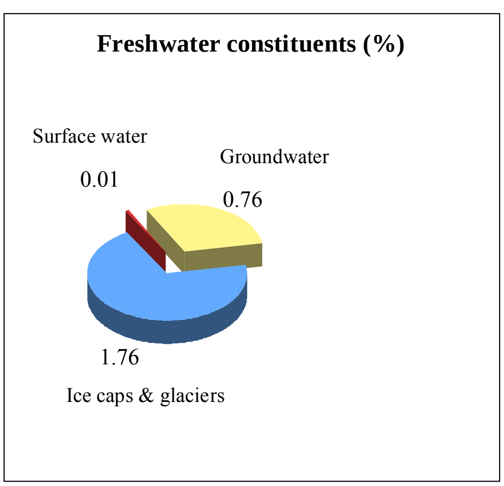
Figure 1.1: Hydrological Cycle

Depending on the geology, the groundwater can flow to support streams. Some groundwater aquifers are very old and may have been there for thousands of years. During the monsoons, overland flow contributes to the streams while during the non-monsoon season, the stream flow is contributed by the sub-surface flow (i.e. water stored in the vadose or sub-surface zone) and the base flow (groundwater). Water leaves the atmosphere and falls on earth as precipitation where it enters surface waters or percolates into groundwater zone via sub-surface vadose zone and eventually gets back to the atmosphere by transpiration and evaporation or as base flow in streams. Various factors influence the distribution of water on earth, leading to issues of water shortages and distribution for human consumption.

1.1.2 DISTRIBUTION OF WATER ON EARTH

Although the earth has enormous amount of water, it is not evenly distributed on the earth. As much as two-thirds of the earth is surrounded by water. Of the total water found on earth, 97.47 percent is deposited in the oceans, seas, lakes and rivers, the most important freshwater resources, account for a measly 2.53 percent (figure 1.2). The amount of fresh-water on earth is very small compared to seawater (oceans), of which 69.6% is locked away in continental ice, 30.1% in underground aquifers, and 0.26% in rivers and lakes. Lakes in particular occupy less than 0.007% of the world's freshwater.





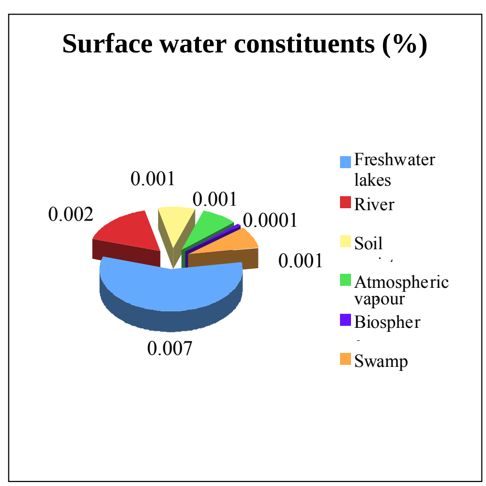


Figure 1.2: Distribution of world water resources (Ramachandra .T.V, 2002[1])

Of whatever little freshwater is available on earth, most of them are tied up in difficult to use forms such as glaciers and deep groundwater. Wetlands are estimated to occupy nearly 6.4% of the earth's surface, 30% of which is made of bogs, 26% fens, 20% swamps, about 15% flood plains, etc. (IUCN, 1990[2]). The distribution of the world water resources compiled from various sources is listed in Table 1.1(Ramachandra .T.V, 2002[1]).

Table 1.1: Distribution of world's water resources

Water resources	***% Total water***	***% Fresh-water***
Oceans	97.47	-
Freshwater	2.53	-
Ice caps and glaciers	1.76	69.13
Groundwater	0.76	30.07
Wetlands (marshes, swamps, lagoons, flood plains, etc.)	0.0001	0.0039
Lakes (excluding saline lakes)	0.007	0.27
Rivers	0.0002	0.0079

1.1.3 WATER RESOURCES IN INDIA

India by virtue of its geographical position and varied terrain and climatic zones, is blessed with many rivers, which supports a rich diversity of inland and coastal waterbodies. The annual precipitation including snowfall, which is the main source of water in the country is estimated to be of the order of 4000 cu.km. For the purpose of monitoring rainfall, the country has been divided into 35 meteorological sub-divisions. The resources potential of the country, which occurs, as natural run-off in the rivers is about 1869 cu.km as per the basin wise latest estimates of Central Water Commission, considering both surface and groundwater as one system. Ganga-Brahmaputra-Meghna system is the major contributor to the total water resources potential of the country. Its share is about 60 percent in the total water resources potential of the various rivers (National Informatics Centre [3]).

India's geographical area of about 329 m.ha is crisscrossed by a large number of small and big rivers (National Informatics Centre[3]) and mountains. There are 12 major rivers, whose total catchment area is 252 million hectare (m.ha). Of these major rivers, the Ganga - Brahmaputra - Meghana system is the biggest with a catchment area of about 110 m.ha, which is more than 43 percent of the catchment area of all the major rivers in the country. The other major rivers with catchment area more than 10 m.ha are Indus (32.1 m.ha.), Godavari (31.3 m.ha.), Krishna, (25.9 m.ha.) and Mahanadi (14.2 m.ha). The catchment area of medium rivers is about 25 m.ha and Subernarekha with 1.9 m.ha catchment area is the largest river among the medium rivers in the country (National Informatics Centre[3]).

Inland Water resources of the country are further classified as rivers and canals, reservoirs, tanks and ponds, beels, oxbow lakes, derelict water and brackish water. Other than rivers and canals, total waterbodies cover all area of about 7 m.ha. Most of the area under tanks and ponds lies in the southern part of the States of Andhra Pradesh, Karnataka and Tamil Nadu. These states along with West Bengal, Rajasthan and Uttar Pradesh, account for 62 percent of total area under tanks and ponds in the country. As far as reservoirs are concerned, major states like Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Orissa, Rajasthan and Uttar Pradesh account for larger portion of area under reservoirs. More than 77 percent of area under beels, oxbow lakes and derelict water lies in the states of Orissa, Uttar Pradesh and Assam. Orissa ranks first as regards the total area of brackish water and is followed by Gujarat, Kerala and West Bengal. The total area of inland water resources is, thus, unevenly distributed over the country with five states, namely, Orissa, Andhra Pradesh, Gujarat, Karnataka and West Bengal accounting for more than half of the country's inland waterbodies.

A survey conducted by the Ministry of Environment and Forests (MoEF) in 1990 showed that wetlands occupied an estimated 4.1 million hectares of which 1.5 million hectares were natural and 2.6 million hectares man-made (excluding paddy fields, rivers and streams) and mangroves occupying an estimated 0.45 million hectares. About 80% of the mangroves were distributed in the Sunderbans of West Bengal and Andaman and Nicobar Islands, with the rest in the coastal states of Orissa, Andhra Pradesh, Tamil Nadu, Karnataka, Kerala, Goa, Maharashtra and Gujarat. A preliminary inventory by the Department of Science and Technology, recorded a total of 1193 wetlands, covering an area of about 3,904,543 ha, of which 572 were natural (Scott and Pole, 1989[4]).

1.1.4 THREATS TO WATER RESOURCES

Most often human interactions with water involve fresh streams, rivers, marshes, lakes, and shallow groundwaters. As is true of all organisms, our very existence depends on this water; we need an abundance of fresh water to live. Globally, there are increasing problems related to the availability of freshwater. Less than 1% of all water on Earth is available for human consumption (figure 1.2). This precious resource is not only being overexploited but also is seriously degraded due to anthropogenic activities involving indiscriminate disposal of pollutants in waterbodies, which has rendered it unfit for sustenance of life. According to the United Nations Environment Program (UNEP), close to one quarter of the world’s population may soon suffer from chronic water shortages.

The most significant threats to water resources are from point sources (sewage, industrial effluents, etc.) and from non-point sources (agriculture, urban, etc.) Apart from these, dumping of solid wastes, chemical spills, thermal pollution, acid precipitation, mine drainage, etc. also contribute. Pollution of any form first affects the chemical quality of the water and then systematically destroys the community, disrupting the delicate food web in these aquatic ecosystems. Understanding the implications of each of these threats requires characterisation of aquatic ecosystems involving detailed understanding of the ecology.

1.2 AQUATIC ECOSYSTEM

Ecosystem is defined as '*the complex of a community of organisms and its environmental functioning as an ecological unit*'. It is a dynamic system where the biotic and abiotic components are constantly acting and reacting upon each other bringing forth structural and functional changes. An aquatic ecosystem is a group of interacting organisms dependent on one another and their water environment for nutrients (e.g., nitrogen and phosphorus) and shelter. An aquatic ecosystem is an ecosystem that is based in water, whether it is a pond, lake, river or an ocean. It involves living aquatic organisms (e.g.: fish, planktons, annelids, etc.), which constitute as the biotic factors and their relationship with their environment, which collectively can be referred to as the abiotic factor. Composing more than 70% of the earth's surface, aquatic ecosystems are not only the dominant features of earth but are also very diverse in species and complexity of interaction among their physical, chemical and biological components.

1.2.1 TYPES OF AQUATIC ECOSYSTEMS

Aquatic ecosystems are broadly categorised based on the differences in their salt content as:

- Freshwater ecosystems
- Marine ecosystems (includes the ocean and the sea) and
- Estuarine ecosystems (region where freshwater from a river mixes with the sea)

Familiar examples of Freshwater ecosystems include lakes, ponds, rivers, streams, and prairie potholes. They also include areas such as floodplains and wetlands, which are flooded with water for all or only parts of the year. Freshwater ecosystems are characterised as

- Lotic (running waters) – streams, rivers, etc.
- Lentic (still waters) – wetlands, ponds, tanks, lakes, etc.

The lotic ecosystems comprises of springs, rivulets, creeks, brooks, rivers, etc. which tread their course from being narrow, shallow and relatively rapid to increasingly broad, deep and slow moving. Waterfalls are common features of lotic ecosystems. Lentic ecosystems generally include ponds, lakes, bogs, swamps, reservoirs, pools, etc. and they vary considerably in physical, chemical and biological characteristics.

Ponds are smaller bodies of still water located in natural hollows, such as limestone sinks, or that result from the building of dams, either by humans or beavers. Ponds are found in most regions and may exist either seasonally or persist from year to year.

Rivers and *streams* are bodies of fresh, flowing water. The water runs permanently or seasonally within a natural channel into another body of water such as a lake, sea, or ocean. Rivers and streams are generally more oxygenated than lakes or ponds, and they tend to contain organisms that are adapted to the swiftly moving waters[5].

A *lake* is a sizable waterbody surrounded by land and fed by rivers, springs, or local precipitation. A lake's structure has a significant impact on its biological, chemical, and physical features. Lakes can be classified on the basis of a variety of features, including their formation and their chemical or biological condition, as *oligotrophic* and *eutrophic*. Oligotrophic lakes are characterised by relatively low productivity and are dominated by cold-water bottom fishes such as lake trout. Eutrophic lakes, which are relatively shallower, are more productive and are dominated by warm-water fishes such as bass. Natural processes of lake formation most commonly include glacial, volcanic, and tectonic forces while human constructed lakes are created by reservoirs or excavation of basins.

Wetlands are habitats that are partially submerged by water and include habitats like marshes, swamps, ponds, etc. they also include lakes, reservoirs and ponds. They function as *ecotones*, transitions between different habitats and have characteristics of both aquatic and terrestrial ecosystems. These habitats support diverse flora and fauna and are highly productive ecosystems akin to the tropical rainforest in terrestrial ecosystems (Ramachandra T.V. Ahalya N., and Rajasekara Murthy C, 2005[6])

1.2.2 WATERSHED – LINKING AQUATIC AND TERRESTRIAL ECOSYSTEMS

Aquatic ecosystems are not simply isolated bodies or conduits but are closely connected to terrestrial environments. Further, aquatic ecosystems are connected to each other and provide essential migration routes for species. Aquatic ecosystems require sediment loads, chemical and nutrient inputs from the adjoining terrestrial ecosystems for sustenance. Even isolated lakes are linked to the land and water around them through the flow of freshwater. Many of the problems faced by freshwater ecosystems come from outside the lakes, rivers, or wetlands themselves. Watershed is all the land and water area, which drains towards a river or a lake, river or a pond. A watershed is a catchment basin that is bound by topographic features, such as ridge tops and performs primary functions of the ecosystem (Ramachandra T.V. Ahalya N., and Rajasekara Murthy C., 2005[6]). Thus, the watershed can constitute slopes, agricultural lands, forests, streams, waterbodies, buildings, etc. People and animals are also a part of the watershed community and all depend on the watershed and they in turn influence what happens there. Accordingly, what happens in a small watershed also affects the larger watershed. Soil, water and vegetation are the most vital natural resources for the survival of man and animals. To obtain the maximum and optimum production from all the resources, the three resources need to be managed efficiently. They need to be managed effectively, collectively and simultaneously, and all these can be conveniently and efficiently managed in a watershed.

1.2.3 FRESHWATER ECOLOGY

Aquatic ecosystems usually contain a wide variety of life forms including bacteria, fungi, and protozoan; bottom-dwelling organisms such as insect larvae, snails, and worms; free-floating microscopic plants and animals known as plankton; large plants such as, grasses and reeds; and also fish, amphibians, reptiles, and birds. Viruses are also a significant part of the microbial ecology in natural waters and have recently been shown to play an important role in the nutrient and energy cycles. Plants, animals and microbes interact with each other and their environment bringing about changes in the water quality with the performance of ecological services, such as decomposition and nutrient cycling.

The assemblages of these organisms vary from one ecosystem to another because the habitat conditions unique to each type of ecosystem tend to affect species distributions. Freshwater ecosystems like rivers are relatively oxygen-rich and fast flowing compared to lakes. The species adapted to these particular river conditions are rare or absent in the still waters of lakes and ponds. Organisms capable of adhering to exposed surfaces are found in the upper reaches of streams. Such adhering organisms are termed periphyton. The periphyton includes attached clumped and filamentous green and blue green algae and various sessile invertebrates including larvae of insects like blackflies and other midges, mayfly and stonefly nymphs and planarians. Farther downstream floating and emergent vegetation may be found along with sessile invertebrates and those that burrow in the softer substrate, such as clams and burrowing mayfly nymphs. Chemically, the upper reaches of lotic environments are rich in oxygen; as the water moves downstream and becomes sluggish, the oxygen level tends to drop. Due to the continual addition of nutrients and detritus en route, nutrient levels tend to be higher downstream. In small streams in which producers are limited or absent, the major source of nutrients is from external ecosystems. Such materials are referred to as being allocthanous.

Lentic ecosystems (still waters) can be considered to have three zones – littoral, limnetic and benthic (figure 1.3). The littoral zone is the near shore area where sunlight penetrates all the way to the sediment and extends from the shoreline to the innermost rooted plants, successively passing form the rooted species with floating leaves, such as water lilies and deeper water to various submerged but rooted species. This zone is populated by frogs, snakes, snails, clams, and considerable variety of adult and larval insects. The limnetic (pelagic) zone is the open water down to the depth of light penetrations: in shallow lentic environments the light may penetrate to the bottom. This zone contains phytoplankton (diatoms, green and blue green algae, etc.), zooplankton (protozoa, microcrustaceans, arthropods, etc.). It is also inhabited by a variety of larger swimming organisms including fish, amphibians and larger insects. The benthic zone (the bottom of the lake) is covered by fine layers of mud consisting mostly of decomposers. Euphotic zone of the lake is the layer from the surface to the depth where light levels become too low for photosynthesis. In the littoral zone, there is enough light for rooted plants to grow, but beyond this zone, there are no rooted plants as the water is too deep for light to reach them. The deepest part of the open water forms the profoundal zone, but this is relevant only in extremely deep lakes. The profoundal zone occurs below the limnetic zone and this zone may constitute the largest water volume of a lake. This zone is beyond the depth of effective light penetration.

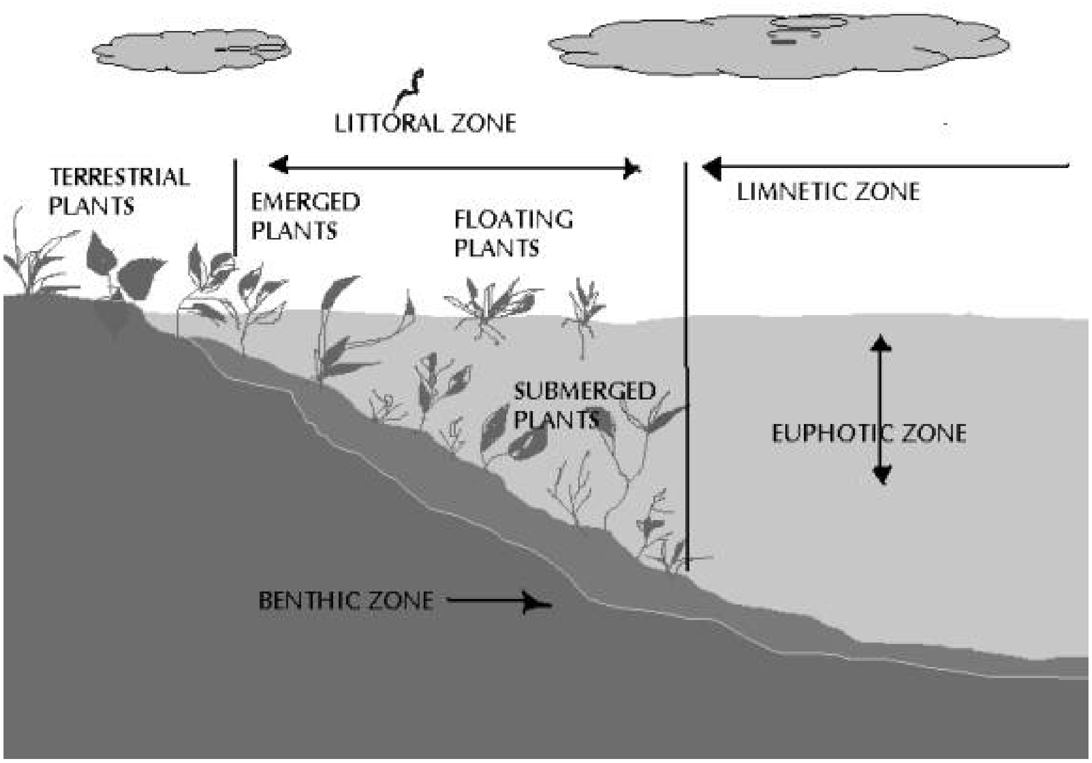


Figure 1.3: Sketch showing major zones of lake[7]

The major food source in the profoundal zone comes from a detritus rain form the limnetic and thus the photosynthetic zone. A pond or a lake ecosystem is a dynamic ecosystem since the boundaries are limited. The water is retained in a trough and lined by terrestrial region. The entry nutrients, sediments through the surface runoffs enter and remain in the system causing fluctuations in the physico-chemical characteristics of these ecosystems.

The organisms are subjected to pressure, changes in quality of water and are adapted to such changes. The primary producers like phytoplankton in the surface water perform photosynthesis and through the food chain and food webs transfer energy to higher trophic levels. The daily alteration of light and darkness forms a rhythm of activities of many aquatic organisms. The plants require light for the photosynthesis to prepare food from natural substance. The light penetration depends much on the turbidity of water caused by suspended particulate matter. The wind generates water currents, which in turn helps in nutrient movement and diffusion of gases. The distribution of oxygen in the dissolved form is essential to all aquatic life. Some organisms are lung breathers while others are gill breathers. The oxygen supply of lakes is reduced in various ways most significantly through respiration of organisms and decomposition of organic matter. In addition high temperatures also prevent the dissolution of atmospheric oxygen.

1.2.4 FRESHWATER ORGANISMS AND FOOD WEB

Freshwater habitats contain representatives of many groups of organism on earth. *Archeae* and *bacteria* are difficult to distinguish unless they can be brought into culture and metabolic characteristics can be used as taxonomic characteristics. *Algae* are the primary autotrophs in many aquatic ecosystems and are well represented in freshwaters. *Protozoa* are common in all freshwater habitats and can often be identified if a good microscope is available. All major phyla of invertebrates, with the exception of Echinodermata, (e.g. star fish) have some freshwater species. Invertebrates are the most fascinating and very important in the ecology of most aquatic habitats. Identification by non-taxonomists can be difficult at the species level, but numerous keys are available for coarser taxonomic resolution. Identification of *Vertebrates* is generally easier, because fewer and better-studied organisms are represented and many of these are assigned names. As with vertebrates many of the plants in aquatic systems have been well characterised. Aquatic plants are moderately diverse. Identification of the more obscure *Mosses and liverworts* is more difficult though.

Among the 'lower' (non-vascular) plants, the mosses and liverworts are virtually all terrestrial, although flourishing only in moist environments; but the larger algae are primarily aquatic. The larger algae comprise some 5,000 species in three major groups (the green, brown and red algae), the great majority of which are marine or brackish water forms ('seaweeds'). The green algae Chlorophyta includes one order of around 80 species (Ulotrichales) that is mainly freshwater. However, one major group sometimes associated with the green algae - the stonewort (Charophyta) – belongs almost entirely to freshwater. The stonewort includes 440 species, most of which are endemic at continental level or below; they tend to be very sensitive to nutrient enrichment and have declined in many areas

Animal species are considerably more diverse and numerous in inland waters than plants. Most of the major groups include terrestrial or marine species as well as freshwater forms. Apart from fishes, important groups with inland water species include crustacea (crabs, crayfishes and many smaller organisms), mollusca (including mussels and snails), insects (including stoneflies Plecoptera, caddisflies Trichoptera, mayflies Ephemoptera), sponges, flatworms, polychaete worms, oligochaete worms, numerous parasitic species in various groups, and numerous microscopic forms.

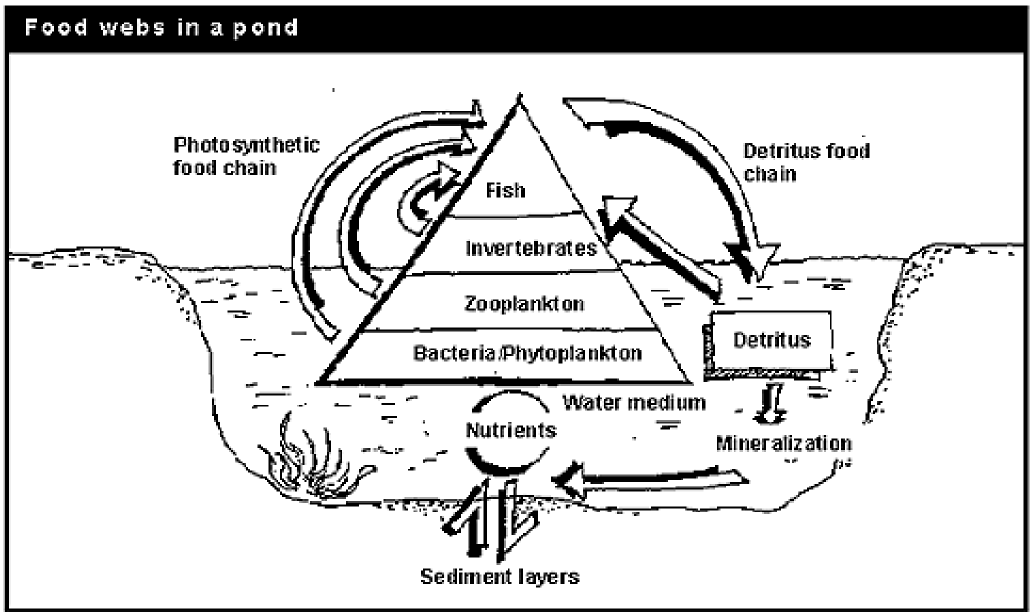


Figure 1.4: A simple aquatic food chain 8

The sun provides the ultimate source of energy in all natural systems. If we look at a simple food chain in a freshwater ecosystem (figure 1.4), it may comprise of the primary producers phytoplankton, wherein they fix sunlight and convert the light energy to chemical energy. They form the base of the food chain, and are eaten by the zooplankton and planktivorous fishes, which make up the primary and secondary consumers in the aquatic food chain. Other small fishes in turn eat the zooplankton. Other larger fishes, birds, etc form the upper trophic levels. When plants or animals die, the chemicals that make up their bodies are broken down and released back into the system as nutrients by the decomposers. The major decomposers are bacteria and fungi, which make up the last trophic level in the food chain.

Phytoplankton comprises of aquatic microscopic plants suspended in water - many species of prokaryotic (blue green alga) and eukaryotic algae. Zooplankton comprises of small (often microscopic) aquatic animals, and non-photosynthetic protists suspended or weakly swimming in water, which feed on the phytoplankton. E.g., protozoa, bacteria, small crustaceans, rotifers, micro invertebrates and fish larvae, etc. Some species from most major groups of aquatic animals can eat phytoplankton, periphyton, macrophytes, detritus or other animals. Omnivory is common in freshwater invertebrates with many organisms representing various trophic levels.

Table 1.2: The major groups of organisms in freshwater (UNEP 9)

Organisms	General features	Significance in freshwaters
Viruses	Microscopic; can reproduce only within the cells of other organisms, but can disperse and persist without host.	Causes diseases in many aquatic organisms, and associated with water-borne diseases in humans (eg. hepatitis).
Bacteria	Microscopic; can be numerically very abundant, eg. 1,000,000 per cm^3, but less so than in soils. Recycles organic and inorganic substances. Mostly derives energy from inorganic chemical sources, or from organic materials.	Responsible for the decay of dead material. Present on all submerged detritus where a food source for aquatic invertebrates. Many cause diseases in aquatic organisms and humans.
Fungi	Microscopic. Recycles organic substances; responsible for decay of dead material; tends to follow bacteria in the decomposition processes. Able to break down cellulose in plant cell walls and chitinous insect exoskeletons.	Present on all submerged detritus where it is a food source for aquatic invertebrates. Some cause diseases in aquatic organisms and humans.
Algae	Microscopic and macroscopic; includes a variety of unicellular and colonial photosynthetic organisms. All lack leaves and vascular tissues of higher plants. Green Algae (Chlorophyta) and Red Algae (Rhodophyta) include freshwater species; Stoneworts (Charophyta) mostly freshwater.	Responsible for most primary production (growth in biomass) in most aquatic ecosystems. Free-floating phytoplankton main producers in lakes and slow reaches of rivers; attached forms important in shallow parts of lakes and streams.
Plants	Photosynthetic organisms; mostly higher plants that possess leaves and vascular tissues. Some free-floating surface species; mostly rooted forms are restricted to water margins.	Provide a substrate for other organisms and food for many. Trees are ecologically important in providing shade and organic debris (leaves, fruit), structural elements (fallen trunks and branches) that enhance vertebrate diversity, in promoting bank stabilisation, and in restricting or modulating floodwaters.

Invertebrates: protozoan	Microscopic mobile single-celled organisms. Tend to be widely distributed through passive dispersal of resting stages. Attached and free-living forms; many are filter feeders.	Found in virtually all freshwater habitats. Most abundant in waters rich in organic matter, bacteria or algae. Feed on detritus, or consume other microscopic organisms; many are parasitic on algae, invertebrates or vertebrates.
Invertebrates: rotifers	Near-microscopic organisms; widely distributed; mostly attached filter feeders, some predatory forms.	Important in plankton communities in lakes and may dominate animal plankton in rivers.
Invertebrates: myxozoans	Microscopic organisms with complex life cycles, some with macroscopic cysts. Formerly classified with protozoa but are metazoa.	Important parasites in or on fishes.
Invertebrates: flatworms	A large group of worm- or ribbon like flatworms; includes free-living benthic (Turbellaria), and parasitic forms (Trematoda, Cestoda).	Turbellaria include mobile bottom-living predatory flatworms. The Trematodes includes various flukes, such as the tropical schistosome that causes *bilharzia*; Cestodes are tapeworms: both these groups are important parasites of fishes and other vertebrates including humans. Molluscs are often intermediate hosts.
Invertebrates: nematodes	Generally microscopic or near-microscopic roundworms.	May be parasitic, herbivorous or predatory. Typically inhabit bottom sediments. Some parasitic forms can reach considerable size. Poorly known; may be more diverse than recognised.
Invertebrates: annelid worms	Two main groups in freshwaters; oligochaetes and leeches.	Oligochaetes are bottom-living worms that graze on sediments; leeches are mainly parasitic on vertebrate animals, some are predatory.
Invertebrates: molluscs	Two main groups in freshwaters; Bivalvia (mussels, etc) and Gastropoda (snails, etc). Very rich in species; tend to form local endemic species.	Snails are mobile grazers or predators; bivalves are attached bottom-living filter-feeders. Both groups have specialised profusely in

		certain freshwater systems. The larvae of many bivalves are parasitic on fishes. Due to its feeding mode, bivalves can help maintain water quality but tend to be susceptible to pollution.
Invertebrates: crustaceans	A very large class of animals with a jointed exoskeleton often hardened with calcium carbonate.	Include larger bottom-living species such as shrimps, crayfish and crabs of lake margins, streams, alluvial forests and estuaries. Also, larger plankton: filter-feeding Cladocera and filter-feeding or predatory Copepoda. Many isopods and copepods are important fish parasites.
Invertebrates: insects	By far the largest class of organisms known. Jointed exoskeleton. The great majority of insects are terrestrial, because they breathe air.	In rivers and streams, grazing and predatory aquatic insects (especially larval stages of flying adults) dominate intermediate levels in food webs (between the microscopic producers, mainly algae, and fishes). Also important in lake communities. Fly larvae are numerically dominant in some situations (eg. in Arctic streams or low-oxygen lake beds), and are vectors of human diseases (eg. malaria, river blindness).
Vertebrates: fishes	More than half of all vertebrate species are fishes. These are comprised of four main groups: hagfishes (marine), lampreys (freshwater or ascend rivers to spawn), sharks and rays (almost entirely marine), and ray-finned 'typical' fishes (>8,500 species in freshwaters, or 40% of all fishes).	Fishes are the dominant organisms in terms of biomass, feeding ecology and significance to humans, in virtually all aquatic habitats including freshwaters. Certain water systems, particularly in the tropics, there is a good number of species. Many species are restricted to a few lakes or river basins. They are the basis of important fisheries in inland waters in tropical and temperate zones.
Vertebrates: amphibians	Frogs, toads, newts, salamanders, caecilians. Require freshwater habitats.	Larvae of most species need water for development. Some frogs, salamanders and caecilians are

		entirely aquatic; generally in streams, small rivers and pools. Larvae are typically herbivorous grazers, adults are predatory.
Vertebrates: reptiles	Turtles, crocodiles, lizards, snakes. All crocodilians and many turtles inhabit freshwaters but nest on land. Many lizards and snakes occur along water margins; a few snakes are highly aquatic.	Because of their large size, crocodiles can play an important role in aquatic systems, by nutrient enrichment and shaping habitat structure. They, as well as freshwater turtles and snakes are all predators or scavengers.
Vertebrates: birds	Many birds, including waders and herons, are closely associated with wetlands and water margins. Relatively few, including divers, grebes and ducks, are restricted to river and lake systems.	Top predators. Wetlands are often key feeding and staging areas for migratory species. Likely to assist passive dispersal of small aquatic organisms.
Vertebrates: mammals	Relatively few groups are strictly aquatic (eg. River Dolphins, platypus), several species are largely aquatic but emerge onto water margins (eg. otters, desmans, otter shrews, water voles, water oppossum, hippopotamus).	Top predators and grazers. Large species widely impacted by habitat modification and hunting. Through damming activities, beavers play an important role in shaping and creating aquatic habitats.

1.2.5 CAUSES AND EFFECTS OF POLLUTION ON AQUATIC ECOSYSTEMS

When pollutants enter lakes, streams, rivers, oceans, and other waterbodies, they get dissolved or lie suspended in water or get deposited on the bed. The system is able to withstand the pollutants up to a certain threshold, beyond which the quality of the water deteriorates, affecting aquatic ecosystems. The most common problems associated with various pollutants are discussed below.

- *Oxygen demanding wastes* are substances that oxidise in the receiving body of water, reducing the amount of dissolved oxygen (DO) available. As DO drops, fish and other aquatic life are threatened and, in the extreme case, get killed. In addition to the fall in DO levels, undesirable odours, tastes, and colours reduce the acceptability of the water as a domestic supply and its attractiveness for recreational purposes. Oxygen demanding wastes are usually biodegradable organic substances contained in municipal wastewaters or in effluents from industries such as food processing and paper production.

- Contaminated water is responsible for the spread of many contagious diseases. *Pathogens* associated with water include bacteria responsible for cholera, dysentery, typhoid, etc., viruses cause hepatitis and poliomyelitis, protozoa are responsible for amoebic dysentery and giardiasis, and helminthes or parasitic worms cause diseases like schistosomiasis, etc.
- *Nutrients,* when present in concentrations that can stimulate the growth of algae can be considered pollutants. The discharge of waste from industries, agriculture, and urban communities into waterbodies generally stretches the biological capacities of aquatic systems. Chemical run-off from fields also adds nutrients to water. Excess nutrients cause the waterbody to become choked with organic substances and organisms. When organic matter exceeds the capacity of the microorganisms in water that break down and recycle the organic matter, it encourages rapid growth, or blooms of algae. When they die, the remains of the algae add to the organic wastes already in the water; eventually, the water becomes deficient in oxygen. Anaerobic organisms (those that do not require oxygen to live) then attack the organic wastes, releasing gases such as methane and hydrogen sulphide, which are harmful to the oxygen requiring (aerobic) forms of life. The result is a foul-smelling, waste-filled body of water. This artificial supplementation of nutrients, and consequent abnormal increase in the growth of water plants is often referred to as *eutrophication*. This is a growing problem in freshwater lakes all over India. Eutrophication can produce problems such as bad tastes and odours as well as green scum algae. Also, the growth of rooted plants increases, which decreases the amount of oxygen in the deepest waters of the lake. It also leads to the death of all forms of life in the waterbodies.
- *Organic inputs* from the food industry, i.e., carbohydrates, lipids, and proteins, all impact lakes and rivers by increasing the biological oxygen demand. The worst-case scenario is the total loss of oxygen from the water as a result of microbial activity. Lipids create the greatest oxygen demand but carbohydrates (more easily biodegradable) also result in unsightly ‘sewage fungus’. Protein waste can be degraded to produce ammonia and sulphide, both of which produce toxicity problems (Gwynfryn Jones J, 2001[10]).
- *Acid precipitation* is caused mainly by humans burning fossil fuels, which leads to increased sulphuric, and nitric acid in the atmosphere. Acidification of aquatic ecosystems impacts all aquatic organisms. Acid rain has major effects on biological systems ranging from altered microbial activity to the ability of fish to survive and reproduce. (Table 1.3).

Table 1.3: Influences of decreasing pH on several groups of aquatic organisms *(Modified from* Jeffries M., and Mills D, 1990[11])

Organism of process	Approximate pH value
Most mayflies disappear	6.5
Phytoplankton species decline/green filamentous periphyton dominate	6
Most molluscs disappear	5.5 – 6
Waterfowl breeding declines	5.5
Bacterial decomposition slows/fungal decomposition predominates	5
Salmonoid reproduction fails/aluminium toxicity increases	5
Most amphibians disappear	5
Caddisflies, stoneflies, and megaloptera disappear	4.5 – 5
Beetles, bugs, dragonflies, and damselflies disappear	4.5
Most adult fish harmed	4.5

Metals and other inorganic pollutants act as toxic pollutants in aquatic ecosystems. Metals can bioaccumulate in many organisms and can be bioconcentrated in trophic food chains. Bioconcentration has led to problems such as excessive lead and mercury contamination in fish. Atmospheric deposition and industrial waste releases, particularly mining are common sources of metallic contamination. Such mining activities have had extensive negative impacts in aquatic habitats. The inorganic inputs, particularly of phosphorus, stimulate undesirable algal growths, some of which may produce particularly dangerous toxins. Arsenic can cause problems because it can be present in high concentrations naturally or as runoff form industrial uses. Historically arsenic was also used as pesticide and subsequently contaminated aquatic ecosystems. In a particularly terrible case, thousands of drinking water wells in West Bengal, India, are contaminated by naturally occurring arsenic. Radioactive compounds can be contaminants in water. They usually occur naturally in water. The primary contaminants are isotopes of radium, radon, and uranium. The effects of natural radioactive materials on aquatic habitats are difficult to gauge.

More than 10,000 organic pollutants have been created and used by man. Several hundred new chemicals are created each year and discharged by humans into the aquatic habitats, including pesticides, oil, and materials in urban runoff. Only a few of them have been tested for toxicity. In some cases microbes can break down these compounds through bioremediation in a given time. The effects of unregulated release of pollutants into large ecosystems are exemplified by the experiences in the Great Lakes of North America.

Worldwide, where, about 2.3 million metric tons of pesticides are used yearly. (Walter K. Dodds, 2002[12]).

Petroleum products are another source of aquatic contamination. Urban runoff is a significant source of oil contamination. Chlorinated hydrocarbons such as poly-chlorinated biphenyl (PCBs) have carcinogenic properties. In addition to this many sewage treatment plants treat their final effluents with chlorine to kill all pathogens and this forms chlorinated hydrocarbons. Bioremediation is one possible way of cleaning up the spills of organic materials. (Walter K. Dodds, 2002[12]).

Turbidity and suspended solids are natural parts of all freshwater environments. Some are naturally highly turbid but human activities have increased the levels of suspended solids in many habitats. Agricultural and urban runoff, watershed disturbance such as logging, construction of roads, etc., removal of riparian vegetation, alteration of hydrodynamic regimes can all lead to anthropogenically attributed increment in the total suspended solids. Sediments can have different biological and physical effects depending on the type of suspended solids. High values of suspended solids can lower the primary productivity of systems by covering the algae and macrophytes, at times leading to almost their complete removal (Walter K. Dodds, 2002[12])

Thermal pollution can cause shifts in the community structure of aquatic organisms. This may allow for the establishment of exotic species and local extinction of native species. As water temperature increases, it makes it more difficult for aquatic life to get sufficient oxygen to meet its needs.

Aquatic systems respond on a much shorter time scale than their terrestrial counterparts. For example, species invasions take 10 to 1000 years in terrestrial systems but only a few weeks to a few months in aquatic systems. Similarly, population changes can take 10 to millions of years on land but can occur within a few months to a few years in water. Therefore, any pressure placed on a freshwater system can result in a very rapid and deleterious response. The driving forces involved (some of which are under man's control) can be divided into the physical and the chemical, but the response is, almost entirely, biological (Gwynfryn Jones J, 2001[10]).

Human encroachment on aquatic ecosystems is increasing at an unprecedented rate. The impacts of human pollution and habitat alteration are most evident and of greatest concern at the microbial level, where a bulk of the production and nutrient cycling takes place. Aquatic ecosystems are additionally affected by natural perturbations, including droughts, storms, and floods, where its frequency and extent may be increasing.

More than 70% of the world's human population live in watersheds that drain to the coast (Vitousek P.M et al, 1997[13]). Further population growth will be centred in these regions, exerting unprecedented pressure on riverine, estuarine and coastal habitats receiving human pollutants (Vitousek P.M et al, 1997[13], Peierls B.L et al, 1991[14]). Multiple negative ecological impacts on these fragile habitats (i.e., loss of biodiversity, increasing frequencies of harmful algal blooms, hypoxia, disease and declines in fisheries) have been documented (Jørgensen B.B and Richardson K. 1996[15], Nixon S.W, 1995[16], Paerl H.W, 1997[17], Conley D.J, 2000[18]). Most evident are water quality and habitat changes attributable to nutrient over-enrichment, leading to excessive primary production or eutrophication (Jørgensen, B.B and Richardson, K. 1996, Nixon S.W, 1995, Paerl H.W, 1997[15, 16, 17]). Eutrophication has caused significant changes in coastal nutrient (C, N, P, Si) cycling, water quality, biodiversity, fisheries, and the overall ecosystem health (Jørgensen, B.B and Richardson, K. 1996, Nixon S.W, 1995, Paerl H.W, 1997, Conley D.J, 2000, Diaz, R.J. and Solow, A., 1999 [15, 16, 17, 18, 19]).

Natural perturbations such as droughts, storms and floods additionally impact aquatic ecosystems. Like human disturbances, these events are predicted to increase in the foreseeable future (Goldenberg S.B et al, 2001[20]). Among aquatic biota, microorganisms are generally highly sensitive to and profoundly affected by environmental perturbations. Microbes comprise the majority of aquatic biomass and are responsible for the bulk of productivity and nutrient cycling in aquatic systems. They have fast growth rates, and respond to low levels of pollutants as well as other physical, chemical, and biotic environmental changes. From detection and effect perspectives, they provide sensitive, meaningful, and quantifiable indications of ecological change.

1.3 WETLANDS

Wetlands are, 'lands that are in transition between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water.' Thus, wetlands serve as a vital link between land and water. Wetlands differ due to variations in water regime, fauna and flora, climate, soils, and topography, and are classified into the major categories of marshes, fens, bogs, swamps, and shallow open water.

Ramsar Convention (http://www.ramsar.org) defines Wetlands as 'areas of marsh or fen, peat-land or water, whether artificial or natural, permanent or temporary, with the water that is static or flowing, fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed 6 m'. This definition evolved with the perspective of conservation and restoration of degrading wetlands worldwide. Mangroves, corals, estuaries, bays, small creeks, flood plains, sea grasses, lakes, etc. are all covered under this definition.

Wetlands can be virtually found in every continent, country and state across the Arctic tundra wetlands in Alaska and peat bogs in Appalachians to riparian wetlands in the arid west. In India, wetlands are distributed in different geographical regions ranging from the cold arid zone of Ladakh to the warm arid zone of Rajasthan, the tropical monsoonal central India to the wet and humid zone of southern peninsula. Most of the wetlands in India are directly or indirectly linked with major river systems like the Ganga, Brahmaputra, Godavari, Narmada, Tapti, Krishna, Cauvery, etc. A few of them which are Ramsar sites and of international significance are Dal lake in Srinagar, Kolleru in Andhra Pradesh, Chilka lake in Orissa, Wulur in Jammu and Kashmir, and the backwaters of Cochin.

In many areas of the world wetlands have been drained, filled in, or considered useless land. In Southeast Asia existing wetlands have been modified or new wetlands have been created to allow for rice culture, and these paddy fields have fed billions of people over the centuries. The decline in wetlands is global and a large percentage of wetlands have been lost consistently every year due to manifold reasons.

1.3.1 FUNCTIONS AND VALUES OF WETLANDS

Wetlands and lakes are an essential part of human civilization; meeting many crucial needs for life on earth such as drinking water, fish and shellfish production, water quality improvement, sediment retention, aquifer recharge, flood storage, transport, recreation, climate stabilisers and so on. Wetlands are also used to treat wastewater in many places. In addition, wetlands are globally important as natural sources of methane as a green house gas, to the atmosphere as this trace gas plays an important role in the regulation of climate. Wetland sediments are valuable because they preserve a long-term record of environmental conditions and the sediments in peat bogs are used in gardens. Wetlands due to their above listed biological, ecological, hydrological, social, cultural and economic values form an important component of the environment. The values of wetlands though overlapping, are thus inseparable. Some of the important functions of wetlands are discussed below.

Wetlands - natural water purifiers: Wetlands act like a water filtration system and improve the water quality by removing contaminants, excessive nutrients, and suspended particles. Wetlands help in filtering the pollutants and soil runoff from upstream sources, which helps keep rivers, bays, and oceans clean in the downstream. In this way, healthy wetlands help mitigate the negative effects that human and farm waste, and some by-products of industrial pollution generate. Wetlands act as natural water purifiers, filtering sediment, nutrients and absorbing many pollutants in surface waters. In some wetland systems, this cleansing function enhances the quality of groundwater supplies as well.

Groundwater recharge and discharge: Wetlands act like giant sponges, storing, then slowly releasing groundwater, melted snow, and floodwater. The extent of groundwater recharge depends on the type of soil and its permeability, vegetation, sediment accumulation in the lakebed, surface area to volume ratio and water table gradient (Ramachandra T.V., Kiran R., and Ahalya N, 2002[21]).

Flood control and stream flow maintenance: Wetlands help control inland flooding and forestalls wave erosion along shorelines; because urban buildings and pavements release water runoff quickly, wetlands downstream from urban areas perform valuable flood control services. Wetlands along rivers and streams store excess water during rainstorms. This reduces downstream flood damage and lessens the risk of flash floods. The slow release of this stored water to rivers and streams helps keep them from drying up during periods of drought.

Wetlands as carbon sinks: Although wetlands occupy only a small portion of the world's area, they are estimated to contain 10-14% of the carbon. Wetland soils such as histosols, may contain upto 20% carbon by weight and of course peats are more carboniferous. Their draining and conversion into agricultural land releases large quantities of carbon dioxide to the atmosphere, thus contributing to the carbon dioxide problem. Their plants and rich soil may provide one buffer against global climate change, by storing carbon instead of releasing it into the atmosphere as carbon dioxide.

Role in biogeological cycles: Wetlands play an important role in atmospheric and natural cycles (biogeological cycles). Nitrogen, phosphorus, sulphur, iron, magnesium and water cycles are all closely tied to the different layers of oxidation in wetlands. The ability of wetlands to transform nutrients and metals, particularly the ability to store phosphorus and transform nitrogen and sulphur to gases suggests that they play an important role in reducing nutrient concentrations in natural waters. Further, artificial wetlands may be used to treat nutrient laden waters produced by human activities. However, overloading a wetland with nutrients, beyond its threshold, impairs its ability to perform basic functions. Wetlands can slow eutrophication by the absorption of eutrophic parameters - phosphorus and nitrogen, thereby reducing algal growth, and excessive aquatic vegetation. Nitrogen fertiliser runoff from farms has overwhelmed the capacity of some wetlands to filter pollutants, creating "dead zones" in areas such as the Gulf of Mexico, where algal blooms are fueled by this and other nutrients have run riot and displaced a once thriving diverse oceanic ecology.

Shoreline and stream bank stabilisation: By absorbing the energy of storm waves and slowing the water currents, wetland vegetation serves as a buffer against shoreline and riverbank erosion, thus reducing sedimentation. Coastal wetlands help to blunt the force of major storms. Mangrove wetlands reduce flooding, coastal erosion, and property damage.

Wildlife habitat: Wetlands filter sediments and nutrients from surface water and support all life forms through extensive food webs and biodiversity. Wetlands provides habitat for many species of amphibians, reptiles, birds, and mammals that are uniquely adapted to wet environments. Upland wildlife such as deer, elk, and bear commonly use wetlands for food and shelter. Essential nesting, feeding, spawning, breeding grounds, and migratory route refuges are provided by the wetland ecosystem. Wetlands are particularly vital to many migratory bird species. They provide habitats and support diverse ranges of biodiversity (e.g., in one square metre of coral reef, there can be up to 3000 species) Wetlands in a sense are biodiversity laboratories. For one, the diversity of conditions in wetlands set the environmental parameters that allow for, even encourage, the evolution of novel survival strategies. For example, many bog species have special adaptations to low nutrient levels, waterlogged conditions, acidic waters, and extreme temperatures. Wetlands are also home to many threatened and endangered species. Freshwater and marine life including trout, striped bass, pike, sunfish, crappie, crab, and shrimp rely on wetlands for food, cover, spawning, and nursery grounds.

Recreation – education: Many wetlands contain a diversity of plants and animals that provide beautiful places for sightseeing, hiking, fishing, hunting, boating, bird watching, and photography. Wetlands provide countless opportunities for environmental education, research and public awareness programs.

Wetland products: Wetland products include fish, timber, housing materials such as reeds, medicinal plants, the provision of fertile land for agriculture (sediments), water supply for domestic, arable, pastoral or industrial purposes, energy resource (fuel wood, etc.), transport, recreation, tourism, etc. By supporting diverse human activities, large wetlands play a particularly important role in the subsistence and development of thousands of people. Direct economic benefits include water supply, fisheries, agriculture, energy resource, wildlife resource, transport, recreation and tourism, supporting a vast diversity of flora, fauna and cultural heritage. Indirect benefits are improved water quality (including drinking water) by intercepting surface runoff and removing or retaining its nutrients, processing organic wastes, reducing sediment before it reaches open water, flood control and other cultural aspects. (Ramachandra T.V., Kiran R., and Ahalya N, 2002[21])

1.3.2 THREATS AND LOSS OF WETLANDS

Throughout the subcontinent, wetlands are degrading rapidly at a rate, which is unacceptable. Despite the government's acceptance of the fact that these invaluable natural resources need to be conserved, wetland loss and degradation continue unabated. Wetlands have been lost and degraded in many ways that are not as obvious as direct physical destruction or degradation. Wetland loss and degradation can be due to conversion of wetland to non-wetland areas as a result of human activity or impairment of wetland functions as a result of human activity.

Habitat degradation on account of accelerating pollution, drainage, weed infestation, siltation and successive droughts has claimed the premature departure of many migratory birds. Apart from habitat loss, silt, chemicals, fertilisers and pesticides pouring into the waters from intensively cultivated land is another major cause of wetland degradation. Vast amounts of spongy wetlands have been drained to get a little extra land for agriculture, urban development, etc. Reclaimed land has soon become worthless lowering the water table, negating the very purpose of producing a good crop. Many wetlands are being drained, filled, cultivated, built upon, denuded and are buckling under the pressure of growing human numbers and the rising tempo of developmental activities.

Apart from pollution, the other major problems include the hydrological manipulations of wetlands in the form of flow alterations and diversions, disposal of dredged or fill material, sewage inflows, encroachment for developmental activities and construction of dykes or levees impacting wetland quality, species composition and functions. Wetlands near urban areas are under increasing developmental pressure for residential, commercial and industrial facilities. Urban areas in addition to altering the natural drainage patterns increase paved surfaces and reduce the land cover which in turn leads to increased amounts of surface runoff resulting in floods and water logging after rainfall. Increased runoff brings with it various substances that degrade water quality, such as fertilisers, chemicals, grease, sediment and oil, etc.

Although the debate over the rate of loss of wetlands is academically interesting, it is not especially important since we know that wetlands are being destroyed at a rate that is incredible. Historically, the pattern has been one of progressive wetland loss; especially in the developed world where a wide range of other land uses compete for wetland area. The largest threats today, however, are in the developing world where uncoupling of the traditional linkages between human communities and ecosystem functioning are likely to result in irretrievable losses.

1.3.3 IMPLICATIONS OF LOSSES AND MISMANAGEMENT OF WETLANDS

Wetlands are one of the most threatened habitats of the world. Wetlands in India, as elsewhere are increasingly facing several anthropogenic pressures. Thus, the rapidly expanding human population, large-scale changes in land use/ land covers, burgeoning developmental projects and improper use of watersheds have all caused a substantial decline of wetland resources in the country (Prasad S.N, Ramachandra T.V., Ahalya N., Sengupta. T., Alok Kumar, Tiwari A. K., Vijayan V. S.and Lalita Vijayan, 2002[22])

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Agricultural conversion: In the Indian subcontinent due to rice culture, there has been a loss in the spatial extent of wetlands. Rice farming is a wetland-dependent activity and is developed in riparian zones, river deltas and savannah areas. Due to captured precipitation for fishpond aquaculture in the catchment areas' and rice-farms occupying areas that are not wetlands, the downstream natural wetlands are deprived of water. Around 1.6 million ha of freshwater are covered by freshwater fishponds in-India. Rice-fields and fishponds come under wetlands, but they rarely function like natural wetlands. Of the estimated 58.2 million ha of wetlands in India, 40.9 million ha are under rice cultivation (MoEF, 1993).

Direct deforestation in wetlands: Mangrove vegetation is flood-and salt-tolerant and grows along the coasts and is valued for fish and shellfish, livestock fodder, fuel wood, building materials, local medicine, honey, bees wax and for extracting chemicals for tanning leather (Ahmad, 1980). Alternative farming methods and fisheries production have replaced many mangrove areas and continues to pose threats. Eighty percent of India's 4240 sq. km of mangrove forests occurs in the Sunderbans and the Andaman and Nicobar Islands (Government of India, 1991). But most of the coastal mangroves are under severe pressure due to the economic demand for shrimps (prawns). Important ecosystem functions such as buffer zones against storm surges, nursery grounds and escape cover for commercially important fisheries are lost. The shrimp farms also caused excessive withdrawal of freshwater and increased pollution load on water, like increased lime, organic wastes, pesticides, chemicals and disease causing organisms. The greatest impacts were on the people directly dependent on the mangroves for natural materials, fish proteins and revenue. The ability of wetlands to trap sediments and slow the flow of water is reduced.

Hydrological alteration: Alteration in the hydrology can change the character, functions, values and the appearance of wetlands. The changes in hydrology include either the removal of water from wetlands or raising the land-surface elevation, such that it no longer floods. Canal dredging operations have been conducted in India from the 1800s due to which 3044 sq. km of irrigated land has increased to 4550 sq. km in 1990 (MoEF, 1994).

An initial increase in the crop productivity has given way to reduced fertility and salt accumulations in soil due to irrigated farming of arid soils. India has 32,000 ha of peat-land remaining and drainage of these lands will lead to rapid subsidence of the soil surface.

Inundation by dammed reservoirs: At present, there are more than 1550 large reservoirs covering more than 1.45 million ha and more than 100,000 small and medium reservoirs covering 1.1 mi11ion ha in India (Gopal, 1994). By impounding the water, the hydrology of an area is significantly altered and allows for harnessing moving water as a source of energy. While the benefits of energy are well recognised, it also alters the ecosystem.

Alteration of upper watersheds: Watershed conditions influence the wetlands. The condition of the land where it precipitates, collects and run off into the soil will influence the character and hydrological regime of the downstream wetlands. When agriculture, deforestation or overgrazing removes the water-holding capacity of the soil, then soil erosion becomes more pronounced. Large areas of India's watershed area are being physically stripped of their vegetation for human use.

Degradation of water quality: Water quality is directly proportional to the human population and its various activities. More than 50,000 small and large lakes are polluted to the point of being considered 'dead' (Chopra, 1985). The major polluting factors are sewage, industrial pollution and agricultural runoff, which may contain pesticides, fertilisers and herbicides.

Groundwater depletion: Draining of wetlands has depleted the groundwater recharge. Recent estimate indicate that in rural India, about 6000 vi1Iages are without a source for drinking water due to the rapid depletion of groundwater.

Introduced species and extinction of native biota: Wetlands in India support around 2400 species and subspecies of birds. But losses in habitat have threatened the diversity of these ecosystems (Mitchell and Gopal, 1990). Introduced exotic species like water hyacinth *(Eichhornia crassipes)* and salvinia *(Salvinia molesta)* have threatened the wetlands and clogged the waterways, competing with the native vegetation. In a recent attempt at prioritisation of wetlands for conservation, Samant (1999) noted that as many as 700 potential wetlands do not have any data to prioritise. Many of these wetlands are threatened.

1.3.4 CONSERVATION OF WETLANDS

Gradually rising awareness and appreciation of wetland values and importance in the recent past have paved way to the signing of many agreements, of which Ramsar convention signed in Iran in 1991 is the most important. Wetlands conservation in India is indirectly influenced by an array of policy and legislative measures. Some of the key legislations are given below [23]:

- The Indian Fisheries Act - 1857
- The Indian Forest Act - 1927
- Wildlife (Protection) Act - 1972
- Water (Prevention and Control of Pol1ution) Act - 1974
- Territorial Water, Continental Shelf, Exclusive Economic Zone and other
- Marine Zones Act - 1976
- Water (Prevention and Control of Pollution) Act - 1977
- Maritime Zone of India. (Regulation and fishing by foreign vessels) Act 1980
- Forest (Conservation Act) - 1980
- Environmental (Protection) Act - 1986
- Coastal Zone Regulation Notification - 1991
- Wildlife (Protection) Amendment Act - 1991
- National Conservation Strategy and Policy Statement on Environment and I Development - 1992
- National Policy And Macro level Action Strategy on Biodiversity-1999

India is also a signatory to the Ramsar Convention on Wetlands and the Convention of Biological Diversity. Apart from government regulations, development of better monitoring methods is needed to increase the knowledge of the physical and biological characteristics of each wetland resource, and to gain, from this knowledge, a better understanding of wetland dynamics and their controlling processes. India being one of the mega diverse nations of the world should strive to conserve the ecological character of these ecosystems along with the biodiversity of the flora and fauna associated with these ecosystems.

1.3.5 CONVENTION ON WETLANDS (RAMSAR, IRAN, 1971)[24]

The Convention on Wetlands is an intergovernmental treaty adopted on 2 February 1971 in the Iranian city of Ramsar, on the southern shore of the Caspian Sea. Thus, though nowadays the name of the Convention is usually written "Convention on Wetlands (Ramsar, Iran, 1971)", it has come to be known popularly as the "Ramsar Convention". Ramsar is the first of the modern global intergovernmental treaties on conservation and wise use of natural resources, but, compared with more recent ones, its provisions are relatively straightforward and general. Over the years, the Conference of the Contracting Parties (the main decision-making body of the Convention, composed of delegates from all the Member States) has further developed and interpreted the basic tenets of the treaty text and succeeded in keeping the work of the Convention abreast of changing world perceptions, priorities, and trends in environmental thinking.

The treaty – *The Convention on Wetlands of International Importance especially as Waterfowl Habitat* – reflects its original emphasis on the conservation and wise use of wetlands primarily to provide habitat for water birds. Over the years, however, the Convention has broadened its scope to cover all aspects of wetland conservation and wise use, recognising wetlands as ecosystems that are extremely important for biodiversity conservation in general and for the well-being of human communities. For this reason, the increasingly common use of the short form of the treaty's title, the "Convention on Wetlands", is entirely appropriate. The Convention entered into force in 1975 and has 150 Contracting Parties. More than 1590 wetlands have been designated for inclusion in the List of Wetlands of International Importance, covering some 134,030,385 hectares. UNESCO serves as Depositary for the Convention, but its administration has been entrusted to a secretariat known as the "Ramsar Bureau", which is housed in the headquarters of IUCN–The World Conservation Union in Gland, Switzerland, under the authority of the Conference of the Parties and the Standing Committee of the Convention. The implementation of the Convention on Wetlands is guided by its mission statement, which is" The Convention's mission is the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world". To mark the date of the signing of the convention on wetlands, 2nd February of each year is observed as World Wetlands Day (WWD). It was celebrated for the first time in 1997 and the beginning was quite encouraging. Each year a theme is suggested for the day. Last year in 2002, it was 'Water, Life, Culture'. In year 2003 the theme was 'No Wetlands – No Water'. This theme was chosen in honour of the UN's International Year of Fresh Water (IYF). This is to strengthen the UN's efforts and also to be the first to initiate the IYF celebrations. As a part of conservation strategy a data book called Montreaux Record is kept of all those wetlands, which require international help for conservation. The inclusion of a site in this list makes it eligible for global package for conservation. Each year an award known as 'International Ramsar Convention Award' is given to the best conservation efforts and it carries a cash prize of $ 10,000 and a commendation[25].

1.3.6 CONSERVATION AND RESTORATION OF WETLANDS -THE ECOSYSTEM APPROACH

Wetlands are an integral part of a watershed; and everything is connected to everything else on this earth. The ecosystem is interactive and there is a continuous interaction between adjacent ecosystems and their components. What happens at one level eventually impacts the other levels. We need to understand the causes and long-term solutions to our environmental problems. The fragmented approach of finding quick fix solutions, although convenient, obscures the essential unity of many processes taking place, ignoring the functional linkages that are vital to natural ecosystems. An ecosystem approach assigns a role to all the components in a larger 'whole', where the individual components contribute to the overall structure. The approach recognises the interrelationships between land, air, water, wildlife, and human activities. This can be evidenced by this simple example of how the air pollution catapulted by the spiralling consumption of fossil fuels has led to the contamination and acidification of lakes and waterbodies which in turn has led to the death and extinction of many aquatic organisms. Thus, to understand a lake ecosystem, the view must be as large as the watershed, the air shed, the landscape and eventually as large as the biome or the planet (Gene.E Likens [26]).

Lack of ecosystem approach in the management of natural resources has led to the current chaos. The water systems should be studied and managed as part of the broader environment through a systems approach. A true systems approach recognises the individual components as well as the linkages between them, and that a disturbance at one point in the system will be translated to other parts of the system. Sometimes the effect on another part of the system may be indirect, and may be damped out due to natural resilience and disturbance. Sometimes the effect will be direct, significant and may increase in degree as it moves through the system. (Ramachandra T.V [27]) .

The 'ecosystem approach' emphasises the management of the watershed along with the waterbody to ensure the sustainable use and management of water resources. In this direction, restoration of catchments with natural vegetation and maintenance of the green belt around the cities to prevent the runoff contaminated with silt and pollutants, reuse and recycling of water through appropriate use and practices becomes essential. There is obviously much ground to be covered in our conservation efforts for wetlands. In addition, a paradigm shift in our conservation ethic is also a strong need of the hour. This shift is necessary and perhaps mandatory due to the very nature of the resource being conserved and 'protected'. Since, wetlands are a common property resource, it is an uphill task to protect or conserve the ecosystems unless the principal stakeholders are involved in the process.

1.3.7 WETLANDS IN INDIA

India has a rich variety of wetland habitats. Most of the wetlands in India are directly or indirectly linked with major river systems such as Ganga, Cauvery, Krishna, Godavari and Tapti. Wetlands distributed from the cold arid Trans-Himalayan zone to wet Terai regions of Himalayan foothills and Gangetic plains extend to the floodplains of Brahmaputra and swamps of northeastern India including the saline expanses of Gujarat and Rajasthan. Along the east and west coasts they occur in the deltaic regions to the wet humid zones of Southern peninsula and beyond, to the Andaman and Nicobar and Lakshadweep Islands. India also shares several of its wetlands with Ladakh and the Sunderbans deltas with Bangladesh. These wetland systems are directly or indirectly associated with river systems of the Ganges, Brahmaputra, Narmada, Tapti, Godavari, Krishna and Cauvery. Southern peninsular India has very few natural wetlands, although there are a number of man-made water storage reservoirs constructed virtually in every village known as 'tanks' providing water for human needs and nesting sites for a variety of avifauna[28]. The total area of wetlands (excluding rivers) in India is 58,286,000 ha, or 18.4% of the country, 70% of which comprises areas under paddy cultivation. The country's wetlands are generally differentiated by region into eight categories (Scott, 1989): the reservoirs of the Deccan Plateau in the south, together with the lagoons and the other wetlands of the southern west coast; the vast saline expanses of Rajasthan, Gujarat and the gulf of Kutch; freshwater lakes and reservoirs from Gujarat eastwards through Rajasthan (Kaeoladeo Ghana National park) and Madhya Pradesh; the delta wetlands and lagoons of India's east coast (Chilka Lake); the freshwater marshes of the Gangetic Plain; the floodplain of the Brahmaputra; the marshes and swamps in the hills of north-east India and the Himalayan foothills; the lakes and rivers of the montane region of Kashmir and Ladakh; and the mangroves and other wetlands of the island arcs of the Andamans and Nicobars[29].

A survey conducted by the Ministry of Environment and Forests (MoEF) in 1990 showed that wetlands occupied an estimated 4.1 million hectares of which 1.5 million hectares were natural and 2.6 million hectares were man-made (excluding paddy fields, rivers and streams) and mangroves occupying an estimated 0.45 million hectares. About 80% of the mangroves were distributed in the Sunderbans of West Bengal and Andaman and Nicobar Islands, with the rest in the coastal states of Orissa, Andhra Pradesh, Tamil Nadu, Karnataka, Kerala, Goa, Maharashtra and Gujarat. A preliminary inventory by the Department of Science and Technology, recorded a total of 1193 wetlands, covering an area of about 3,904,543 ha, of which 572 were natural (Scott and Pole, 1989[30]). A Directory of Indian Wetlands published by WWF and Asian Wetland Bureau in 1995 records 147 sites as important of which 68 are protected under the National Protected Area Network by the Wildlife Protection Act of 1972.

Table 1.4: Area Estimates of Wetlands of India (in million ha) (Table source: *Directory of Asian Wetlands, IUCN,* 1989)

Area under paddy cultivation	40.9
Area suitable for fish culture	3.6
Area under capture fisheries (brackish and freshwater	2.9
Mangroves	0.4
Estuaries	3.9
Backwater	3.5
Man-made impoundments	3.0
Rivers, including main tributaries	(28,000 km)
Canals and irrigation channels	(113,000 km)
Total Area of Wetlands (Excluding Rivers)	58.2

Table 1.5: Distribution of wetlands in India Table source: (Ramachandra T.V., Kiran R., and Ahalya N, 2002[21])

Sl.No	State	Natural		Artificial	
		Nos.	**Area (ha)**	**Nos**	**Area (ha)**
1	Andhra Pradesh	219	1,00,457	19,020	4,25,892
2	Arunachal Pradesh	2	20,200	NA	NA
3	Assam	1394	86,355	NA	NA
4	Bihar	62	2,24,788	33	48,607
5	Goa	3	12,360	NA	NA
6	Gujarat	22	3,94,627	57	1,29,660
7	Haryana	14	2,691	4	1,079
8	Himachal Pradesh	5	702	3	19,165
9	Jammu and Kashmir	18	7,227	NA	21,880
10	Karnataka	10	3,320	22,758	5,39,195
11	Kerala	32	24,329	2,121	2,10,579
12	Madhya Pradesh	8	324	53	1,87,818
13	Maharashtra	49	21,675	1,004	2,79,025
14	Manipur	5	26,600	NA	NA
15	Meghalaya	2	NA	NA	NA
16	Mizoram	3	36	1	1
17	Nagaland	2	210	NA	NA
18	Orissa	20	1,37,022	36	1,48,454
19	Punjab	33	17,085	6	5,391
20	Rajasthan	9	14,027	85	1,00,217
21	Sikkim	42	1,107	2	3
22	Tamil Nadu	31	58,068	20,030	2,01,132
23	Tripura	3	575	1	4,833
24	Uttar Pradesh	125	12,832	28	2,12,470
25	West Bengal	54	2,91,963	9	52,564
	TOTAL	2167	14,58,580	65,251	25,87,965

Sl No	Union territories	Natural		Artificial	
		Nos	**Area (ha)**	**Nos**	**Area (ha)**
1	Chandigarh	-	-	1	170
2	Pondicherry	3	1,533	2	1,131
	Total	**3**	**1,533**	**3**	**1,301**
	Grand Total	**2,170**	**14,60,113**	**65,254**	**25,89,266**

A Directory of Wetlands in India (1988) gives information on the location, area and ecological categorisation of wetlands of our country. Efforts to conserve wetlands in India began in 1987 and the main focus of governmental efforts is on biological methods of conservation rather than adopting engineering options. Chilka lake and Keoladeo Ghana national park were the first two Ramsar sites in India. Later in 1990 Harike lake in Punjab, Wulur lake in Jammu and Kashmir, Loktak lake in Manipur and Sambhar lake in Rajasthan were included. Recently, eleven wetlands in India have been categorised for seeking international assistance to save them from distress situation. These include Point Calimere in Tamil Nadu, Astamudi, Sasthamkolta lake and Vembanad wetlands in Kerala, Kolleru lake in Andhra Pradesh, Bhitrakanika mangroves in Orissa, Pong Dam lake in Himachal Pradesh, East Calcutta wetlands in West Bengal, Bhoj wetlands in Madhya Pradesh, Tsomoriri in Jammu and Kashmir and Deepor Beel freshwater lake in Assam..

Chilka lake was on Montreaux Record of Ramsar due to adverse changes in its ecological character caused by pollution and other anthropogenic pressure was removed from the list in 2002. Subsequently, it bagged the International Ramsar Conservation Award.

1.3.8 STATUS OF WETLANDS IN BANGALORE

Bangalore, capital city of Karnataka is the sixth largest metropolis in the country. Bangalore urban with a population of more than five million consists of three taluks namely Anekal, Bangalore North and South. The city apart from being the political capital of the state is also a very important commercial centre housing some of the major industrial establishments, multinationals and software giants.

The district supports about 9.41% of the state's total population and 27.41% of the total urban population of the state. The urban agglomeration is spread between North and South taluks of Bangalore covering an area of about 151 sq. km. with an average population density of 16,399 individuals/ sq. km (census, 1991).

Table 1.6: Growth of Bangalore urban agglomeration(*Table source – Indian Express, October 30, 2005*)

Growth of Bangalore urban agglomeration		
Year	**Population**	**Area in Sq. Km**
1871	144,479	Not available
1941	410,967	69.93
1971	1,664,208	177.30
1981	2,921,751	365.65
1991	4,130,288	445.91
2001	5,686,844	530.85

Bangalore District is located in the heart of south Deccan of Peninsular India. It is situated in the southeastern corner of Karnataka state (12°39' – 13°18' N latitude and 77°22' – 77°52' E longitude) with a geographical area of about 2,191 sq. km (Bangalore rural and urban districts) at an average elevation of 900 m above the mean sea level. The climate of the district has agreeable temperature ranging from the highest mean maximum of 36.2° C in April to lowest mean maximum of 11.4° C in January. It has two rainy seasons from June to September and from October to November coming one after the other but with opposite wind regime, corresponding to south-west and north-east monsoons. The mean annual rainfall of about 900 mm with a standard deviation of 18.7 mm was recorded from the year 1875 to 1976 (Srinivasa et al, 1996) (Ramachandra T.V., Kiran R., and Ahalya N, 2002[21]).

Wetlands of Bangalore occupy about 4.8% of the city's geographical area (640 sq. km) covering both urban and rural areas (Krishna et al., 1996). Bangalore has many man-made wetlands but no natural wetlands. They were built for various hydrological purposes to serve the needs of irrigation and drinking water supply. The vast majority of the wetlands in Bangalore occur on the outskirts of the city in the rural fringe. Studies on lakes of Bangalore during the past decade show that 35% tanks were lost owing to various anthropogenic pressures. (Ramachandra T.V., Kiran R., and Ahalya N, 2002[21]). The number of man-made wetlands has fallen from 379 in 1973 to 246 in 1996 and further reduced to 81 at present (Lakshman Rau et al., 1986[31])

Bangalore – 'the garden city', once sported a large number of lakes, ponds and marshy wetlands, which ensured a high level of groundwater table and a pleasant climate. Urbanisation and anthropogenic stress in Bangalore city has led to the discontinuity of the drainage network due to loss of wetlands. Many lakes and ponds have already disappeared due to various developmental activities and pressures due to unplanned urbanisation and expansion. The remaining lakes are dying fast, as they are filled with solid waste materials and sewage. The present trends in decrease in the water quality and number of waterbodies are the result of unplanned development of the city, resulting in vast tracts of wetlands being cleared. Recent studies on lakes in Bangalore show that nearly 40 percent of lakes are sewage fed, 13 percent surrounded by slums, and 35 percent showed loss of catchment area. Lakes situated on the city outskirts are facing problems due to brick kilns contributing to the declining water quality. (Ramachandra T.V., Kiran R., and Ahalya N, 2002[21]).

1.3.9 NEED FOR ECOSYSTEM QUALITY ASSESSMENT OF WATERBODIES

Burgeoning human populations coupled with agricultural and industrial developments increase the pressure on water requirements. The restoration, conservation and management of these water resources require a thorough understanding of what constitutes a healthy ecosystem. Monitoring and assessment provides basic information on the condition of our waterbodies. Monitoring can be conducted to (EPA [32]):

- Characterise waters and identify changes or trends in water quality over time;
- Identify specific existing or emerging water quality problems;
- Gather information to design specific pollution prevention or remediation programs;
- Determine whether program goals -- such as compliance with pollution regulations or implementation of effective pollution control actions -- are being met; and
- Respond to emergencies, such as spills and floods.

Some types of monitoring activities meet several of these purposes at once; others are specifically designed for one reason. The information thus collected influences the legislative, economic and social practices adopted by society to improve and maintain the quality of the natural environment.

1.4 ECOLOGICAL ASSESSMENT OF WETLANDS

The overall condition or health of aquatic ecosystems is determined by the interaction of all its physical, chemical and biological components, which make up its ecosystem. Information on and understanding of environmental change is necessary to allow for the protection and remediation of ecosystems. Ecological assessment by way of analyses of all the components of the ecosystem helps in arriving at restoration methods towards the conservation, management and sustainable use of natural resources.

1.4.1 ASSESSMENT OF WATER QUALITY

Water pollution may be defined as the presence of impurities in such quantity and of such nature as to impair the use of water for a stated purpose. Thus, the definition of water quality is predicted on the intended use of the water, and the gross determination of the quantity of suspended solids and dissolved impurities, while useful in some cases, it is not sufficient to completely define water quality (Howard S. Peavy., Donald R. Rowe., and George Tchobanoglous, 1985[33]). Many parameters have evolved that qualitatively reflect the impact that various impurities have on selected water uses. Analytical procedures have been developed that quantitatively measure these parameters. APHA's *Standard methods for the Examination of Water and Wastewater* [2-15] have been one of the standard test procedures.

Many methods and criteria are available to assess aquatic ecosystems. A physico-chemical approach to monitor water pollution is most common and plenty of information is available on these aspects. Such data is valuable and necessary but does not provide all the information required in the assessment of water quality of the waterbody. It is not the pollution or the contamination alone that is the concern in water quality, rather the effects on the organisms. It is only by documenting these effects that the true impacts are defined. One of the most striking features of the past water assessment procedures has been the reliance placed upon physical and chemical techniques with relative neglect of biological parameters. Since water pollution in many instances is a biological phenomenon, it would appear logical that it ought to be measured biologically (Ramachandra T.V. Ahalya N., and Rajasekara Murthy C, 2005[34]).

Traditionally, water quality monitoring actions have focused on physical and chemical measurements. It is widely recognised that the use of other indicators, in addition and complimentary to traditional chemical and physical water quality monitoring techniques, can greatly enhance the assessment and management of aquatic ecosystems. In this regard, biological monitoring or biomonitoring has proved to be an important tool in assessing the condition of aquatic ecosystems. Biological methods used for assessing the water quality include the collection, counting, and identification of the aquatic organisms (APHA, 1985). Biomonitoring in conjunction with physical and chemical observation of water quality is potentially useful in characterising waterbodies. Chemical data measure concentration of pollutants, etc. in the waterbody, and the ecosystem imbalances are measured by biological information. Biological and chemical data are essential in understanding the ecosystem integrity.

1.4.2 PHYSICO CHEMICAL ASSESSMENT[35,36,37,38]

Physical character of lakes such as size, depth, number and the size of inflowing and out flowing streams and shoreline configuration influence the character of the lake. They also influence decisions about sampling locations, water quality parameters and how to interpret data collected. Shallow lakes are more likely homogenous, i.e. they are the same from top to the bottom and water is well mixed by wind. Physical characters like the temperature and oxygen vary little with depth. Sunlight reaches all the way to the lake bottom, photosynthesis and growth occurs throughout the water column and thus the growth rate or productivity is higher.

Physical parameters define those characteristics of water that respond to the sense of sight, touch, taste or smell. Suspended solids, turbidity, colour, taste, odour and temperature fall under this category. Chemical parameters are related to the solvent capabilities of water. Total dissolved solids, alkalinity, hardness, fluorides, metals, organics, and nutrients are chemical parameters of concern in water-quality management. Some of the important physical and chemical parameters, few of which are estimated in this study are discussed below.

1.4.2.1 **Temperature:** Temperature exerts a major influence on the biological activities and growth. To a certain point the increase in temperature leads to greater biological productivity, above and below which it falls and it also governs the kind of organisms (species composition). At elevated temperatures metabolic activity of the organisms' increases, requiring more oxygen but at the same time the solubility of oxygen decreases, thus accentuating the stress. Temperature influences water chemistry, e.g. DO, solubility, density, pH, conductivity etc. Water holds lesser oxygen at higher temperatures. Some compounds are more toxic to aquatic organisms at higher temperatures. Additionally temperature of drinking water has an influence on its taste. Temperature is expressed in Celsius and a thermometer- 0.1^{o} C division is used to measure temperature.

1.4.2.2 Total solids, Total suspended solids & Total dissolved solids: Solids refer to matter suspended or dissolved in water or wastewater. Solids may affect water or effluent quality adversely in a number of ways. Waters with high dissolved solids generally are of inferior palatability. Waters high in suspended solids may be aesthetically unsatisfactory especially for purposes such as bathing. Solid analyses are important in the control of biological and physical wastewater treatment processes. Total solids are the term applied to the material left in the vessel after evaporation of a sample and its subsequent drying in the oven at a defined temperature. Total solids include total suspended solids, the portion of total solids retained by a filter, and total dissolved solids, the portion that passes through the filter. Total solids are expressed as mg/L of water. A limit of 500 mg/L TDS is desirable for drinking waters. Total dissolved solids can be measured using a meter and the total solids and total suspended solids can be weighed in the lab by evaporation.

1.4.2.3 **Turbidity:** Suspension of particles in water interfering with passage of light is called turbidity. Turbidity of water is responsible for the light to be scattered or absorbed rather than its straight transmission through the sample, it is the size, shape, and refractive index of suspended particulates rather than the total concentration of the latter present in the water samples that are responsible for turbidity. The turbidity and transparency values are inter related, just like that of total dissolved solids and conductivity values. Turbidity in natural waters restricts light penetration thus limiting photosynthesis, which consequently leads to depletion of oxygen content. Turbid waters are highly undesirable from aesthetic point of view in drinking water supplies and may also affect products in industries. Turbidity can be removed by filtration, coagulation, etc. in drinking water treatment plants. Turbidity in water is caused by a wide variety of suspended matter, which range in size from colloidal to coarse dispersions and also ranges from pure organic substances to those that are highly organic in nature. Clay, silt, organic matter, phytoplankton and other microscopic organisms cause turbidity in natural waters. Turbidity is expressed in Nephlometric turbidity units (NTU) and is measured using a nephelometer. The term Nephelometric refers to the way the instrument estimates how light is scattered by suspended particulate material in the water. Turbidity can also be expressed in ppm. Permissible limit in drinking water is <10 NTU.

1.4.2.4 **Transparency:** Transparency is a characteristic of water that varies with the combined effect of colour and turbidity. It measures the light penetrating through the waterbody. Clear water lets light penetrate more deeply into the lake than does murky water. This light allows photosynthesis to occur and oxygen to be produced. Pollution tends to reduce water clarity. Transparency values are expressed in cm or mm. Secchi disc, a metallic disc of 20 cm diameter with four quadrats of alternate black and white on the upper surface is used to measure transparency.

1.4.2.5 **pH:** pH – potential of hydrogen, is the measure of the concentration of hydrogen ions. It provides the measure of the acidity or alkalinity of a solution and is measured on a scale of 0 – 14. The pH of water is 7, which is neutral, and lower than 7 is acidic, while higher than 7 is termed as alkaline. The pH of water determines the solubility and biological availability of certain chemical nutrients such as phosphorus, nitrogen, carbon and heavy metals like lead, copper, cadmium, etc. pH determines how much and what form of phosphorus is most abundant in water. It also determines whether aquatic life can use the form available. In the case of heavy metals the degree to which they are soluble determines their toxicity. Metals tend to be more toxic at lower pH because they are more soluble in acidic waters. pH is measured on a scale of 0 – 14. pH of natural waters would be around 7, but mostly basic. pH of seawater is around 8.5. pH of natural water usually lies in the range of 4.4 to 8.5. BDH Indicator (Universal Indicator) and test tubes or a pH meter can be used to measure pH.

1.4.2.6 **Specific conductivity:** Conductivity is the capacity of water to conduct electric current which varies both with the number and types of ions the solution contains. Most dissolved inorganic substances in water are in the ionised form and hence contribute to conductance. Thus, measurement of conductivity also gives a rapid and practical estimate of the dissolved mineral contents of water. Conductivity is highly dependant on temperature and therefore is reported normally at 25°C to maintain comparability of data from various sources. Conductivity is reported in mmho or μ mhos/cm, though the recent unit of conductivity has been named Siemens/cm (S) instead of mho. Conductivity meter is used to measure conductivity.

1.4.2.7 **Dissolved oxygen:** Sources of oxygen in water are by diffusion of oxygen from the air into the water, photosynthetic activity of aquatic autotrophs and inflowing streams. DO is a very important parameter for the survival of fishes and other aquatic organisms. Diffusion of oxygen or transfer of oxygen in these organisms is efficient only above certain concentrations of oxygen. Too low concentrations of oxygen may not be enough to sustain life. Oxygen is also needed for many chemical reactions that are important to lake functioning (oxidation of metals, decomposition of dead and decaying matter, etc.). Measurement of DO can be used to indicate the degree of pollution by organic matter. DO is expressed as mg/L. DO concentrations of below 5 mg/L may adversely affect the functioning and survival of biological communities. Below 2 mg/L may lead to fish mortality. DO can be determined in the laboratory using various methods, which are explained in detail in the forth-coming chapters.

Table 1.7: Dissolved oxygen level and water quality

D.O (mg/L)	Water quality
Above 8.0	Good
6.5-8.0	Slightly polluted
4.5-6.5	Moderately polluted
4.0-4.5	Heavily polluted
Below 4.0	Severely polluted

1.4.2.8 **Alkalinity:** The alkalinity of water is a measure of its capacity to neutralise acids. The alkalinity of natural waters is due to the salts of carbonates, bicarbonates, borates, silicates and phosphates along with the hydroxyl ions in free state. However, the major portion of the alkalinity in natural waters is caused by hydroxide, carbonate and bicarbonate, which may be ranked in order of their association with high pH values. Alkalinity values provide guidance in applying proper doses of chemicals in wastewater treatment processes, particularly in coagulation, softening and operational control of anaerobic digestion. Alkalinity is expressed as mg/L.

1.4.2.9 **Total hardness, Calcium hardness & Magnesium hardness:** Water hardness is the traditional measure of the capacity of water to react with soap, hard water requiring a considerable amount of soap to lather. Hardness is generally caused by the calcium and magnesium ions (bivalent cations) present in water. Polyvalent ions of some other metals like strontium, iron, aluminium, zinc and manganese, etc. are also capable of precipitating the soap thus contributing to hardness. However, the concentration of these ions is very low in natural waters, therefore hardness is generally measured as concentration of only calcium and magnesium, which are far higher in quantities over other hardness producing ions. Hardness is measured in terms of mg/L using standard methods involving reagents.

1.4.2.10 **Nitrates:** Freshly polluted systems, especially by sewage contamination, show higher concentration of ammonia nitrogen, which in an aerobic environment is converted into nitrites and then to nitrates. Nitrate nitrogen is an indicator of past pollution in the process if stabilisation. The increasing application of fertilisers in agricultural land has resulted in water pollution due to leaching of nutrients like nitrogen and phosphorus. Total oxidised nitrogen is the sum of nitrate and nitrite nitrogen. Nitrates, in excessive amounts in drinking water leads to an illness known as methemoglobinemia in infants. Nitrates are measured in terms of mg/L and are measured in the laboratory using reagents. WHO has imposed a limit of 10 mg/L nitrate as nitrogen on drinking water to prevent the disorder of methemoglobinemia. Nitrates may be found in concentrations of up to 30 mg nitrates as nitrogen /L in some effluent of nitrifying biological treatment plants.

1.4.2.11 **Phosphates:** Phosphorus occurs in natural waters and in wastewaters almost solely as phosphates. These are classified as orthophosphates, condensed phosphates and organically bound phosphates. They occur in solution, in particles or detritus or in the bodies of aquatic organisms. Orthophosphate is the phosphorus form that is directly taken up by algae, and the concentration of this fraction constitutes an index of the amount of phosphorus immediately available for algal growth. Phosphorus is essential to the growth of organisms and can be the nutrient that limits the primary productivity in water. In instances where phosphate is a growth limiting nutrient, the discharge of raw or treated wastewater, agricultural drainage, or certain industrial waste to that water may stimulate the growth of photosynthetic aquatic micro and macro organisms in consequential quantities. Phosphates are measured in terms of mg/L in the laboratory using standard methods.

1.4.2.12 **Sodium:** The increased pollution of surface and groundwater during the past has resulted in a substantial increase in the sodium content of drinking water in many regions. Sewage, and industrial effluents and the use of sodium compounds for corrosion control and water softening processes all contribute to sodium concentration in water because of high solubility of sodium salts and minerals. It is expressed as mg/L. In surface waters the concentrations may be less than 1 mg/L or exceed 300 mg/L depending on the geographical area. The recommended guideline value is 200 mg/L. Sodium in water is measured using a flame photometer in the laboratory.

1.4.2.13 **COD:** COD is the oxygen required by the organic substances in water to oxidise them by a strong chemical oxidant. The determination of COD values are of great importance where the BOD values cannot be determined accurately due to the presence of toxins and other such unfavourable conditions for growth of microorganisms. COD usually refers to the laboratory dichromate oxidation procedure. COD test has an advantage over BOD determination in that the result can be obtained in about 5 hours as compared to 5 days required for BOD test.

Impact of pollution on DO – BOD and COD: Pollution like sewage contributes oxygen demanding organic matter or nutrients that stimulate growth of organic matter, which causes a decrease in the average DO concentrations. The decomposition process takes up the DO and results in the decrease in average DO. If the organic matter is formed in the lake by algal growth, at least some oxygen is produced during growth to offset the loss of oxygen during decomposition. It is expressed as mg/L and the analysis is done in the laboratory.

1.4.3 BIOLOGICAL MONITORING

Biological monitoring or bio-monitoring is the use of biological response to assess changes in the environment. Bio-monitoring is a valuable assessment tool that is receiving increased use in water quality monitoring programs of all types (Kennish, 1992[39]). In the operational context, the term aquatic biomonitoring is used to refer to the gathering of biological data in both the laboratory and the field for the purposes of making some sort of assessment, or in determining whether regulatory standards and criteria are being met in aquatic ecosystems. Biomonitoring involves the use of biotic components of an ecosystem to assess periodic changes in the environmental quality of the ecosystem. Biomonitoring of aquatic communities can be subdivided into a number of categories, as follows: (Roux et al, 1993): (RHP-South African River Health Programme [40])

- Bioassessments are based on ecological surveys of the functional and/or structural aspects of biological communities.
- Toxicity bioassays are a laboratory-based methodology for investigating and predicting the effect of compounds on test organisms.

- Behavioural bioassays explore sub-lethal effects of fish or other species when exposed to contaminated water; usually as on-site, early warning systems.
- Bioaccumulation studies monitor the uptake and retention of chemicals in the body of an organism and the consequent effects higher up in the food chain.
- Fish health studies deal with causes, processes and effects of diseases; and can form a complementary indication of overall ecosystem health.

Biomonitoring involves the use of indicators, indicator species or indicator communities. An indicator signals messages, potentially from numerous sources, in a simplified and useful manner. An indicator may reflect biological, chemical or physical attributes of ecological condition. The primary uses of an indicator are to characterise current status and to track or predict significant changes. An ecological indicator has been used to identify major ecosystem stress through their presence, condition, and numbers of the types of fish, insects, algae, amphibians, and plants, etc. These types of plants and animals are called biological indicators or bioindicators (EPA). The fundamental principle behind biological indicator theory is that organisms provide information about their habitats.

Bioindicators are evaluated through presence/absence, condition, relative abundance, reproductive success, community structure (i.e. composition and diversity), community function (i.e. trophic structure), or any combination thereof (Hellawell, 1986[41], Landres et al. 1988[42]). The presence or absence of the indicator or of an indicator species or indicator community reflects the environmental conditions of the waterbody under study. Absence of a species is not as meaningful as it might seem, as there may be reasons, other than pollution, that result in its absence (e.g. Predation, competition or geographic barriers which prevented it from ever being at the site). Absence of multiple species of different orders with similar tolerance levels that were present previously at the same site is more indicative of pollution than absence of a single species. It is necessary to know which species should be found at the site or in the system.

Biological indicators integrate, in themselves, the effects of various stressors, aquatic organisms and their communities reflecting current conditions, as well as changes over time and cumulative effects. Biodiversity of microbes, invertebrates and fishes can be used to indicate chronic pollution problems. Biological indicator species are unique environmental indicators as they offer a signal of the biological condition in a watershed. Using bioindicators as an early warning of pollution or degradation in an ecosystem can help sustain critical resources.

Assessing the status of aquatic systems through biological analyses is an old endeavour. European studies of pollution dating back to the 1800's identified aquatic organisms indicating environmental degradation. Since then, investigations and monitoring of aquatic environment health has relied heavily on indicator species as the primary diagnostic and monitoring tool (Mark B. Bain et al.[43]).

Generally, benthic macro invertebrates, fish / or algae are used. Certain aquatic plants have also been used as indicator species for pollutants including nutrient enrichment (Philips and Rainbow, 1993; Batiuk et al., 1992[44]). A great deal of work has been done on using algae as bio-indicators of pollution (Mohanty, 1983[45]; Reddy and Venkateswarlu, 1986[46]; Tripathy, 1989[47]; Mohapatra & Mohanty, 1992[48]).

Apart from information derived from monitoring of in-stream biotic communities, the evaluation of the health aquatic ecosystems must also include other system descriptors. The assessment of the available habitat is crucial when comparing biomonitoring results from different sites. The characterisation of geomorphological characteristics, hydrological and hydraulic regimes, chemical and physical water quality and riparian vegetation form essential components in aquatic ecosystem health assessment.

Different approaches have been used to prepare and analyse biological indicator data. But they all start out with a list of aquatic life that was collected and identified. This list is often called a "species" list, but because many benthos can not be identified to species, it is also called a "taxon" list. In the past, the presence or absence of a few indicator species, such as game fish, was used to assess watershed health. Eventually, length and weight measurements of fish were also used, and numeric indices for benthos were developed. Such indices were first called biotic indices because they assigned number scores to the pollution tolerance of many different biological indicator species. While biotic indices were expanding in use, other indices, such as diversity indices, grew in popularity and were used for many years. Recently, multiple metric indices, such as the Index of Biotic Integrity by Dr. James Karr (1981), have become the standard in the United States for accurately assessing watershed health.

Biological indicators are currently used and promoted by numerous conservation agencies as a means to monitoring and assess human impacts on environments, including the World Conservation Union (IUCN), World conservation Monitoring Centre (UNEP), U.S. Environmental Protection Agency (US EPA), as well as the Nature Conservancy, World Wide Fund for Nature (WWF), Friends of the Earth (FOE), and Greenpeace (IUCN 1989[49], US EPA 2002a [50], UNEP 2002[51]).

1.4.3.1 Plankton as indicators of water quality

'Plankton' refers to those microscopic aquatic forms swimming with little or no resistance to currents and living free floating suspended in open or pelagic waters. Planktonic plants are called phytoplankton and planktonic animals are called the zooplankton.

Phytoplankton (microscopic algae) usually occurs as unicellular, colonial or filamentous forms and is mostly photosynthetic and is grazed upon by the zooplankton and other organisms occurring in the same environment. Zooplankton principally comprise of microscopic protozoans, rotifers, cladocerans and copepods. The species assemblage of zooplankton also may be useful in assessing water quality.

Plankton, particularly phytoplankton, has long been used as indicators of water quality. Because of their short life spans, planktons respond quickly to environmental changes. They flourish both in highly eutrophic waters while a few others are very sensitive to organic and/or chemical wastes. Some species have also been associated with noxious blooms sometimes creating offensive tastes and odours or toxic conditions. Because of their short life cycles planktons respond quickly to environmental changes, and hence the standing crop and species composition indicate the quality of the water mass in which they are found. They strongly influence certain non-biological aspects of water quality such as pH, colour, taste, odour and in a very practical sense they are a part of the water quality.

Phytoplankton growth is dependent on sunlight and nutrient concentrations. An abundance of phytoplankton / algae is indicative of nutrient pollution (De Lange, 1994[52]). Moreover algae are sensitive to some pollutants at levels, which may not visibly affect other organisms in the short term or may affect other communities at higher concentrations. Algae is used as indicator organisms because of the following advantages:

- Algae have very short life cycles and rapid reproduction.
- Algae tend to be most directly affected by physical and chemical environmental factors.
- Sampling is easy and inexpensive which requires few persons for assessment and has a lesser impact on other organisms.
- Standard methods exist. (Plafkin et al., 1989[53]).

For a number of years there has been a series of proposals indicating that one or more algae could be used as organisms indicative of water quality (Palmer, 1959[54]). It also demonstrated that algal assemblages could be used as indicators of clean water or polluted water. Clean water would support a great diversity of organisms, whereas polluted water would yield just a few organisms, with one or few dominant forms (Trainor, 1984[55]). In this context, the micro algae have great potential for monitoring and evolving the water quality of the waterbodies. (Venkataraman et al, 1994[56]).

Zooplankton in freshwaters principally comprises of microscopic protozoan, rotifers, cladocerons and copepods, a much greater variety of organisms are encountered in marine waters. They range in size from microscopic protozoan to larger jellyfish of over 10 m long, wherein in freshwater they generally are small and microscopic in size: in salt water, larger forms are observed more frequently. The species assemblage of zooplankton is also used in the assessment of water quality. Most zooplankton occupy an intermediate second or the third trophic level of aquatic food webs feeding on algae and bacteria and in turn being eaten by numerous invertebrates and fish. Therefore, any adverse effect to them will be indicated in the health of the fish populations. Protozoan plankton, though important requires specific and more elaborate study techniques. Zooplankton as indicators for the assessment of water quality has the following advantages:

- Zooplankton are sufficiently large and easy to identify, but small enough to be handled in large numbers within a limited space.
- Samples can be collected easily and processed rapidly.
- Their reproductive cycle is short enough to enable the study through several generations in a relatively short time.
- Some of the commonly occurring species like *Daphnia, Cyclops, Brachionus* and *Moina* can be easily cultured to ensure constant supply for experimental purposes.
- They respond more rapidly to environmental changes than fishes, which have been traditionally used as indicators of water quality.

1.4.3.2 Macroinvertebrates as indicator species

Aquatic invertebrates live in the bottom parts of waterbodies. They are also called benthic macroinvertebrates, or benthos, (benthic = bottom, macro = large, invertebrate = animal without a backbone). Examples of some macroinvertebrates are nymphs of stoneflys, mayfly, caddisfly larvae, snails, mussels, crustaceans, rat-tailed maggot, etc. Macroinvertebrates convert and transport nutrients from one part of the waterbody to another, influencing nutrient cycling. They ingest organic matter such as leaf litter and detritus and in turn become food for higher aquatic organisms such as fish, forming a basic link between organic matter and higher aquatic animals in the food web. They are sensitive to changes in habitat and pollution, especially to organic pollution (Ramachandra T.V. Ahalya N., and Rajasekara Murthy C, 2005[57])

They make good indicators of watershed health because they:

- live in the water for all or most of their life
- stay in areas suitable for their survival
- are easy to collect
- differ in their tolerance to amount and types of pollution

- are easy to identify in a laboratory
- often live for more than one year
- have limited mobility
- are integrators of environmental condition

The use of aquatic organisms, particularly benthic invertebrates, as biomonitors of the local availabilities of potentially toxic trace metals has become increasingly widespread (Cain[58]; Hare[59] and Phillips[60]). Bioaccumulation of heavy metals by aquatic insect larvae including mayflies is comparatively well studied (Hare[61]; Hare and Goodyear[62]), and larvae have been employed in biomonitoring studies of freshwaters.

1.4.3.3 Fish as indicator species

Fish are the most abundant, widespread and diverse group of vertebrates with various forms, shapes and sizes. Fish are keystone species in many aquatic food webs, where they may regulate the abundance and diversity of prey organisms through top-down effects (e.g., Northcote, 1988[63]; Carpenter and Kitchell, 1993[64]; Vanni et al., 1997[65]). Fish have been used for many years to indicate whether waters are clean or polluted, doing better or getting worse. Knowing just whether fish live in the waters is not enough - we need to know what kinds of fish are there, how many, and their health. Fish are excellent indicators of watershed health because they:

- live in the water all of their life
- differ in their tolerance to amount and types of pollution
- are easy to collect with the right equipment
- are easy to identify in the field

However, sampling fish requires high level of resources (time labour, and cost of equipment) and this increases with the size of the habitat.

LITERATURE REVIEW

The geographical distribution, morphometry and water quality of lakes within large calderas (> 2 km in diameter) were evaluated by Gary L. Larson[66] (1989) through a review of the literature and maps. Eighty-eight lakes in 75 calderas were located in 31 volcanic sub regions. As a group, the lakes varied greatly in elevation, surface area, maximum depth, and shoreline development. The 'average' surface area was 16.9 sq. km, surface elevation 873 m, depth 151.1 m, and shoreline development 1.35. Water quality ranged from ultraoligotrophic to highly eutrophic. Water clarity in some lakes was among the highest recorded for freshwater systems, but there were indications of possible declining clarity in some cases. Secondary volcanic activity, such as primary (hydrothermal) water and eruptions, has been associated with deteriorated water quality conditions in some lakes. The study suggested that, as a group, the water quality characteristics exhibited by caldera lakes are not only a function of their size, shape, and watersheds and climate, but also a function of secondary volcanic activity as well.

The International Joint Commission (IJC) established by the 1909 Boundary Waters Treaty between Canada and the United States stands to cooperatively resolve disputes between the two countries, including water and air pollution, lake levels, power generation, and other issues of mutual concern has been involved in assessing and tracking aquatic ecosystem health in the Great Lakes. As the concern for pollution increased, the IJC was given the responsibility to assist in the implementation of the Great Lakes Water Quality Agreement (GLWQA), to restore and maintain the chemical, physical, and biological integrity of the waters (Canada & the United States, 1972). In 1987, the International Joint Commission's Great Lakes Water Quality Board (GLWQB) recommended and adopted, in principle, a set of quantitative and qualitative listing/delisting criteria for each of the 14 use impairments.

John H. Hartig and Michael A. Zarull[67] (1992) established a consistent set of criteria that can be uniformly applied throughout the Great Lakes basin to assist in making recommendations on listing and delisting Great Lakes Areas of Concern, which are intended to provide a 'set of rules' that are consistent with the GLWQA and can be uniformly applied throughout the Great Lakes basin.

Huang, Yiping, Zhu, Min[68] (1996) discussed basic strategies to protect water quality and prevent eutrophication in relation to lake Tailhu, the third largest freshwater lake in the most advanced economic zone in China, with a surface area of 2338 sq. km, in Changjiang River Delta,. Water quality monitoring was done during 1986 to 1993, the dynamic variations of water quality and eutrophication trends were analysed, showing obvious spatial and temporal variations. Great quantities of pollutants had been discharged into the lake, due to which its nutrient content had increased continuously, and phytoplankton blooms occurred in some areas.

Many rivers were being dammed owing to the irregular distribution of water supply in Africa in an effort to aid development. Volta, along with Nasser, Kariba, Kainji is one such large, man-made reservoir occupying over 7000 sq km of the total area of Ghana. Viner A.B[69] (1969) discusses the general limnology of lake Volta and provides comparison of the lake's hydrological regime to other tropical lakes, based on investigations in January 1965 about six months after the closure of the dam. There was an initial brief boom of productivity followed by extreme deoxygenation with high turbidity, low light penetration and no thermocline. There was fish mortality, and the conditions common upon the immediate impoundment of water.

1.5 STUDIES USING ORGANISMS AS BIO INDICATORS

The term 'bioindicator species' was coined by Kolkwitz and Marsson in 1908 and 1909 regarding the impact of organic pollution (i.e. sewage) on aquatic organisms (Rosenburg & Resh 1996). Bioindicator literature has since developed to include the concepts of population and biodiversity indicators. Indices of Biotic Integrity and other similar multi metric concepts have developed since the 1970's as methods to quantitatively assess environmental condition through habitat indicators. Biological indicators are currently used and promoted by numerous conservation agencies as a means to monitoring and assessing human impacts on environments, including the World Conservation Union (IUCN), World conservation Monitoring Center (UNEP), U.S.Environmental Protection Agency (US EPA), as well as the Nature Conservancy, World Wide Fund for Nature (WWF), Friends of the Earth (FOE), and Greenpeace (IUCN 1989[70], US EPA 2002a[71], UNEP 2002[72].

It has been established that environmental disturbances induce changes in the structure and function of biological systems. The benthic flora and fauna of freshwaters has been the subject of intensive ecological research because they play an important role as indicators of aquatic pollution (Wilhm[73], 1975; Tudorancea[74] et al., 1979; James[75], 1979; Mason[76], 1981 and Olivieri[77], 1982). The benthic community structure represents an integral measure of autotrophic and heterotrophic process in lakes, and reflects disturbances in these processes. A better understanding of the effects of pollution is obtained when biological data are correlated with the physical and chemical parameters. However, biological indicators provide direct evidence of the effects of pollution, whereas physical and chemical data provide only indirect evidence. No single species by itself will indicate the full scope of potential hazards coincident with the various uses of water or provide all the information for an adequate evaluation.

Viner A. B[78] gives an account of some biological features associated with the hydrological and morphological characteristics of Lake Volta, which have already been described (Viner, 1969). It discusses some biological effects of water mixing and morphometry of lake Voltas. Both the zooplankton and the phytoplankton showed relationships to the physico-chemical regime of Lake Volta. Very little plankton was found below the thermoclines and oxygen discontinuities whenever they existed, even though the temperature drop at the thermal discontinuity was always very small (approx. 0.5°C). The preliminary survey of the phytoplankton in Lake Volta has shown that there was some relationship between the morphometry and degree of stratification.

Tariq A. Khan[79] (2003) recorded bi-monthly, November 1999–September 2001, major biological parameters of four permanent (Lake Colac, Modewarre, Bolac and Tooliorook), shallow and slightly saline lakes in the volcanic plains of western Victoria, Australia. Chlorophyll *a* concentration ranged from 3–29 μg l−1 with peaks in autumn. Phytoplankton taxa recorded were diverse, with Chlorophyta and Bacillariophyta being common. Cyanobacterial blooms were recorded mostly in summer. Zooplankton abundance in the lakes ranged from 12–368 individuals per litre. Rotifera dominated Lake Bolac, Copepoda dominated Lake Modewarre and they co-dominated Lake Colac and Tooliorook. A decline in the abundance of zooplankton in summer in Lake Modewarre was attributed to predation by high number of exotic larval carp at that time of the year. A total of 25 benthic macroinvertebrate taxa were recorded from Lake Colac, 30 from Modewarre, 22 from Bolac and 35 from Tooliorook. Twenty-one of the 45 taxa identified occurred in at least three lakes. Nine of the 12 taxa that occurred in only one lake were from Lake Tooliorook. Physico-chemical parameters revealed that the lakes were homogenous with few differences between sites within lakes. Of the four lakes, Lake Modewarre had the highest salinity of 8 ppt with weak seasonal fluctuations in salinity in all the lakes. All the lakes were turbid (turbidity range 30–659 NTU), with low light penetration (suspended solids range 23–465 mg l−1) and low Secchi depth (Secchi depth range 7.7–89 cm). pH of the lakes varied between 8.2 and 9.3 with low seasonal variations, indicating well buffered waters. Based on nutrient status, lakes were classified as eutrophic to highly eutrophic with higher nutrient concentrations. Nitrogen was limiting in one lake (Lake Colac) and phosphorus in the other three lakes. The study suggested that meteorological events probably influenced the physico-chemical parameters of these lakes strongly.

Biswas[80] (1992) discusses relationship between the temperature and the density of phytoplankton in Ogelube a tropical African oligotrophic lake. Desmids dominated the phytoplankton during the warmest period between harmattan and rainy seasons. They declined with a high death rate as the increasing rains cooled the lake, shifting dominance successively to various algae other than desmids, regardless of any hydrological changes. Cooling continued as harmattan advanced and the resultant lowest temperature caused phytoplankton minimum probably by inhibiting vegetative increase rather than by killing. Desmids dominated phytoplankton rapidly arose to peak as water warmed up, suggesting the importance of temperature. Presence of desmids in all depths throughout the period bore no evidence of stratification.

Roasas[81] *et al.* (1985) evaluated the impact of the urban development and the discharges of liquid and solid wastes on water quality by biological methods using bacteria and macroinvertebrates as indicators, as well as physicochemical parameters in Lake Patzcuaro, which is one of the most important lakes in Mexico. The bacteriological determinations showed critical areas near the two main villages, Patzcuaro and Janitzio. The bacterial investigations indicated significant amounts of animal excreta throughout the lake. In areas of less urban influence, abundance of immersed vegetation with the benthic macroinvertebrate community presented high biotic diversity (> 2), and equitability indices (> 0.6). At the most polluted station (8), Oligochaetes, which are tolerant to organic matter, comprised 94% of the organisms. Physico-chemical characteristics are similar in the lake, except at station 8 where the lowest DO levels, highest ammonia and phosphorus concentrations were registered. This area, adjacent to a fish processing plant, is affected by domestic and industrial wastewater discharges. The authors concluded based on the results that the lake has been moderately polluted.

Rosas I[82]. *et al.* (1993) carried out an evaluation of water quality and phytoplankton composition position in order to determine the trophic conditions of Lake Patzcuaro (2035 m above sea level), a high altitude tropical lake in Mexico. Temperatures ranged from 15 to 23°C. Total phosphorus and inorganic nitrogen showed a seasonal variation; highest values coincided with the rainy season (0·48 and 2·1 mg litre^{-1}, respectively). Dissolved oxygen ranged from 2 to 7·9 mg/L at the surface and from 0·6 to 7·3 mg/L on the bottom, the lowest values being found in shallow zones. Average transparency varied from 0·62 to 1·4 m of Secchi depth. Rainfall was a primary factor in seasonal variability as it influenced both physical and biological conditions by contributing to the transport and deposition of silt, which mixed with sinking algal cells. The composition of the surface phytoplankton comprised a total of 49 species. General seasonal patterns of dominance alternated in a sequence beginning with Bacillariophyta, through Chlorophyta to Cyanophyta. Diatoms, the dominant group from February to early June, included *Melosira granulata, Stephanodiscus* sp., *Synedra* sp. and *Fragilaria* sp. During the rainy season (late June to September), *Microcystis aeruginosa, Oscillatoria* sp., *Anabaena* sp., *Merismopedia* sp., *Crucigenia cuadrata, Oocystis lacustris, Selenastrum gracile, Mallomonas* sp. and *Tetraediella* sp. were important. *Melosira granulata* was present throughout the period of study. Spatial and temporal variability in both physical and biological conditions made it difficult to assign a specific trophic state to Lake Patzcuaro. Nevertheless, the analysis of the algal community indicated a generally mesotrophic condition.

Liliana Favari[83] *et al.* studied the limnology, plankton, and biomagnification of pesticides at Ignacio Ramírez (IR) reservoir (Mexico). The reservoir is located in central Mexico, in an agricultural zone with high soil erosion. The dominant group of phytoplankton was Bacillariophyta (20–85%) in May, Cyanophyta (22–65%) in September, and Cyanophycean (10–65%), Chlorophycean (10–60%), and Bacyllariophycean (5–80%) species in March. The zooplankton were dominated by cladoceran species (40–70%). Organochlorine and organophosphate insecticides were bioconcentrated (2- to 10-fold) from water to algae, 10- to 25-fold in zooplankton, and 8- to 140-fold in fish. The authors' suggested that the bioaccumulation of these contaminants in fish and the potential for biomagnification in humans are perceived as threats.

1.6 STUDIES IN INDIA

Biological studies have been increasingly employed in monitoring water quality in lakes. (Zafar *et al.* 1981). Phytoplankton, zooplankton, macrophytic plants and fishes were used considerably in biomonitoring of lake ecosystems. Indian lentic ecosystems were investigated extensively for phytoplankton from mid 20th century (Biswas[84] 1949, Das and Srivastava[85] 1959, Munnavar 1970, Zafar 1967, V.S Rao, 1977 Sharma *et al.* 1982). These studies show that the dominant phytoplankton and their seasonality are highly variable in different waterbodies according to their nutrient status, age, morphometry and other locational factors. However, in majority of the cases, phytoplankton is dominated by cyanobacteria followed by diatoms, chlorococcales and euglenoids (Zafar, 1986).

Zooplankton was investigated in Indian lentic ecosystems (Arunachalam[86] *et al.* 1982, Suganan[87] 1995). These studies reveal different groups of zooplankton have their own peak periods of density, which is also affected by local environmental conditions prevailing at the time.

Ali M. B[88] *et al.* (1999) focused on toxic metal pollution, nutrient status of the lake and their magnification by algae and macrophytes in Lake Nainital, the sole source of drinking water for the local people and even to the majority of tourists. Water was found to be contaminated with metals like Cr, Cu, Fe, Mn, Ni, Pb and Zn. Concentration of some of them like Fe, Pb and Ni were higher than the recommended maximum permissible limits. Concentration of these metals was also found high in lake sediments. The level of metals amongst various components of lake varied considerably in different seasons. Plants and algae growing therein accumulated an appreciable amount of metals where water roots of *Salix* was more efficient than others in accumulation. Phytoremediation technology is proposed to restore water quality by harvesting submerged and floating biomass inhabiting littoral zone of the lake.

Aftab Alam[89] et al., (1996) adopted both qualitative and quantitative estimation of plakton, the presence of plankton, and the dynamics and effects of varying dominant biota on the plankton population in four freshwater ponds receiving pollutants. Plakton were identified using standard monographs of Edmondson (1959) and Pennak (1980). 'A' pond, which received detergent pollutants, showed less plankton with thirteen genera of phytoplankton and seven genera of zooplankton, the dominant phytoplankton being *Microcystis, Tetrapedia, Nostoc, Selenestrum, Euglena, Phacus* and certain diatom species and zooplankton such as *Branchionus, filinia, Hexarthra, Euchlanis, Monia, Cyclops and Diaptomus.* The poor results for pond 'A' compared to ponds 'B' (24 species of phytoplankton and 15 species of zooplankton) and 'D' (30 species of phytoplankton and 17 species of zooplankton) was attributed to the influx of phosphorus into the waterbody by washing activities and dominance of certain planktivorous insects. Also, presence of certain pollution tolerant species of phytoplankton such as *Oscillatoria, Scenedesmus, and Euglena* indicated a high degree of organic pollution. The study concluded that both eutrophication and macrophytic infestation are responsible for plankton richness of ponds and the dominant biota affected other biota, bringing changes in the biotic composition with few others interfering directly with the biotic community.

Khan M.A[90] (1996) discusses the comparison of the phytoplankton periodicity of a tropical upland reservoir in Nigeria (Liberty Dam, Jos Plateau) and a temperate type lake (L.Naranbagh) from the Kashmir Himalaya. Liberty Dam conformed to the ologotrophic-desmid plankton type whilst in L.Naranbagh, phytoplankton resembled the eutrophic chlorococcales-diatom plankton type. It was found that phytoplankton associations and periodicities in each of the two warm belt lakes were strongly driven by their respective local environments, including the marked seasonality of the climatic variables – rain, wind and solar radiation.

Muralidhar V.N[91] *et al* (2002) describes the physico-chemical characteristics of water, diversity and periodicity of phytoplankton in Gubbi tank, Tumkur city, Karnataka, India. Surface water samples were collected at an interval of 30 days for a period of one year. The physico-chemical parameters studied were within the permissible limits. Five classes and seventy two species represented the phytoplankton community namely Cyanophyceae, Chlorococcales, Bacillariophyceae , Euglenophyceae and Desmidiaceae.
The density of phytoplankton shows that Bacillariophyceae dominated and constituted 36.36% of total phytoplankton population followed by Chlorococcales (25%), Cyanophyceae (25%) and Desmidiaceae (6.82%) and Euglenophyceae (6.82%). In the

present study the maximum density of phytoplankton was recorded in May - 72760 Organisms/ Litre and minimum in September - 60099 Organisms / Litre. It was found that the density of the different groups of phytoplankton was more in the summer season than during rainy and winter seasons. Based on the results of Nygaard's and Palmer's algal indices the authors deduced that, the tank was eutrophic.

Shankar P Hosmani[92] (2002) adopted an integrated approach towards indicators of organic pollution in freshwaters. The advantage of each of the Biological indicators of water quality such as Saprobic index, Nyggard's index, Palmer's algal pollution index, biological index of pollution, inhibition threshold for dehydrogenase activity, Colilert defined substrate test, H_2S strip test: Detection of faecal pollution in water.

1.7 STUDIES IN BANGALORE, KARNATAKA, INDIA

Bangalore district is located in the heart of South Deccan of Peninsular India. It is situated in the southeastern corner of Karnataka state (12^o 39' – 13^o 18' N latitude and 77^o 22' – 77^o 52' E longitude) with a geographical area of about 2,191 sq. km and an average elevation of 900 m above the mean sea level. The climate of the district enjoys an agreeable temperature range from the highest mean maximum of 36.2^o C in April to lowest mean maximum of 11.4^o C in January. It has two rainy seasons from June to September and from October to November coming one after the other but with opposite wind regime, corresponding to south-west and north-east monsoons.

Bangalore city once sported a large number of lakes, ponds and marshy wetlands, which ensured a high level of groundwater table and a pleasant climate. It is a great pity that many lakes and ponds have already disappeared due to various anthropogenic activities and pressures due to unplanned urbanisation and expansion. Surviving lakes are reduced to cesspools due to direct discharge of industrial effluents and unregulated dumping of solid wastes.

Large-scale episodic mortality among the freshwater fishes of certain lakes of Bangalore City, Karnataka State, India occurred in June 1995. Benjamin Ranjeev[93] *et al* (1995) conducted an intensive study of the Sankey Lake, which is situated in Sadashiva Nagar of Bangalore city where fish mortality occurred on quite a large scale during June - July 1995. These studies revealed that the fish-kill in Sankey Lake was due to a sudden and considerable fall in dissolved oxygen (DO) levels in some locations caused by sewage let into the lake resulting in asphyxiation. It was not due to any kind of infection because none of the fishes appeared to show any symptom of disease.

Ramachandra T.V[94] *et al*, discussed aspects and strategies for monitoring, which include physical, chemical and biological aspects. Commonly monitored parameters have been discussed in detail, which include the detailed methodology for analysing various physico-chemical and biological (plankton, fish, avifauna, macroinvertebrates) parameters. The methods adapted for characterisation of wetlands are illustrated with case studies, which can help in evolving overall strategies for characterisation of wetlands.

Wetlands in Bangalore are threatened owing to the pressures of unplanned urbanisation and land use pattern. In order to accommodate the burgeoning populace, many of the city's wetlands have paved way to residential layouts, industrial complexes, etc. This has also contributed to the deteriorating water quality.

Ramachandra T.V., and Ahalya N[95] (2001) discussed restoration, post-restoration and management strategies through a holistic approach based on the findings of pilot studies in Bangalore city, Karnataka State, India. The pilot studies cover spatio-temporal analysis, restoration plans, socio-economic evaluation, community's perception of lake restoration program and the role of the various agencies and departments.

The exploratory survey and physico-chemical and biological characterisation of lakes located all over the city show that lakes are polluted mainly due to sewage from domestic and industrial sectors. Detailed quantitative investigations of seven waterbodies (selected based on location and the type of input source) involving physical and chemical parameters and statistical analysis of selected parameters reveal that Kamakshipalya, Yediur, Hebbal and Ulsoor lakes have higher degree of pollution compared to the Sankey and Bannergatta tanks which have no major source of pollution.

The preliminary socio-economic survey carried out in the region surrounding Hebbal lake through Contingency Valuation Method showed high level of dependency on wetlands for groundwater, food, fodder, fish, fuel, etc. The high level of dependency on wetlands and its poor quality calls for immediate restoration of degraded lakes and appropriate measures for conservation and management in order to maintain ecological balance in the region.

Ranjani[96] and Ramachandra T.V (1999) studied the Hebbal lake, situated on NH-7, Bangalore, which is now a restored lake. Sewage and industrial effluents were let into the lake and the excessive sewage inflow led to the eutrophication of the lake. A preliminary socio-economic survey was carried out in the surrounding regions of the lake, which showed a high level of dependency on wetlands for groundwater, food, fodder, fuel, etc.

Rajinikanth[97] and Ramachandra T.V (2000) carried out a study of Amruthahalli lake, situated in Bangalore north taluk. It was found that the lake had attained eutrophic conditions owing to the excessive inputs of nutrients and organic matter, the sources being, sewage, storm water, and industrial effluents. The lake exhibited severe pollution with high values of alkalinity, hardness, phosphates, TSS, odour and a low level of dissolved oxygen.

Rachenahalli lake, situated in Bangalore North and South taluks was studied by Rajinikanth[31] and Ramachandra T.V (2000). The lake was polluted due to discharges of wastewaters form the dumping of organic wastes from the surrounding areas, mainly poultry wastes. The quality of the water was affected which manifested in the values of parameters analysed, such as nutrients, alkalinity, hardness, etc.

Priyadarshini[98] and Ramachandra T.V (1998) studied the water quality of Ulsoor lake, which has very broad and deep feeder channels through which sewage and sullage flow in. It was observed by the authors that the water quality of the lake was greatly influenced by the runoff and discharges from Commercial Street, automobile workshops, aeronautical industries and a cinema hall located in the vicinity. High TSS, fishy odour, high alkalinity, hardness and phosphates, coliform population, and predominance of *Microsystis* were also observed which indicated high pollution in the lake.

Madiwala lake, a perennial tank located in south eastern part of Bangalore city has been reduced from 114 ha to around 100 ha due to encroachment by the BDA for a road and illegal development of private layouts. Ayesha[99], Parveen and Ramachandra T.V (1998) did a study of the lake and observed that the direct discharge of sewage from parts of Jayanagar and J.P. Nagar has increased the pollution of the lake. This was seen in low DO, high alkalinity, hardness, coliform bacteria and the predominance of the pollution indicating the algae *Microsystis.*

OBJECTIVES AND STUDY AREA

1.8 OBJECTIVES

The objective of this study is to assess the ecological status of two waterbodies in Bangalore. The study details the water quality aspects of Chamarajasagar and Madiwala, lake whose selection is based on their current use and location. Chamarajasagar reservoir is a source of drinking water supply to Bangalore city and is located on the outskirts of Bangalore city in Magadi Taluk, while Madiwala lake is situated in Bangalore city and is of recreational value with boating and fishing facilities for the public. The assessments include the analysis of the physical, chemical and biological parameters.

1.9 STUDY AREA

1.9.1 Chamarajasagar reservoir

The reservoir was constructed in 1933, which at the time was 60 feet deep and later in 1958 was raised to 74 feet, which is also the current depth (table 3.1). Chamarajasagar reservoir is constructed at the confluence of Arkavathi and Kumudavathi rivers, both tributaries of river Cauvery, at Tippagondana halli near Magadi taluk, Bangalore south – 56º21'20" (Figure 3.1, 3.2). Arkavati, which originates at Nandi hills, flows into the Hesarghatta tank in Bangalore city whose surplus overflows cutting through the Bangalore Tumkur National Highway 4 as Arkavathi and drains into the reservoir. The other inlet, Kumudavati, originates in Shivaganga near Dabaspete and after joining Arkavathi at Tippagondanahalli it continues to flow as Arkavati. Both these tributaries of river Cauvery meet at the Sangama at a place popularly known as Meke daatu near Kanakapura. Both Kumudavati and Arkavati are dry most of the year and the flow is obvious only during the monsoons. The reservoir's surplus in turn is let into a canal, which connects to the Manchinabale reservoir near Ramanagaram. This reservoir in addition to the overflow form Chamarajasagar reservoir receives its main inflow from a lake Chik tore.

Table 3.1: Chamarajasagar reservoir factfile

Inception	1933
Area of the reservoir	896 hectares
Current water level	61 feet (18.90 m)
Total capacity	74 feet (22.56 m)
Filled every year prior to	1985
Totally dry in	1986
Lack of inflow in the catchment since	1986
Reservoir filled to the maximum in	1988
Reservoir was almost full	1990, 1994
Reservoir filled to 72 feet in	1998
Inlet 1	Kumudavathi
Inlet 2	Arkavati
Outlet	Manchinabale reservoir

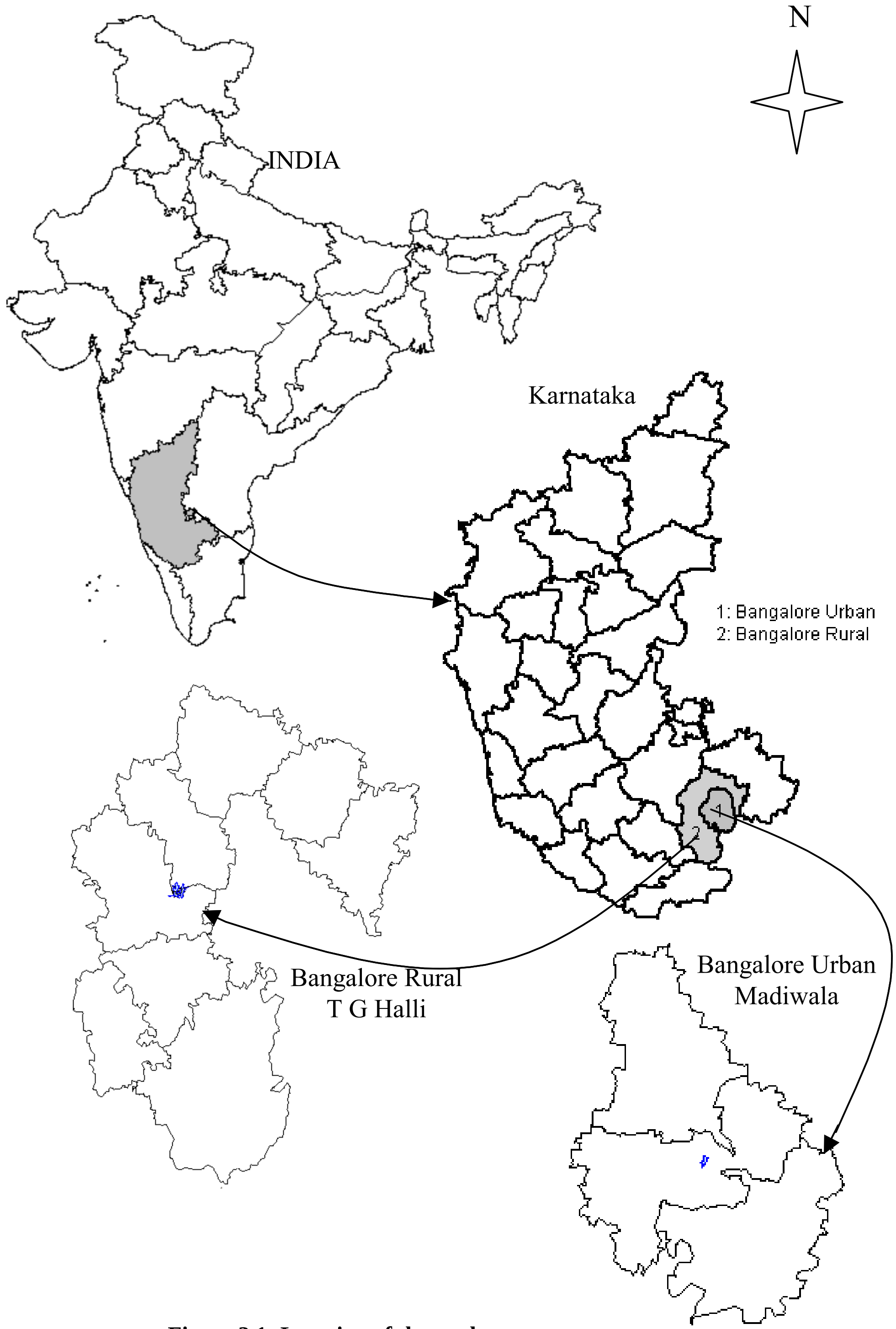


Figure 3.1: Location of the study areas

The recent filling of the Chamarajasagar reservoir is due to the independent catchments of the valley rather than any surplus flows from the interconnected waterbodies. The reservoir receives most of its inflow during the post monsoons, which is in September and October.

Large portion of the catchment area is dry open land, rocky regions, and small-forested pockets or monsoon dependent agricultural land. The forest department has recently been planting trees, which cover a considerable area around the reservoir. With the onset of the monsoons at the end of July there is sufficient land cover which during September - October, when the monsoon results in peak inflows combats the erosion form the dry barren lands reducing turbidity and runoff. The inflowing turbidity is further diluted once it enters the reservoir. There have not been problems related to siltation in the reservoir since its inception. Further the water is impounded with no continuing inflows, which cease after the monsoons recede, which again explains the consistent water quality of the reservoir.

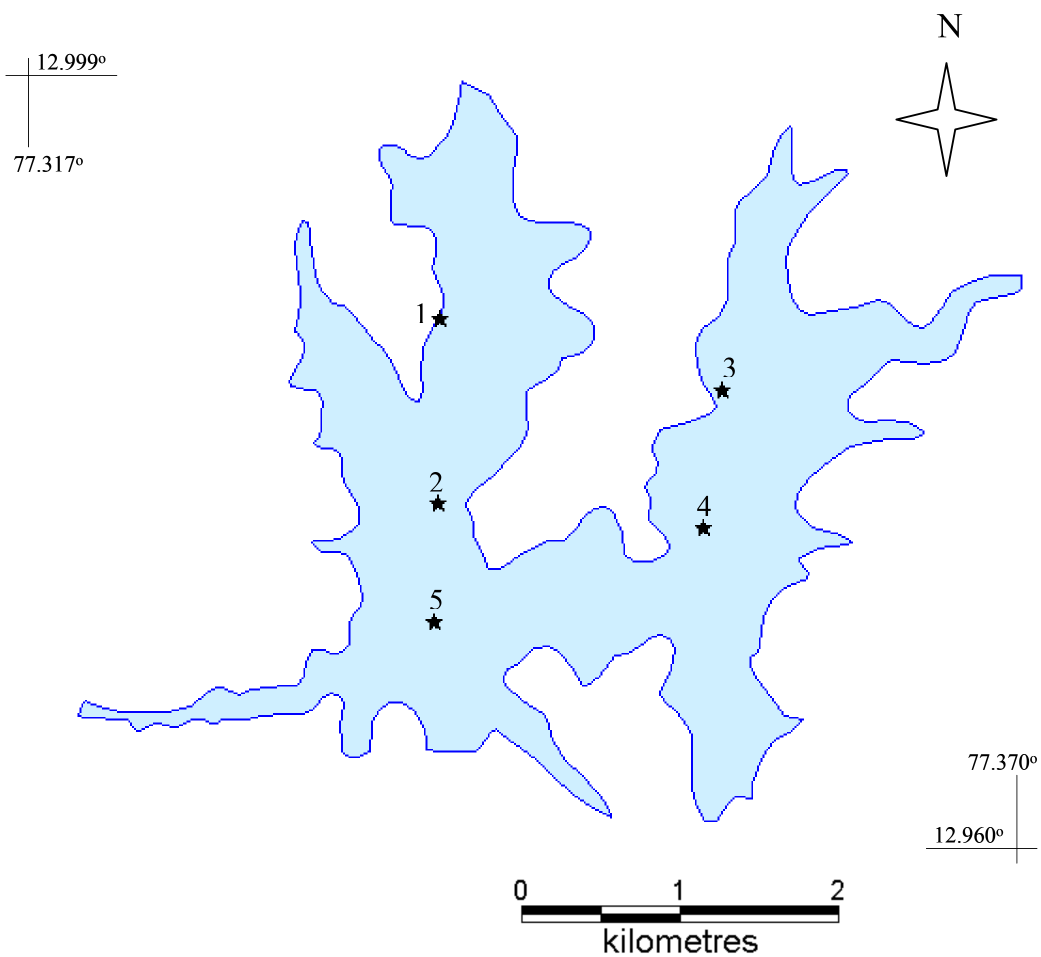


Figure 3.2: Chamarajasagar reservoir with sampling sites

Although there is no immediate threat to the water quality of the reservoir there is a growing concern over the rapidly mushrooming industries in the catchment areas more importantly along the Bangalore – Tumkur National highway 4,where it is feared that the effluent flow as a consequence of rapid industrialisation in this belt could pollute the valley leading to degradation of the water quality in the downstream. In addition to this there has been an increased activity related to stone quarries leading to the degradation of the catchment. Along the Kumudavati there has been major quarry establishments and a few in the catchments of Arkavati and around the reservoir. Encouraging such activities not only disrupts the ecological balance in the watershed but also poses a serious threat to the very structure of the reservoir.

1.9.2 Madiwala Lake

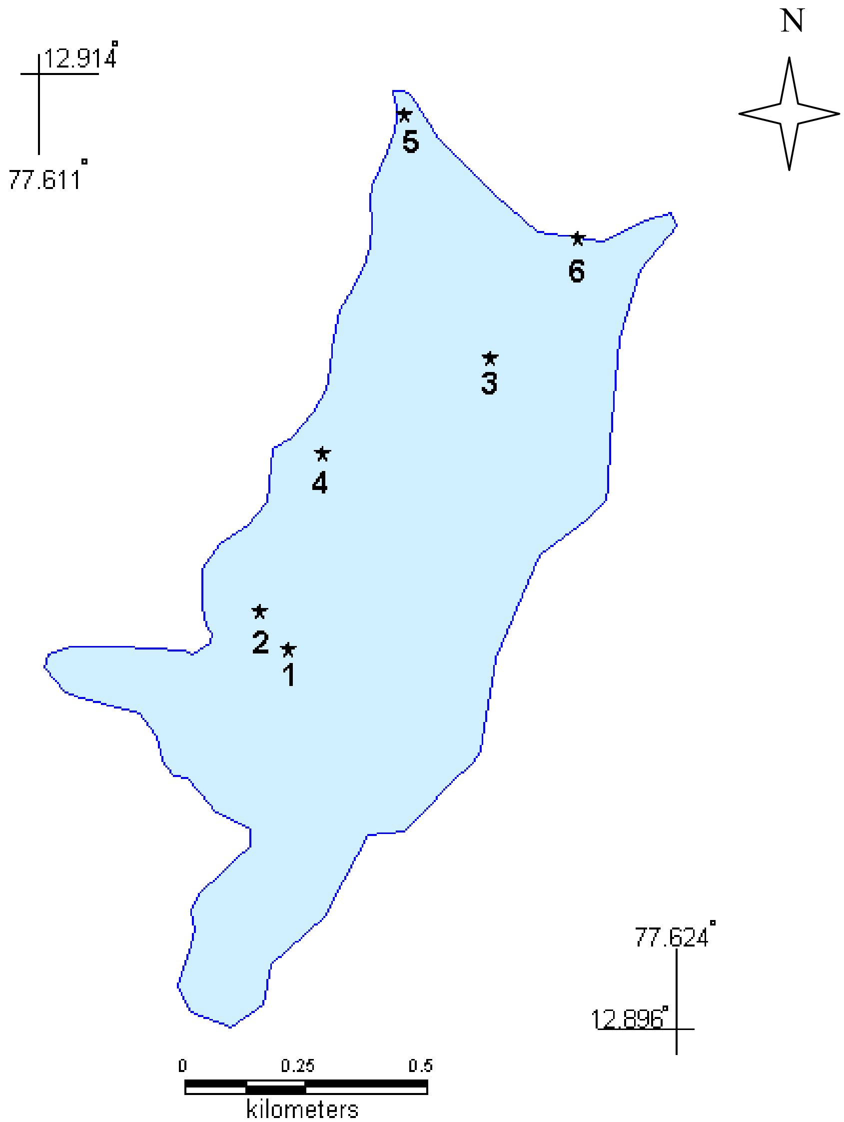
The Madiwala Lake is located in Bangalore south between Bannerghatta road and Hosur road covering an extent of 272 acres (110.07 ha) (table 3.2). The water-spread area is about 200 acres (80.93 ha) and the wetland area is about 72 acres (29.13 ha). Earlier the lake formed an important landmark of the city and had a wide catchment area, which filled to the maximum water level every monsoon. (Figure 3.3). Madiwala Lake receives water from two lakes Hulimavu and Jaraganahallikere on the upstream. With a large catchment area spread into the Hulimavu valley and Jaraganahallikere, Madiwala Lake has the capacity to fill up to the maximum during a good monsoon season and helps with the important wetland functions of recharging of the sub-soil ground water table around the area. Lately the holding capacity of the lake is considerably reduced due to the blockage of the inflowing channels, illegal encroachments in the catchment area, etc.

Table 3.2: Madiwala lake factfile

Location	Begur hobli, Bangalore south
Extent	272 acres (110.07 ha)
Water spread area	200 acres (80.93 ha)
Wetland area	72 acres (29.13 ha)
STP capacity	4 mld
Total sewage inflow	Approx 12 mld
Main inflows (south and southwestern sides)	Hulimavu, Sarakki and Jarganahalli
Outflows (north and north eastern side)	Agaram lake and Bellandur lake
Catchment areas	Rupena agrahara, bommanahalli, J.P.Nagar, Jayanagar, bilakahalli, hulimavu, madiwala, kodi chikkanahalli, devarchikkanahalli, dorasamipalya
Lake surrounds	♦ Rupena agrahara slum on the south eastern side ♦ BDA layout on the northeastern side ♦ STP of 4-5 mld capacity near south west end ♦ Mud walk path & entrance to the lake on the western side

Sewage water has become the only major source of inflow into the lake, which has led to a drastic change in the water quality. The lake has a STP (sewage treatment plant) of 4 million litres per day (mld) capacity (total amount of sewage produced in the area is around 12 mld) on the south west end, which treats a portion of the inflowing sewage and the remaining sewage is let into the sewage diversion channels untreated, which is on the eastern side of the lake. There is a storm water drain towards the north side near the bund region. The lake is fenced with barbed wires and on the western side of the lake is a walk path, which was developed during the restoration of the lake. During this study the fencing was incomplete on the northern side, which paves way for people to dump garbage and filth into the lake. The adjoining slum dwellers have converted this side of the shore into a major defecating zone. The lake also allows for fishing and the fisheries department undertakes this. The Karnataka State, Forest department and the Lake Development Authority, under the Indo- Norwegian Environment Programme had undertaken restoration of the lake in the year 2000 and today Madiwala Lake is a popular recreational spot, with boating facilities and bird watching.

Construction activities in the catchment area have increased dramatically over the last few decades due the pressure of urbanisation and pressure on land. The area has been converted into huge residential and commercial properties without providing for the basic amenities and infrastructure. With this, Madiwala Lake perhaps became the most convenient site to dump the construction debris and sewage. During the monsoons, the excess storm waters choke the drains and the weir at the outlet is blocked leading to the mixing of the sewage with the storm water, which eventually finds its way into the lake. The depth of the lake has also decreased due to the increased sedimentation, thus reducing the capacity of the lake. As a result of the increased pollutants there is proliferation of rooted aquatic plants and water hyacinth. The weed growth prevents surface aeration and penetration of sunlight, which in turn affects the dissolved oxygen content in the lake and consequently influencing the biodiversity of the lakes' flora and fauna. The proliferating growth of weeds also contributes to the spread of mosquitoes and water borne diseases.


N
12.914°
77.611°
5
6
3
4
2
1
77.624°
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0
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kilometers

MATERIALS AND METHODS

An integrated study of physical, chemical and biological components of the lakes was done to determine the health of the waterbodies. The monitoring was done for a period of two months, January and February 2006. The sampling was done in the morning hours from five sites in Chamarajasagar reservoir and six sites in Madiwala Lake. The sampling sites were selected to represent the water quality at different points, the inlets – points where the feeder opens into the lake, centre – the point which represents a general water quality of the lake and the outlets – the place where the overflow occurs.

Grab samples were collected in one-litre pre washed polythene cans from the surface from each station in the morning to assess various physico-chemical parameters. Two field replicates were collected from each station. Few parameters, which undergo changes quickly such as temperature, pH, DO, conductance along with alkalinity, hardness and TDS, were evaluated on the spot at the field immediately after collection. The analysis was done based on APHA, standard methods (1985) and NEERI, water and wastewater analysis (1986). The various physical and chemical parameters that were anlaysed in the current study are: Temperature, pH, conductivity, Total dissolved solids, Alkalinity, Total hardness, Calcium, Magnesium, DO, COD, Sodium, Potassium, Phosphates, Nitrates.

1.10 PHYSICO – CHEMICAL ANALYSIS

1.10.1 Temperature

Temperature is one of the most important parameters that influence almost all the physical, chemical and biological properties and thus the water chemistry.

Apparatus required: The temperature is measured in the field using a thermometer with 0.1^{o}C division on a Celsius scale. For measuring the temperature of open waterbody, the thermometer is dipped directly into the water and the reading is taken while it is in the waterbody.

Procedure: Thermometer is immersed directly in the waterbody for a period of time sufficient to permit constant reading. While collecting the sample, care was taken that it is not exposed to heat or direct solar radiation.

1.10.2 Total dissolved solids

Dissolved solids are solids that are in dissolved state in solution. Waters with high dissolved solids generally are of inferior palatability and may induce an unfavourable physiological reaction in the transient consumer.

Apparatus required: An electronic probe, which also measures pH, and conductivity, is used to measure TDS. The values are expressed as mg/L of water.
Procedure: The probe is immersed directly in the water collected in a wide mouthed sampling bottle at the sampling site immediately after collection for a period of time sufficient to permit constant reading.

1.10.3 Transparency

Transparency is a characteristic of water that varies with the combined effect of colour and turbidity. It measures the depth to which light penetrates in the waterbody.
Apparatus required: Secchi disc, a metallic disc of 20 cm diameter with four quadrats of alternate black and white on the upper surface is used to measure transparency and the values are expressed in cm or mm.
Procedure: The disk is attached to a rope and lowered into the water until it is no longer visible. Secchi disk depth, then, is a measure of water clarity. Lower readings indicate turbid or coloured water. Transparency is measured by gradually lowering the Secchi disc at respective sampling points. The depth at which it disappears in the water (X_1) and reappears (X_2) is noted.

Estimation: The transparency of the waterbody is computed as follows:

$$\text{Transparency (Secchi Disc Transparency)} = (X_1 + X_2) / 2$$

Where, X_1 = Depth at which Secchi disc disappears
X_2 = Depth at which Secchi disc reappears.

1.10.4 pH

pH – potential of hydrogen, is the measure of the concentration of hydrogen ions. It provides the measure of the acidity or alkalinity of a solution.
Apparatus required: An electronic probe or a pH meter, which also measures, TDS and conductivity, and is used to measure pH at a scale of 0 – 14.
Procedure: Immerse the probe directly in the water collected in a wide mouthed sampling bottle at the sampling site immediately after collection for a period of time sufficient to permit constant reading.

1.10.5 Specific conductivity

Conductivity is the capacity of water to conduct electric current and varies both with number and types of ions in the solution. The values of conductivity and TDS are interrelated.
Apparatus required: Conductivity meter, is used to measure conductivity. Conductivity is reported in mmho or μ mhos/cm or as μS/cm.
Procedure: the electrode of the conductivity meter is immersed directly in the water collected in a wide mouthed sampling bottle at the sampling site immediately for a period of time sufficient to permit constant reading.

1.10.6 Dissolved oxygen

DO content indicates the health and ability of the waterbody to purify itself through biochemical processes. DO is a very important parameter for the survival of fishes and other aquatic organisms.

Sampling: Samples from surface waters is collected in narrow mouthed bottles with glass-stopper. It is important not to let the sample remain in contact with air, air bubbles to be formed or to be agitated, because either condition can cause a change in its gaseous content. The bottles should be filled to overflow and stoppered. Entraining or dissolving atmospheric oxygen should be avoided. DO should be determined immediately on the sampling site.

Method: Winkler's method. Titration.

Principle: Oxygen present in the sample oxidises the dispersed divalent manganous hydroxide to the higher valency to precipitate as a brown hydrated oxide after addition of potassium iodide and sodium hydroxide. Upon acidification, manganese reverts to its divalent state and liberates iodine from potassium iodide, equivalent to the original dissolved oxygen content of the sample. The liberated iodine is titrated against 0.025N sodium thiosulphate using fresh starch as an indicator.

Apparatus required: BOD bottles-125 ml capacity, lab glassware - measuring cylinder, conical flasks, analytical balance, glass rods and Bunsen burner.

Reagents:

- *Manganese sulphate:* 480 g of manganous sulphate tetra hydrate is dissolved and made up to 1000 ml with distilled water
- *Conc. sulphuric acid*
- *Starch indicator:* 0.5 g of starch is dissolved in glycerine and boiled for few minutes. Once cooled 2 drops of formaldehyde is added as a preservative.
- *Stock sodium thiosulphate:* 24.82 g of sodium thiosulphate pentahydrate ($Na_2S_20_2$. $5H_2O$) is dissolved in distilled water and made up to 1000ml.
- *Standard sodium thiosulphate (0.025N):* 250 ml of the stock sodium thiosulphate pentahydrate is made up to 1000 ml with distilled water to give 0.025N.

Procedure: The sample is collected in BOD bottles (125 ml), to which 2ml of manganous sulphate and 2ml of potassium iodide are added and sealed. This is mixed well and the precipitate allowed to settle down. At this stage 2ml of conc. sulphuric acid is added, and mixed well until all the precipitate dissolves. 25 ml of the sample is measured into the conical flask and titrated against 0.025N sodium thiosulphate using starch as an indicator. The end point is the change of colour from blue to colourless. The amount of titrant consumed gives the direct reading for DO in ppm. DO is calculated using the following formula.

Estimation:

DO (mg/L) = (ml * N) of titrant * 8 * 1000 / V_2 [(V_1-v)/V_1]

Where, V_2 = volume of the part of contents from the sample bottle titrated

V_1 = volume of the sample bottle

v = volume of added

N = normalcy of sodium thiosulphate

1.10.7 Alkalinity

The alkalinity of water is a measure of its capacity to neutralise acids. It is an anionic phenomenon.

Method: Sulphuric acid titrimetric method

Principle: Alkalinity of a water sample is estimated by titrating with standard sulphuric acid. Decolourisation of phenolphthalein indicator (phenolphthalein alkalinity) or a sharp change from yellow to pinkish orange (total alkalinity) will indicate the end point.

Apparatus: Conical flasks, standard flask, measuring cylinder, burette, pipette and analytical balance

Reagents:

- Standard H_2SO_4 0.02 N
- Phenolphthalein indicator: 0.5 g of phenolphthalein is dissolved in 50 ml (as per NEERI, it is 500) 95% ethyl alcohol. To this another 50 ml of distilled water is added. 0.02 N NaOH is added drop wise till a faint pink colour appears.
- Methyl orange indicator: 0.5 g of methyl orange is dissolved in 100 ml of distilled water.

Procedure:

- 25 ml of sample is taken in a conical flask, to which 2-3 drops of phenolphthalein indicator is added
- If pink colour develops, this is titrated with 0.02 N H_2SO_4 till the colour disappears. The volume of H_2SO_4 needed is noted.
- To the same flask 2-3 drops of methyl orange indicator is added and titration is continued with 0.02 N H_2SO_4 till the yellow colour changes to pinkish orange. Again the volume of H_2SO_4 needed is noted.
- In case the pink colour does not develop after addition of phenolphthalein, the titration is continued after adding methyl orange indicator.

Estimation:

- P (phenolphthalein alkalinity), mg/L= A * 1000 / ml of sample
- T (total alkalinity), mg/L= B * 1000 / ml of sample
- In case H_2SO_4 is not 0.02 N, then the following formula is applied

  Alkalinity, mg/L = A / B * N * 50000 / ml of sample

Where,

A = ml of H_2SO_4 required to change from pink to colourless with phenolphthalein indicator

B = ml of H_2SO_4 required to change from yellow to pinkish orange with methyl orange indicator

N = normality of H2SO4 used

1.10.8 Total hardness, Calcium hardness & Magnesium hardness

Water hardness is the traditional measure of the capacity of water to react with soap, hard water requiring a considerable amount of soap to lather. Hardness is generally caused by the calcium and magnesium ions (bivalent cations) present in water. The total hardness is defined as the sum of calcium and magnesium concentrations, both expressed as $CaCO_3$ in mg/L. Carbonates and bicarbonates of calcium and magnesium cause temporary hardness. Sulphates and chlorides cause permanent hardness.

Method: EDTA titrimetric method

Principle: In alkaline conditions EDTA (Ethylene-diamine tetra acetic acid) and its sodium salts react with cations forming a soluble chelated complex when added to a solution. If a small amount of dye such as Eriochrome black-T is added to an aqueous solution containing calcium and magnesium ions at alkaline pH of 10.0 ± 0.1, it forms wine red colour. When EDTA is added as a titrant, all the calcium and magnesium ions in the solution get complexed resulting in a sharp colour change from wine red to blue, marking the end point of the titration. Hardness of water prevents lather formation with soap rendering the water unsuitable for bathing and washing. It forms scales in boilers, making it unsuitable for industrial usage. At higher pH>12.0, Mg^{++} ion precipitates with only Ca^{++} in solution. At this pH, murexide indicator forms a pink color with Ca^{++} ion. When EDTA is added, Ca^{++} gets complexed resulting in a change from pink to purple indicating the end point of the reaction.

When EDTA (Ethylene-diamine tetra acetic acid) is added to the water containing calcium and magnesium, it combines first with calcium. Calcium can be determined directly with EDTA when pH is made sufficiently high such that the magnesium is largely precipitated as hydroxyl compound (by adding NaOH and iso-propyl alcohol). When murexide indicator is added to the solution containing calcium, all the calcium gets complexed by the EDTA at pH 12-13. The end point is indicated from a colour change from pink to purple. The difference between total hardness and calcium hardness is the magnesium hardness.

Apparatus: conical flasks, measuring cylinder, burette, pipette, micropipette and analytical balance.

Reagents:

- *EDTA solution 0.01 M:* 3.723 g of disodium salt of EDTA is dissolved in distilled water and made up to 1000 ml.
- *Buffer solution*: 6.9 g of ammonium chloride and 1.25 g of magnesium salt of EDTA is dissolved in 143 ml of concentrated ammonium hydroxide and diluted to 250 ml with distilled water.
- *Eriochrome black T indicator*: 0.5 g of Eriochrome black-T indicator is dissolved in 100 g of triethanolamine.
- *Sodium hydroxide 1 N (NaOH)*
- *Murexide indicator (ammonium purpurate*): 0.2 g of murexide is ground well with 100 g of sodium chloride thoroughly.

Procedure: (total hardness)

- 1 ml each of buffer solution and inhibitor is added to 25 ml of the sample in a conical flask
- One pinch of EBT indicator is then added to this solution
- This is titrated against EDTA solution until the (wine red) pink colour changes to blue
- The amount of titrant used is noted.
- (*Calcium hardness):* 1 ml of NaOH and a pinch of murexide indicator is added to 25 ml of the sample in a conical flask
- This is titrated against EDTA solution until the dull pink colour changes to purple
- The amount of titrant used is noted.

Estimation:

Total hardness as mg/L = ml EDTA used * 1000 / ml sample

Calcium hardness as mg/L = ml EDTA used * 400.8 / ml sample

Magnesium hardness as mg/L = total hardness – calcium hardness

1.10.9 Nitrates

Nitrates are the most oxidised forms of nitrogen and the end product of the aerobic decomposition of organic nitrogenous matter. Nitrogen along with phosphorus is termed as a bio stimulant. Nitrogen is an essential building block in the synthesis of protein. The evaluation of nitrogen is therefore of paramount importance in understanding the nutritional status of waterbodies.

Method: Phenyl disulphonic acid method

Principle: Nitrate reacts with phenol disulphonic acid to form a nitro derivative, which in an alkaline medium (liquid ammonia) develops a yellow colour. The concentration of NO_3 can be determined colorimetrically, since the colour so formed obeys the Beer's law. (The concentration of the colour is directly proportional to the concentration of nitrates in the sample).

Apparatus: porcelain crucibles, measuring cylinder, Nesslers tubes, standard flasks, pipette, micropipette, glass rods, spectro photometer and analytical balance.

Reagents:

- Phenol disulphonic acid
- Liquid ammonia, 30 %
- Standard nitrate solution: 0.7218 g of KNO_3 is dissolved in distilled water and made up to 1000 ml in a standard flask. This will be 100 mg N/L (100 ppm solution). From this an intermittent solution of 10 ppm is prepared by adding 25 ml of the stock standard and making it up to 250 ml in a standard flask with distilled water.

Procedure:

- 50 ml of sample is poured into the crucibles
- Standards of 0.1 – 0.5 mg N/L are also prepared and are poured into the crucibles
- These are kept in a steam water bath to evaporate
- The crucibles are cooled and the residue is dissolved in 2 ml of phenol disulphonic acid and the contents are diluted to 50 ml with distilled water in Nesslers tubes
- 6 ml of liquid ammonia is added to this which gives it a yellow colour
- The reading is then taken after thoroughly mixing the samples in a spectro photometer at 410 nanometer

Estimation: The standard curve between concentrations and absorbance for the standards is prepared. The concentration of nitrate nitrogen is calculated from the standard curve. The standard graph is plotted by taking concentration along X-axis and the spectrophotometric readings (absorbance) along Y-axis. The value of nitrate is found by comparing absorbance of sample with the standard curve and expressed in mg/L. The high concentration of nitrate in water is indicative of pollution.

Calculation: Nitrates (mg/L) =

Absorbance of sample * Conc. of Std * 1000 / Absorbance of Std. * Sample taken

1.10.10 Phosphates

Phosphorus is essential to the growth of organisms and can be the nutrient that limits the primary productivity in water. Phosphorus occurs in natural waters and in wastewaters almost solely as phosphates.

Method: Stannous chloride and ammonium molybdate method

Principle: The phosphates in water react with ammonium molybdate and forms the complex molybdophosphoric acid, which gets reduced to a complex of blue colour in the presence of stannous chloride. The absorption of light by this blue colour can be measured at 690 nm to calculate the concentration of phosphates.

Apparatus: measuring cylinder, Nesslers tubes, standard flasks, pipette, micropipette, glass rods and analytical balance.

Reagents:

- Ammonium molybdate solution:
- 6.25 g of ammonium molybdate is dissolved in 44 ml of distilled water.
- 70 ml of concentrated sulphuric acid is slowly added to 100 ml of distilled water and cooled. Solutions i and ii are mixed together.
- Stannous chloride solution: 1.25 g of stannous chloride ($SnCl_2$) is mixed with 50 ml of glycerol by heating on a water bath for rapid dissolution.
- Standard phosphate solution: 0.2195 g of anhydrous potassium hydrogen phosphate (KH_2PO_4) is dissolved in distilled water and made up to 1000 ml. this gives us a 50 ppm solution. From this an intermittent solution of 5 ppm of 250 ml is prepared. From this intermittent solution standards of 0.1 – 0.5 concentrations are prepared

Procedure:

- 50 ml of samples are taken in Nesslers tubes along with one each of blank and the standard concentrations of 0.1 – 0.5 ppm
- To this 2 ml of ammonium molybdate is added followed by 5 drops of stannous chloride solution
- A blue colour will appear.

Estimation: Reading is taken at 690 nm on a spectrophotometer using distilled water as blank with the same amount of the chemicals. The readings need to be taken after 5 minutes but before 12 minutes of the addition of the last reagent and calibration curve is prepared. The concentration of phosphates in the sample is found with the help of the standard curve. A reagent blank is always run with same treatment with distilled water as sample. The value of phosphate is obtained by comparing absorbance of sample with the standard curve and expressed as mg/L.

Calculation: Phosphates (mg/L) =

Absorbance of sample * Conc. of Standard * 1000 / Absorbance of Standard * Sample taken

High phosphorus content causes increased algal growth till nitrogen becomes limiting, although blue green algae continues to dominate because of its ability to utilise molecular nitrogen. Besides sedimentation, high uptake by phytoplankton is one of the reasons for the fast depletion of phosphorus in water.

1.10.11Sodium

Sodium is one of the most abundant elements and is a common constituent of natural waters. The sodium concentration of water is of concern primarily when considering their solubility for agricultural uses or boiler feed water. The concentration ranges from very low in the surface waters and relatively high in deep groundwaters and highest in the marine waters. Sodium is present in a number of minerals, the principal one being rock salt (sodium chloride). The increased pollution of surface and groundwater during the past has resulted in a substantial increase in the sodium content of drinking water in many regions of the world.

Method: Flame photometric method

Principle: A characteristic light is produced due to excitation of electrons when the sample with sodium is sprayed into the flame. The intensity of this characteristic radiation is proportional to the concentration of sodium and can be read at 589 nm by using suitable filter devices. For determination of sodium, the samples need to be stored in polythene bottles to check the leaching of sodium from the glass.

Apparatus: Flame photometer, measuring cylinder, Nesslers tubes, standard flasks, pipette, glass rods and analytical balance

Reagents:

- *Stock sodium solution:* 0.2545 g of NaCl (anhydrous sodium chloride) is dissolved in distilled water and make up to 100 ml in a standard flask. This will be 100-ppm solution.
- *Standard sodium solution:* From the stock solution, standards of 10, 20, 40, 60-ppm concentrations of 50 ml solutions are prepared.

Procedure:

- Highly polluted samples and wastewaters are pretreated before determination of total sodium. For non-polluted samples where only sodium is to be determined, the sample needs to be filtered to avoid clogging of the capillary of the flame photometer.
- The concentration of sodium is determined using the flame photometer.
- The filter of the flame photometer is set to 589nm (marked for Sodium, Na). By feeding distilled water the scale is set to zero and maximum using the standard of highest value. A standard curve between concentration and emission is prepared by feeding the standard solutions. The sample is filtered through filter paper and fed into the flame photometer and the concentration is found from graph or by direct readings.
- Calibration curve is prepared in the ranges for the various standards of 10, 20, 40, 60 ppm and blank.
- If the sample is having higher concentrations of sodium, it can be diluted to come to in the range of determination and the dilution factor is taken into account during the estimation.

Estimation: The standard curve is a linear one at lower concentrations of sodium, however at higher concentrations it has got a tendency to level off. This curve is used to estimate the concentration of sodium in the sample.

1.10.12 Potassium

Potassium ranks seventh among the elements in order of abundance, behaves similar to sodium and remains low. Though found in small quantities (<20mg/L) it plays a vital role in the metabolism.

Method: Flame photometric method

Principle: Like sodium, potassium can also be determined accurately by flame photometer. The characteristic radiation for potassium is 768 nm, the intensity of which can be read on a scale by using a filter for this wavelength.

Apparatus: The estimation of potassium is based on the emission of spectroscopy. This is done using a flame photometer. Other apparatus include measuring cylinder, Nesslers tubes, standard flasks, pipette, glass rods and analytical balance.

Reagents:

- Stock potassium solution: Dissolve 0.1907 g of KCl (anhydrous potassium chloride) in distilled water and make up to 100 ml in a standard flask. This will be 100 ppm solution.
- *Standard potassium solution:* From the stock solution standards of different concentrations are prepared. Generally, 10, 20, 40, 60 ppm of 50 ml solutions are prepared.

Procedure:

- The concentration of potassium is determined using the flame photometer.
- The filter of the flame photometer is set at 768 nm (marked for Potassium, K) the flame is adjusted for blue colour. The scale is set to zero and maximum using the highest standard value. A standard curve of different concentrations is prepared by feeding the standard solutions. The sample is filtered through the filter paper and fed into the flame photometer.
- Calibration curve in the ranges of 10, 20, 40 and 60 ppm and for blank are prepared
- The concentration is found from the standard curve or as direct reading.
- If the sample is having higher concentrations of potassium, it can be diluted to come to in the range of determination and the dilution factor is taken into account during the estimation.

Estimation: The standard curve is used to estimate the concentration of potassium in the sample.

1.10.13 COD

COD is the oxygen required by the organic substances in water to oxidise them by a strong chemical oxidant. This shows the oxygen equivalent of the organic substances in water that can be oxidised by a strong chemical oxidant such as potassium dichromate in acidic solution. The determination of COD values are of great importance where the BOD values cannot be determined accurately due to the presence of toxins and other such unfavourable conditions for growth of microorganisms the COD usually refers to the laboratory dichromate oxidation procedure.

Method: Open reflux method using potassium dichromate.

Principle: COD is the measure of oxygen consumed during the oxidation of the oxidisable organic matter by a strong oxidising agent. Potassium dichromate ($K_2Cr_2O_7$) in the presence of sulphuric acid is generally used as an oxidisng agent in the determination of COD. The sample is treated with potassium dichromate and sulphuric acid and titrated against ferrous ammonium sulphate (FAS) using ferroin as an indicator. The amount of $K_2Cr_2O_7$ used is proportional to the oxidisable organic mater present in the sample.

Apparatus: Conical flasks, measuring cylinder, Nesslers tubes, standard flasks, pipette, micropipette, titration burette, glass rods and analytical balance.

Reagents:

- *FAS (ferrous ammonium sulphate or Mohr's salt) 0.1 N:* 8.07 g of ammonium ferrous sulphate is dissolved in a little distilled water, to which 5 ml conc. H_2SO_4 is added. This is allowed to cool and then diluted and made it up to 250 ml in a standard flask
- ($K_2Cr_2O_7$) *Potassium dichromate 1 N (stock):* 4.90 g of potassium dichromate, is dissolved in distilled water and made up to 100 ml in a standard flask
- *Potassium dichromate 0.025 N:* 25 ml of Potassium dichromate 1 N is taken and made up to 1000 ml with distilled water
- *Ferroin indicator:* 0.69 g of Ferrous sulphate and 1.4 g of phenonthroline monohydiate is dissolved in distilled water and made up to 100 ml.

Procedure:

- 0.1 N FAS is standardised and the normality value of the prepared reagent is calculated using the formula N (FAS) = V ($K_2Cr_2O_7$) * N ($K_2Cr_2O_7$) / V (FAS). The value thus got will be the normality of the FAS prepared and it is supposed to be closer to the normality required for the COD analyses, i.e. 0.1
- 10 ml of each sample and a blank is taken in conical flasks
- 10 ml $K_2Cr_2O_7$ is added to this
- 15 ml of conc. H_2SO_4 is added carefully from the sides of the flask, allowed to cool, digested for about 30 minutes.
- To this 50 ml distilled water and 5 drops of ferroin indicator is added
- This is titrated with FAS in a burette carefully till the orange turns bluish green to wine red (deeper wine red indicates high COD) and the amount of titrant consumed is noted

Estimation: COD value is calculated using the formula:

(Volume of titrant used in blank – volume of titrant used in sample) * N of FAS * 8 * 1000 / volume of sample taken.

1.11 PLANKTON ANALYSIS

The physical and chemical characteristics of water affect the abundance, species composition, stability and productivity of the indigenous populations of aquatic organisms. The biological methods used for assessing water quality include collection, counting and identification of aquatic organisms; and processing and interpretation of biological data. The work involving plankton analysis would help in:

- Explaining the cause of colour and turbidity and the presence of objectionable odour, tastes and visible particles in waters.
- The interpretation of chemical analyses.
- Identifying the nature, extent and biological effects of pollution.
- Providing data on the status of an aquatic system on a regular basis.

Plankton: A microscopic community of plants (phytoplankton) and animals (zooplankton), found usually free floating, swimming with little or no resistance to water currents, suspended in water, non-motile or insufficiently motile to overcome transport by currents, are called "Plankton". Phytoplankton (microscopic algae) usually occur as unicellular, colonial or filamentous forms and is mostly photosynthetic and is grazed upon by the zooplankton and other organisms occurring in the same environment. Zooplankton principally comprise of microscopic protozoans, rotifers, cladocerans and copepods. The species assemblage of zooplankton also may be useful in assessing water quality.

Plankton, particularly phytoplankton, has long been used as indicators of water quality. Because of their short life spans, planktons respond quickly to environmental changes. They flourish both in highly eutrophic waters while a few others are very sensitive to organic and/or chemical wastes. Some species have also been associated with noxious blooms causing toxic conditions apart from the tastes and odour problems.

Plankton net: The plankton net is a field-equipment used to trap plankton. It has a polyethylene filter of a defined mesh size and a graduated measuring jar attached to the other end. A handle holds the net. The mesh size of the net determines the size range of the plankton trapped

Sampling Procedure: Plankton net number 25 of mesh size 60 µm was used for collecting samples. 100 litres of water was measured in a graduated bucket and filtered through the net and concentrated in a 100 ml bottle. Samples were collected as close to the water surface as possible in the morning hours and preserved for further analysis.

Labelling: The samples are labelled with the date, time of sampling, study area-lake name, sampling site name and the volume measured and pasted on the containers.

Preservation of the sample: Between the time that a sample is collected in the field and until its analysis in the laboratory, physical, chemical and biochemical changes may take place altering the intrinsic quality of the sample. It is therefore necessary to preserve the samples before shipping, to prevent or minimise changes. This is done by various procedures such as keeping the samples in the dark, adding chemical preservatives, lowering the temperature to retard reactions by freezing or by a combination of these methods. For a phytoplankton sample to be analysed for an extended period, commonly two preservatives are used: Lugol's iodine using acetic acid which will stain cells brownish yellow and will maintain cell morphology and of 4% formaldehyde. The samples collected for this study were preserved by adding suitable amounts of 1 ml chloroform to act as the narcotising agent and 2ml of 4% formalin for preservation and analyses.

Concentration technique: The plankton nets were used to collect samples for the qualitative and quantitative estimation of the plankton, by filtering a known volume of water (100 litres) through the net. The sample was allowed to settle for 24-48 hours and was further concentrated to approximately 30 ml by decanting. The concentration factor is used during the calculations.

Qualitative and quantitative evaluation of plankton: Detailed analyses of phytoplanktonic populations are done by estimating the numbers in each species. The phytoplankton consisting of individual cells, filaments and colonies are counted as individual cells. When colonies of species are counted, the average number of cells per colony is counted, and in filamentous algae, the average length of the filament has to be determined.

Mounting the slides: Preserved samples in bottles are mixed uniformly by gentle inversion and then one drop of the sample is pipetted out from a calibrated pipette onto the glass slide for analysis. A cover slip is carefully placed ensuring no air bubbles remain and the cover slip is ringed with a transparent nail enamel to prevent evaporation during the counting process.

Microscope: A binocular compound microscope is used in the counting of plankton with different eyepieces such as 10X and 40X. The microscope is calibrated using an ocular micrometer.

Counting method: Drop count method – In this method one drop of the sample is pipetted out from a calibrated pipette onto a glass slide and the planktonic organisms are counted in strips. The total area under the cover slip represents the number of organisms present per given volume of the sample. This volume expanded to an appropriate factor yields the organisms per litre of water for the lake.

Phytoplankton Counting Units: Some plankton are unicellular while others are multicellular (colonial), posing a problem for enumeration. For analysis, a colony of plankton is accounted as a single count.

Formula for calculating organisms per litre:

Total plankton count per litre = $A * (1/L) * (n/v)$

Where,

A = number of organisms per drop

L = volume of original sample (l)

n = total volume of concentrated sample (ml)

v = volume of one drop (ml)

RESULTS AND DISCUSSION

Water samples collected from Chamarajasagar reservoir and Madiwala Lake were assessed for physico-chemical and biological parameters. Biological parameter assessment also includes an experiment to arrive at a representative sampling volume of water to be filtered for phytoplankton analysis.

Different volumes (25, 50, 75, 100 and 125 litres) of samples were collected, filtered, concentrated and analysed to estimate the composition (species richness) and counts of phytoplankton. It was found that 100 litres of lake water was a more appropriate sampling volume as per the experiment listed in Table 5.1 and the figure 5.1.

Table 5.1: Standardisation of sampling volume for phytoplankton analysis

	Phytoplankton		**Zooplankton**
Volume of water filtered (liters)	**Number of Species**	**Total species count**	**Species count**
25	8	265	10
50	10	317	32
75	11	314	28
100	11	520	28
125	11	527	26

As is evident from the data and graph, 100 litres seemed to be the most appropriate volume for the current study as further effort in sampling did not include new species and the number of species has reached the threshold (which initially showed increasing trend and was stabilised at 100 l). Consequently, this was taken as the standard amount of sample volume throughout the study.

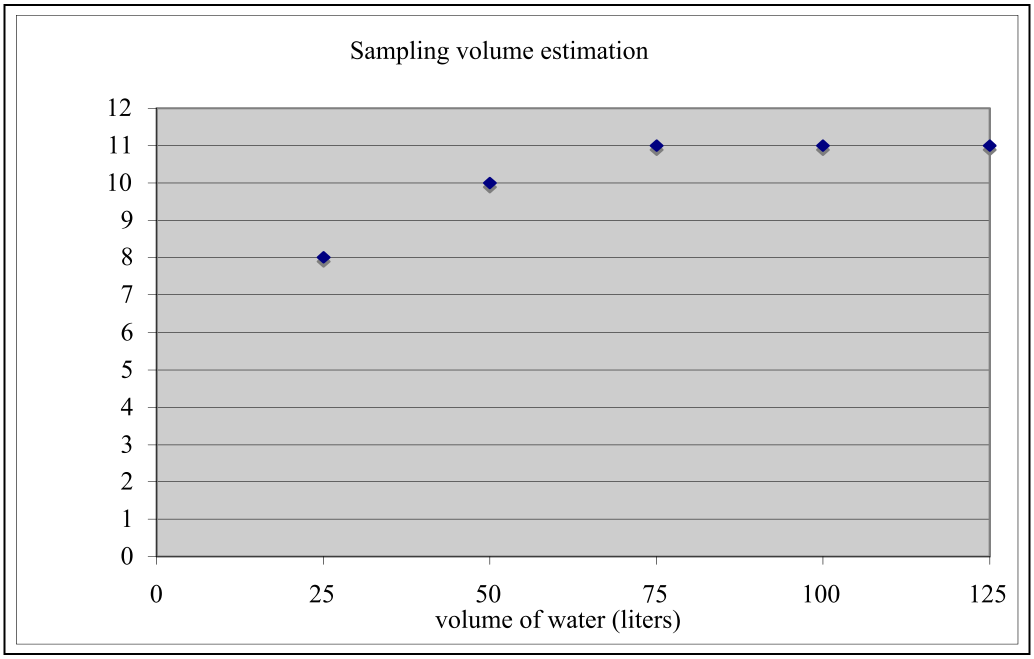


Figure 5.1: Graph showing relation between species and volume of sample filtered

1.12 Physico-chemical analysis

Samples were collected from sites covering the inlets, centre and the outlets. Five sampling sites were selected for analysis of various parameters from Chamarajasagar reservoir and six sampling sites from Madiwala Lake. The results of the analysis are presented in this section.

1.12.1 Chamarajasagar reservoir

The physicochemical analysis of Chamarajasagar reservoir (table 5.2) reflects a fairly unpolluted nature of the water body. pH, is one parameter which varied between the range of 7.27 to 7.77, which is above the tolerance limits. The sampling was done post monsoons and thus the slightly higher value indicating mild alkalinity may be attributed to the agricultural runoff from the catchment and natural processes. Water temperature measured between 22.33°C and 23.90°C during the study.

Table 5.2: Chamarajasagar reservoir – physico chemical analysis

Chamarajasagar reservoir - Physico-chemical analysis					
Sampling sites	**1**	**2**	**3**	**4**	**5**
pH	7.77	7.42	7.61	7.28	7.27
W. Temperature ℃	22.33	22.80	22.80	23.50	23.90
Conductance µS/cm	289.33	288.67	307.33	293.67	284.67

TDS mg/L	144.67	144.00	153.67	146.33	142.33
Transparency cm	128	168	137	167	145
Hardness mg/L	84.40	84.60	80.60	80.00	80.00
Ca Hardness mg/L	20.68	18.28	20.68	19.96	19.56
Mg Hardness mg/L	15.55	16.18	14.62	14.65	14.75
DO mg/L	7.20	6.54	5.73	4.46	2.90
Alkalinity mg/L	98.07	101.92	109.61	123.07	97.11
COD mg/L	9.72	9.72	9.72	9.72	6.48
Nitrates mg/L	0.022	0.013	0.019	0.025	0.025
Phosphates mg/L	0.014	0.008	0.006	0.005	0.003
Sodium mg/L	59.03	57.22	59.83	57.82	55.01
Potassium mg/L	13.11	13.11	13.79	13.69	13.11

Electric conductivity was in the range of 284.67 – 307.33 µS/cm, indicating less dissolved solids and no major source of pollution from the catchment. Transparency was not too good given the drinking use value of the water source. Remarkably this drinking water source had relatively high density of algae (an average of 1300 organisms per litre) due to which the transparency was reduced. Dissolved oxygen is relatively higher than the desirable limits in the sampling points 1, 2, 3, which are located at the inlets of Kumudavati and Arkavati. DO at the sampling point 5; the centre of the reservoir is below the desirable limits. This may be due to the less turbulence in the centre, which has resulted in the less contact between the atmosphere and the water surface resulting in low DO content owing to the less solubility of oxygen in water. Relatively higher concentration of oxygen at other sampling points is due to enough turbulence created in the region. The other physico – chemical parameter values are well within the tolerance limits indicating that there is no major threat to the water quality of this waterbody.

1.12.2 Madiwala Lake

pH of Madiwala was found to be slightly high, ranging 7.26 - 7.79 (table 5.3). This may be attributed to the domestic sewage entering the waterbody from the sewage treatment plant located on the southwest end of the lake. The temperature measured during the time of sampling varied from 21 – 23°C. Electrical conductivity of 590 – 620 µS/cm (5.90 – 6.20 milli Siemens / cm) indicates high dissolved solids. Low transparency indicates low light penetration. The Madiwala Lake water was greenish owing to the high plankton density, which manifested in its low transparency of 51.92 cm. The calcium and magnesium hardness of water are high indicating hard water. Dissolved oxygen is lower than the desirable limits, i.e. below 5 mg/L. The dissolved oxygen level in the sampling point 1 is relatively higher (4.39mg/L) compared to the other sampling points because of the turbulence created by the flow at the inlet.

Table 5.3: Madiwala lake– physico chemical analysis

Madiwala lake -Physico-chemical analysis						
Sampling sites	**1**	**2**	**3**	**4**	**5**	**6**
pH	7.72	7.26	7.78	7.79	7.57	7.68
W. Temperature ℃	22.17	22.93	22.47	23.27	21.87	21.90
Conductance µS/cm	601.33	608.00	589.67	591.00	620.33	594.33
TDS mg/L	303.67	304.33	294.33	296.33	310.33	296.33
Transparency cm	47.00	51.00	53.50	49.00	52.00	59.00
Hardness mg/L	186.00	189.00	186.40	189.80	193.00	194.00
Ca Hardness mg/L	70.22	48.10	56.03	56.91	73.83	58.44
Mg Hardness mg/L	28.25	34.38	31.81	32.42	29.08	33.08
DO mg/L	4.39	2.45	3.74	2.97	1.94	2.40
Alkalinity mg/L	233.64	236.53	240.38	240.38	228.84	232.68
Nitrates mg/L	0.074	0.085	0.083	0.081	0.084	0.081
Phosphates mg/L	0.458	0.670	0.589	0.547	0.598	0.632
Sodium mg/L	152.46	154.07	153.06	153.26	150.84	147.22
Potassium mg/L	40.40	41.62	40.81	40.40	39.80	39.19

The sampling point 5 at the outlet has the lowest DO (1.94 mg/L), which, at the time of sampling was replete with weeds and water hyacinth. The other point 6, which is also another outlet, has a reduced DO owing to the washing activities at the dhobi ghat located on the banks. Overall, the DO content of the lake is low owing to the organic pollution due to sewage inflow, and high phytoplankton density. Alkalinity of Madiwala lake water was also found to be high, probably due to the increased inflow from the dhobi ghat (located on the southeastern side of the lake), anthropogenic activities and dissolved alkaline substances. A comparison of the physico chemical anlaysis of both the waterbodies is listed in the table 5.4.

Table 5.4: Chamarajasagar reservoir and Madiwala Lake – physico chemical analysis

Physico-chemical parameters	**Chamarajasagar reservoir Mean ± S.D**	**Madiwala Lake Mean ± S.D**	**Tolerance limits***
pH	7.47 ± 0.22	7.63 ± 0.20	5.5 – 8.5
W. Temp ℃	23.07 ± 0.62	22.43 ± 0.57	40°C

Conductance µS/cm	292.73 ±8.76	600.78 ±11.79	-
TDS mg/L	146.20 ± 4.41	300.89 ± 6.22	200 - 500
Transparency cm	149.00 ± 17.93	51.92 ± 4.15	
Total hardness mg/L	81.92 ± 2.37	189.70 ± 3.30	300
Ca Hardness mg/L	19.83 ± 0.99	60.59 ± 9.62	75
Mg Hardness mg/L	15.15 ± 0.69	31.50 ± 2.37	30
DO mg/L	5.37 ± 1.71	2.98 ± 0.92	>5
Alkalinity mg/L	105.96 ± 10.76	235.41 ± 4.57	< 200
Nitrates mg/L	0.02 ± 0.005	0.08 ± 0.004	10
Phosphates mg/L	0.01 ± 0.004	0.58 ± 0.074	5
Sodium mg/L	57.78 ± 1.85	151.82 ± 2.50	200
Potassium mg/L	13.36 ± 0.35	40.37 ± 0.83	-

**Tolerance limit is as prescribed by the Indian Standards Institution (IS 10500-1989).*

1.13 Phytoplankton analysis

The study revealed that the two tropical waterbodies under study, Chamarajasagar reservoir and Madiwala Lake sustain dense populations of phytoplankton. However, the density of phytoplankton is less in Chamarajasagar reservoir. In soft waters the population density is observed to be less and generally does not exceed a few thousands of organisms per litre, as is the case with Chamarajasagar reservoir. The formula for calculating the number of organisms per litre of the sample using the drop count method is as below:

Total plankton count per litre = A *(1/L)*(n/v)

A = number of organisms per drop

L = volume of original sample (l)

n = total volume of concentrated sample (ml)

v = volume of one drop (ml)

In the present study,

n = 30 ml

L = 100 litre

25 drops = 1 ml

v = 1/25 ml = 0.04 ml

1.13.1 Chamarajasagar reservoir

The sampling points 3 and 4 at the inlet of Arkavati show a higher density of phytoplankton, an average of 1328 and 2344 organisms per litre respectively, (table 5.5) which may be due to the anthropogenic activities on the banks, which adjoins a village. It was observed during the study, that the local villagers accessed the reservoir to wash cattle and clothes. On the other hand, at sampling points 1 and 2 at the other inlet Kumudavati, the phytoplankton density is relatively less and showed an average 304 and 683 organisms.

Table 5.5: Chamarajasagar reservoir – phytoplankton counts at five sampling sites

Chamarajasagar reservoir											
Phytoplankton composition		**Sampling stations**									
		1		**2**		**3**		**4**		**5**	
Class	**Species name**	**i**	**ii**	**i**	**ii**	**i**	**ii**	**i**	**ii**	**i**	**ii**
Cyanophyceae	*Microcystis aeruginosa*	26	29	70	81	150	170	314	300	216	215
Chlorophyceae	*Pediastrum duplex*	4	4	3	2	3	3	1	1	1	2
	Order Ulotichales	3	2	-		2	1	1	1	-	1
	unknown	1	1	3	1	3	1	-	-	10	6
Dinophyceae	*Ceratium hirudinella*	5	6	10	9	10	10	4	3	-	-
Bacillariophyceae	*Synedra species*	-	-	1	1	1	-	-	-	-	-
	Rhopalodia gibba	-	-	1	-	-	-	-	-	-	-
Unknown		-	-	-	-	-	-	-	-	1	-
Total plankton count / drop		39	42	88	94	169	185	320	305	228	224
Total plankton count / liter		293	315	660	705	1268	1388	2400	2288	1710	1680
Total average plankton count per station per liter		304		683		1328		2344		1695	

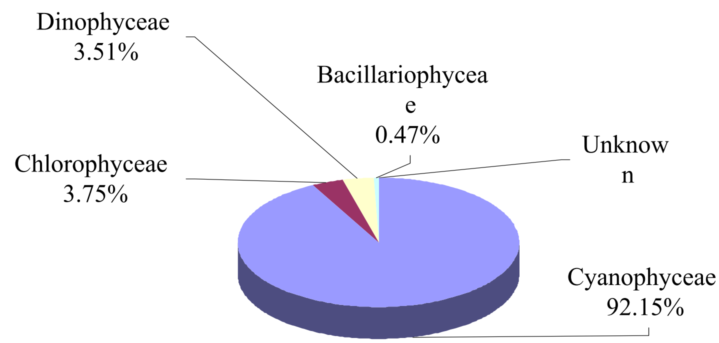
per litre respectively. The waters here are not influenced by any activities as in the cases of sampling points 3 and 4.

The algal population of the Chamarajasagar reservoir consists of five classes (fig 5.2, and table 5.6) including an unknown group that could not be identified due to the limitations of the study. Cyanophyceae (92.15 percent) dominated other algal forms

Table 5.6: Chamarajasagar reservoir – summary of phytoplankton counts and composition

Chamarajasagar reservoir						
Total phytoplankton counts						
		Sampling stations				
Sl no	**Class**	**1**	**2**	**3**	**4**	**5**
1	Cyanophyceae	28	76	160	307	216
2	Chlorophyceae	8	5	7	2	10
3	Dinophyceae	6	10	10	4	-
4	Bacillariophyceae	-	2	1	-	1
5	Unknown	-	-	-	-	1
Total plankton count per drop		**42**	**93**	**178**	**313**	**228**
Total plankton count per liter		**304**	**683**	**1328**	**2344**	**1695**

comprising of one single species of *Microsystis aeruginosa.* the next major class of algae is Chlorophyceae (3.75 percent) members followed by Dinophyceae (3.51 percent),



Phytoplankton composition of Chamarajasagar reservoir

Figure 5.2: Graph indicating phytoplankton composition of Chamarajasagar reservoir

Bacillariophyceae (0.47 percent) and an unknown class (0.12 percent). The Chlorophyceae class includes *Pediastrum duplex* members of the order Ulotrichales. Dinophyceae consists of a single species *Ceratium hirudinella.* As compared to the other classes of algae, Bacillariophyceae sp. *Synedra sp..* and *Rhopalodia gibba* were recorded as the least in number.

1.13.2 Madiwala Lake

The sampling point 1 which is located at the inlet shows a high density of phytoplankton (table 5.7). This inlet is the point where sewage is let into the lake after

Table 5.7: Madiwala Lake – phytoplankton counts at six sampling site

Madiwala Lake													
Phytoplankton compositioin		**Sampling stations**											
		1		**2**		**3**		**4**		**5**		**6**	
Class	**Species**	**i**	**ii**	**i**	**ii**	**i**	**ii**	**i**	**ii**	**i**	**ii**	**i**	**ii**
Cyanophyceae	*Microcystis aeruginosa*	195	215	58	51	30	41	83	77	68	66	58	55
	Spirulina sp..	3	2	4	4	-	5	-	-	-	-	-	-
Chlorophyceae	*Chlorella sp..*	121	111	58	43	27	22	80	73	12	10	25	17
	Pediastrum duplex	12	10	2	1	3	2	12	17	5	5	14	19
	Pediastrum simplex	-	1	-	-	-	1	2	4	-	-	-	-
	Pediastrum tetras	-	-	1	-	-	-	-	1	1	3	-	1
	Scenedesmus sp.. 1	14	16	6	4	11	14	26	29	3	3	22	29
	Scenedesmus sp.. 2	1	6	1	-	-	-	2	3	-	-	1	-
	Scenedesmus sp.. 3	-	-	1	-	-	-	-	-	-	-	3	1
	Actinastrum sp..	1	-		-	2	1	1	-	-	1	1	4
	Unknown sp..	5	1	5	-	18	12	70	79	3	6	10	2
	Tetraedron sp..	-	-		-	-	-	-	-	-	-	1	1
	Crucigenia sp.. 1	-	-	3	2	-	-	-	-	1	1	2	1
	Crucigenia sp.. 2	270	231	98	113	86	78	194	200	85	73	120	111
	Desmids sp..	-	-	-	-	-	-	-	-	1		1	-
Bacillariophyceae	*Navicula sp..*	-	-	-	-	-	-	1	1	-		-	-
Euglenophyceae	*Phacus sp..*	-	-	-	-	-	-	1	-	-	-	-	

Unknown		-	-	-	-	-	-	2	2	-	-	-	-
Total plankton count per drop		622	593	237	218	177	176	474	486	179	168	258	241
Total plankton count per liter = A *(1/L)*(n/v)		4665	4448	1778	1635	1328	1320	3555	3645	1343	1260	1935	1808
Total average plankton count per station per liter		**4556**		**1706**		**1324**		**3600**		**1301**		**1871**	

primary treatment High numbers of Chlorophyceae species , (73.44 peercent) which, dominate the lake waters is an indication of organic pollution. The phytoplankton composition of Madiwala Lake consists of five classes (fig 5.3 and table 5.8) including

Table 5.8: Madiwala Lake – summary of phytoplankton counts and composition

Madiwala Lake							
Total phytoplankton counts							
		Sampling stations					
Sl no	**Class**	**1**	**2**	**3**	**4**	**5**	**6**
1	Cyanophyceae	205	55	36	80	67	57
2	Chlorophyceae	400	167	139	397	106	191
3	Bacillariophyceae	-	-	-	2	-	-
4	Euglenophyceae	-	-	-	1	-	-
5	Unknown	-	-	-	4	-	-
Total plankton per drop		**605**	**221**	**174**	**480**	**173**	**247**
Total plankton per liter		**4556**	**1706**	**1324**	**3600**	**1301**	**1871**

species of an unknown class. Chlorophyceae species were dominated by *Chlorella sp..,* followed by *Pediastrum duplex*, *Pediastrum simplex, Pediastrum tetras, Scenedesmus sp.., Actinastrum sp.., Tetraedron sp.., and Crucigenia sp*.. all mentioned in the order of dominance. The next major class of phytoplankton in Madiwala Lake was Cyanophyceae (26.20 percent), which was dominated by *Microcystis aeruginosa*. followed by *Spirulina sp.*.This dominance again is noticeable at the sampling point 1 (Table 5.8), which is at the inlet, where sewage is let in from the Sewage treatment plant. Bacillariophyceae and Euglenophyceae consisted of a single species *Navicula sp.* and *Phacus sp.* respectively.

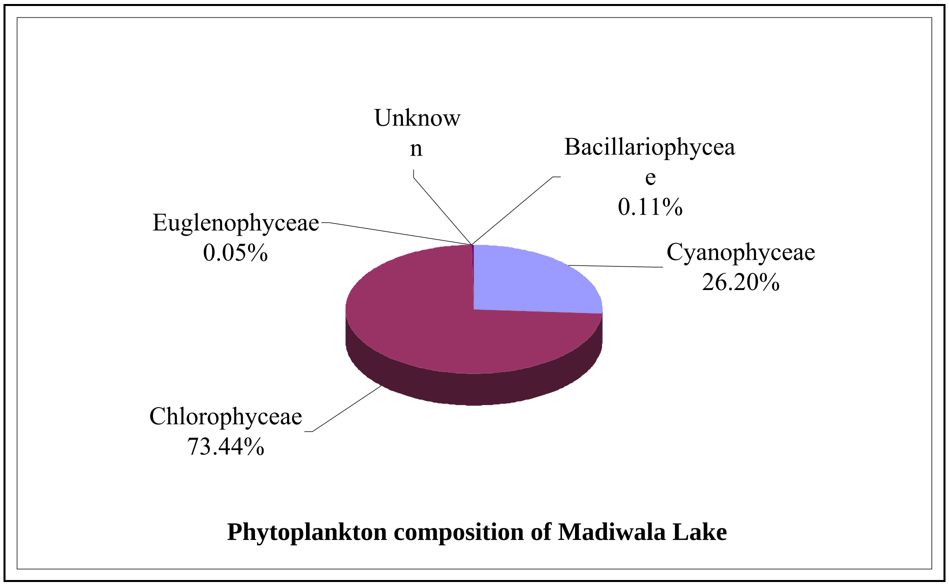


Figure 5.3: Graph indicating phytoplankton composition of Madiwala Lake

As compared to the other classes Euglenophyceae and Bacillariophyceae species were the lowest in numbers.

The species of phytoplankton common to both the waterbodies under study have been presented in the table 5.9. Similarly, species unique to Chamarajasagar reservoir and species unique to Madiwala Lake have been tabulated in tables 5.10 and 5.11 respectively.

Table 5.9: Species of phytoplankton common to Madiwala Lake and Chamarajasagar reservoir

Class	Order	Species name
Cyanophyceae		*Microcystis aeruginosa*
Chlorophyceae	Chlorococcales	*Chlorella sp.*
		Pediastrum duplex
		Unknown
	Ulotrichales	

Table 5.11: Species unique to Madiwala Lake

Class	Order	Family/genus/species
Chlorophyceae	Chlorococcales	*Chlorella sp..*
		Pediastrum simplex
		Pediastrum tetras
		Scenedesmus sp.. 1
		Scenedesmus sp.. 2
		Scenedesmus sp.. 3
		Actinastrum sp..
	Desmids	
Bacillariophyceae		*Navicula sp..*
Euglenophyceae		
Unknown 1		

Table 5.10: Species unique to Chamarajasagar reservoir

Class	Family/genus/species
Dinophyceae	*Ceratium hirudinella*
Bacillariophyceae	*Synedra sp..*
	Rhopalodia gibba
Unknown 2	

1.14 Zooplankton

Zooplankton by their heterotrophic activity play a key role in the cycling of organic materials in aquatic ecosystems. Zooplankton, like phytoplankton have long been used as indicators of water quality. Rotifers form an important cosmopolitan component of the zooplankton and they are one of the principal links in the food chain. Copepods and cladocerons are the principal planktonic groups of microcrustaceans present in waterbodies.

Due to the limitations of time and resources, a detailed analysis of zooplankton and the other organisms in the aquatic food chain was not possible. However, the list of other organisms observed during the study is presented in the tables below. The limited study reveals that the zooplankton community in surface waters of both the waterbodies is comprised of Rotifera, microcrustaceans – Cladocera and Copepoda.

1.15 Fish

The fisheries department at both the study lakes is in charge of the fishing operations. The fishes have been introduced by them for commercial fishing and therefore there are only a few types of fishes in the lake and are mentioned in the table 5.12.

Fish forms the upper trophic levels of an aquatic food chain. They feed on detritus, zooplankton, phytoplanakton, macroinvertebrates and other aquatic organisms and thus can be of use in indicating the cumulative effect of pollution on its habitat – water. For example, increase in temperatures can alter the population structure of fishes – increasing less desirable species and reducing the desirable species. Similarly, pH and DO of the environment is very important for the survival of fish.

Table 5.12: Fish observed at the study areas

Fish observed at the study areas		
Sl no	**Madiwala Lake**	**Chamarajasagar reservoir**
1	Tilapia	Tilapia
2	Rahu	Catla
3	Catfish	Catfish
4	Kacchu menu (local name)	Common carp
5	Common carp	
6	Mrigal	

1.16 Birds

Wetlands support a large diversity of avifauna. Wetland birds form an important link in the aquatic food chain depending on the wetland and other wetland associated organisms for foraging, breeding, resting, nesting, etc. Aquatic vegetation is a valuable source of food, especially for waterfowl. Birds have also been used as indicators of the health of a waterbody.

During the period of the investigation at the study area a few birds that were observed have been listed in table 5.13.

Table 5.13: Birds observed at the study areas

Birds observed at the study areas		
Sl no	**Madiwala Lake**	**Chamarajasagar reservoir**
1	Little cormorant	Little cormorant
2	Great cormorant	Great cormorant
3	Grey heron	Grey heron
4	Medium egret	Medium egret
5	Cattle egret	Cattle egret

6	Pelican	Indian peafowl
7	Common myna	Red wattled lapwing
8	Jungle myna	Lesser pied kingfisher
9	House crow	Common sand piper
10	Pariah kite	Brahminy kite
11	Brahminy kite	Spotted dove
12	Pied kingfisher	Rose ringed parakeet
13		Asian koel
14		House swift
15		White breasted kingfisher
16		Singing bush lark
17		Little ringed plover
18		Common swallow
19		Black drongo
20		Common myna
21		Jungle myna
22		House crow
23		Red whiskered bulbul
24		Indian robin
25		Large pied wagtail
26		Purple rumped sunbird
27		Black kite

CONCLUSIONS

1.17 Conclusion

The detailed investigations of the parameters, which are well within the tolerance limits, indicate that the Chamarajasagar reservoir is fairly unpolluted, except for the pH values, which indicate greater alkalinity. This may be attributed to the natural causes and the agricultural runoff from the catchment. On the contrary, the limnology of Madiwala Lake is greatly influenced by the inflow of sewage that contributes significantly to the dissolved solids, total hardness, alkalinity and a low DO of the lake water.

As a major element in aquatic biota, the algal community often exhibits dramatic changes in response to changes in physico – chemical properties of the aquatic environment. The differences in the dominant phytoplankton assemblage of the lakes reflect their trophic levels. It is reported that eutrophic lakes were found to be dominated by Myxophycean forms (Prescot[100]. 1939). The eutrophic lakes had mainly Cyanophycean element dominated by *Microcystis.* In the present study, although, the two study areas, differ in age, physiography, chemistry and type of inflows, yet they maintain phytoplankton overwhelmingly dominated by Cyanophyceae members, specifically *Microcystis aeruginosa.* Madiwala Lake phytoplankton also show a high density of Chlorophyceae members dominated by *Scenedesmus sp.*, *Pediastrum sp.,* and *Euglena sp.* which is an indication of organic pollution. These findings are in agreement with those of Chaturvedi[101] *et al.* (1999). The bulk of the domestic sewage, which enters the Madiwala Lake, has a major influence on the chemistry and in turn on the biological aspects of the lake. The sewage treatment though treats the sewage and helps in lowering the BOD and COD, the N, P, K values remain high, which explains the high density of phytoplankton, and the reduced transparency, high hardness, dissolved solids and alkalinity values.

The results also reveal that due to anthropogenic activities (encroachments, construction activities, waste dumping, sewage disposal, etc.) in the Madiwala Lake catchment area, the drainage connectivity between wetlands have been lost and heavily altered, resulting in reduced water storage capacity and shrinkage in the wetland area which has also contributed to depletion in the groundwater table. While HSR Layout, a residential area in the vicinity was being formed, the drain connecting Agaram lake and Madiwala lake should have been widened. Instead, water was simply diverted to an area where slums have mushroomed. Today the drains are not enough to carry the water and the area was flooded during the recent downpour in Bangalore city.

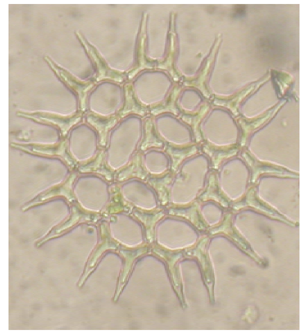
Remarkably little attention is given to the alarming loss of wetlands in the city. Hence, there is a need to create awareness in public about the loss and to conserve and restore these natural resources. This necessitates the need for restoration and formulation of conservation strategies for sustainable management of wetlands. Further research is required towards understanding:

- the role of individual indicator species in an aquatic system
- linkages between aquatic ecosystem quality and food chain
- interrelationship with other abiotic factors involved
- life history, prey predator relationship, inter and intra – specific competition of indicator species
- the effect of pollution on them

APPENDIX A: PHYTOPLANKTON – OBSERVED DURING THE STUDY

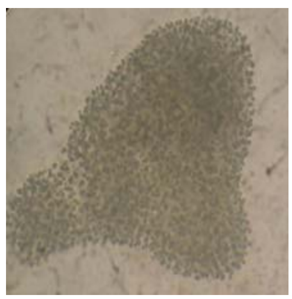
Phacus sp..

Tetraedoron sp..



Pediastrum sp..

Unknown sp..



Scenedesmus

Microcystis

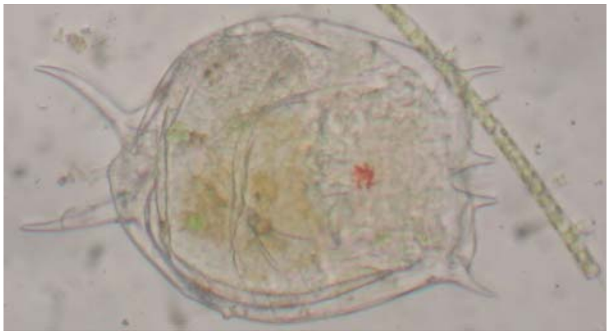
Unknown sp..

Rhopalodia gibba

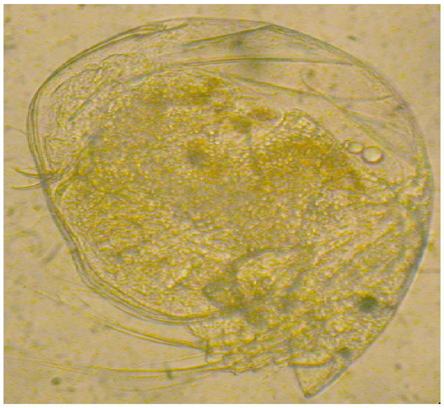
Ceratium hirudinella

Navicula sp..

APPENDIX B: : ZOOOPLANKTON – OBSERVED DURING THE STUDY




Rotifers



Cladoceran

Copepods

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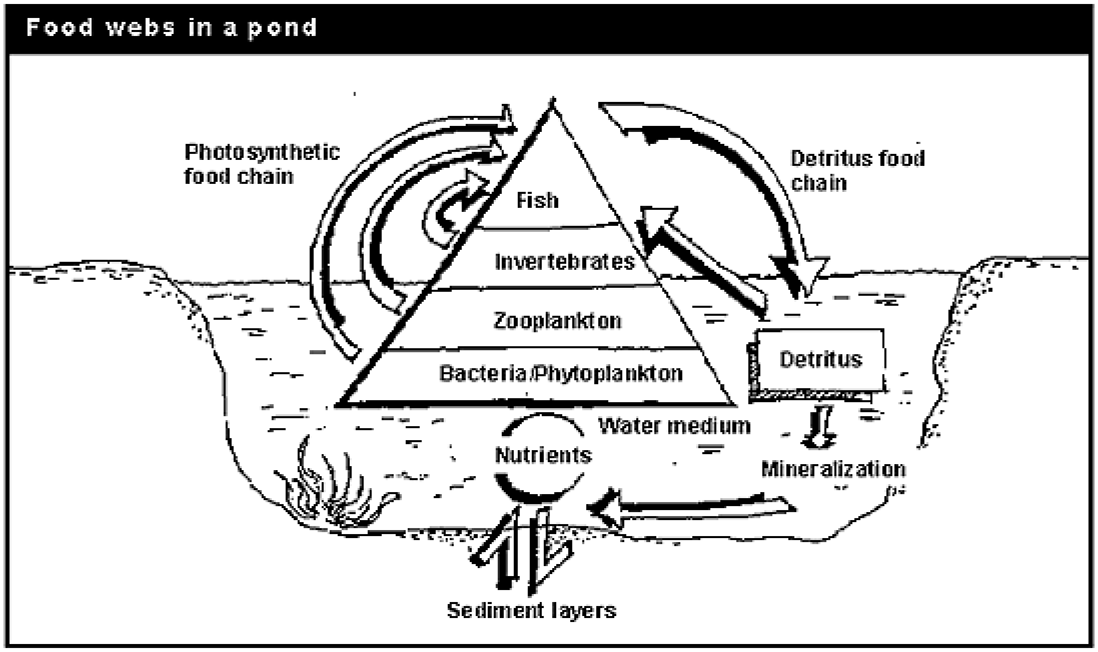

ENERGY AND WETLANDS RESEARCH GROUP
CENTRE FOR ECOLOGICAL SCIENCES
INDIAN INSTITUTE OF SCIENCE
BANGALORE 560 012

Telephone : 91-80-23600985/22932506/22933099
Fax : 91-80-23601428/23600085/23600683[CES-TVR]
Email : cestvr@ces.iisc.ernet.in,
energy@ces.iisc.ernet.in
Web: http://ces.iisc.ernet.in/energy
http://ces.iisc.ernet.in/biodiversity
Open Source GIS: http://ces.iisc.ernet.in/grass