INTRODUCTION

Indian fisheries has made great strides during the last five decades with production of fish and shellfish showing over eight-fold increase from capture fisheries and aquaculture, contributing immensely to the food basket of the country. India being the fourth largest producer of fish is playing an important role in global fisheries. With current production of over 2.4 mmt from aquaculture, the country also occupies second position in the world after China (CIFA, 2007).

At present, about 610,000 acre of freshwater area is under fish culture in India and more than 50% human population depends on various fish species for food (Gaur, 2005). Keeping in view the current fish production, still there is the requirement to have an adequate supply of this nutritious and productive food for human consumption. To ensure high fish production, there is a need of both qualitative and quantitative development and scientific management of available freshwater resources (CIFA, 2007).

India has a great variety of topographical and climatic conditions. As a result, the freshwater flora and fauna fluctuate to great extent. Odum (1971) reported that water and biota of an aquatic ecosystem are inseparable and complementary to each other. In fact, India has enormous potential for the development of freshwater aquaculture circumvallating about 742 species inhabiting the lakes, ponds and reservoirs (Jayaram, 1981).

Lotic and lentic reservoirs, especially ponds are one of the important sources of fish production through proper management of water resources on scientific lines (Gaur, 2005). The abiotic environment determines the biological productivity of any water body, including fish
production. The study of physico-chemical parameters and primary productivity of any water body is the prime requisite for the successful implementation of various fish culture programs. Major physico-chemical parameters include temperature, pH, Dissolved Oxygen (DO), free CO₂, turbidity, total alkalinity, Biological Oxygen Demand (BOD), nitrate nitrogen and phosphates. These are the important factors, which determine the change in aquatic environment (Odum, 1971). The most outstanding feature in the aquatic ecosystem is the direct or indirect relationship between planktonic population, macrophytes, fishes and their environment (Pahwa and Mehrotra, 1966).


Biological parameters include the cyanobacteria, which are an ancient and morphologically diverse group of prokaryotes. All cyanobacteria are photo-autotrophic (Gr. auto = "self", tropho -
organisms, yet many can grow heterotrophically, using light for energy and organic compounds as a carbon source (Adams, 1997). The cyanobacteria are a remarkably widespread and successful group, colonizing freshwater, marine and terrestrial ecosystems, including extreme habitats such as Antarctic lakes, salt lakes and hot springs (Fogg et al., 1973). Historically considered to be algae, botanists and phycologists placed them into the Cyanophyceae on the basis of International Code of Botanical Nomenclature (Castenholz and Waterbury, 1989; Greuter et al., 1994).

Cyanobacteria are also known as blue-green algae, Myxophyceaeans, Cyanophyceans, Cyanophytes, Cyanoprokaryotes etc. in existing literature (Bartram et al., 1999). This apparent confusion in use of names highlights the important position that these organisms occupy in the development of biology as a science. From their earliest observations and recognition by botanists (Linné, 1755; Vaucher, 1803; Geitler, 1932) and onwards to their treatment in modern text-books (Anagnostidis and Komárek, 1985; Staley et al., 1989), the amazing combination of properties found in algae and bacteria which these organisms exhibit, have been a source of fascination and attraction for the scientists.

The cyanobacteria have an extensive fossil record. The oldest known fossils, in fact, are cyanobacteria from Archaean rocks of Western Australia, dated 3.5 billion years old (Brock 1973; Schopf, 1996). This is somewhat surprising, since the oldest rocks are only a little older i.e. 3.8 billion years old. Therefore, cyanobacteria are among the easiest microfossils to recognize. Small-fossilized cyanobacteria have been extracted from Precambrian rocks, and studied through the use of SEM and TEM (Scanning and Transmission Electron Microscopy). The cyanobacteria have also been tremendously important in shaping the
course of evolution and ecological change throughout the history of earth (Brock, 1973; Schopf, 1996). Numerous Cyanobacteria photosynthesizing during the Archaean and Proterozoic Era generated the oxygen atmosphere on which we depend. Before that time, the atmosphere had a very different chemistry, unsuitable for life, as we know it today.

The other great contribution of the cyanobacteria is the origin of plants. The chloroplast with which plants make food for themselves is actually a cyanobacterium living within the plant's cells (Brock, 1973; Schopf, 1996). Sometime in the late Proterozoic or in the early Cambrian period, cyanobacteria began to take up residence within certain eukaryotic cells, making food for the eukaryotic host in return for a home. This event is known as endosymbiosis, and is also the origin of the eukaryotic mitochondrion (Douglas, 1994).

For many years, cyanobacterial taxonomy was determined by morphological variation (Geitler, 1932). According to Geitler (1932), all cyanobacteria are divided into unicellular coccoid forms (i.e., order Chroococcales) and filamentous forms. Filamentous cyanobacteria were further subdivided into two orders- Nostocales and Stigonematales, based on their ability to form heterocysts and/or trichomes. Unicellular cyanobacteria that form aggregates by sharing outer wall layers were grouped into the Pleurocapsales. Recognizing their bacterial characteristics, Stanier et al. (1978) proposed that cyanobacterial taxonomy follow the International Code of Nomenclature of Bacteria, and later, Rippka et al. (1979) published a taxonomy of the cyanobacteria that was based on physiological, morphological and some genetic criteria.

Although, the cyanobacteria are truly prokaryotic, yet they have an elaborate and highly organized system of internal membranes which
functions in photosynthesis (Ormerod, 1992). Chlorophyll a and several accessory pigments (phycoerythrin and phycocyanin) are embedded in these photosynthetic lamellae, the analogs of the eukaryotic thylakoid membranes (Douglas, 1994). Most cyanobacteria contain chlorophyll a together with various proteins called phycobilins, which provide a typical blue-green to grayish-brown colour to the cells (Cohen-Bazire and Bryant, 1982). However, few genera of cyanobacteria lack phycobilins and have chlorophyll a as well as chlorophyll b, providing bright green colour to them (Douglas, 1994).

The enhancement of primary productivity in water bodies is termed as eutrophication, i.e. heavy nutrient load in the form of phosphorus and nitrogen compounds, which often leads to the excessive growth of some harmful cyanobacteria. It is a growing global problem in large number of water bodies. A common symptom of pond eutrophication is the appearance of cyanobacterial species such as Microcystis, Anabaena, Oscillatoria, Nodularia, Nostoc etc. (Skulberg et al., 1984; Codd et al., 1989; Carmichael, 1992). Such cyanobacterial blooms are not desirable in fish ponds, as they disturb diurnal oxygen balance of the fish ponds and cause gill clogging of some surface feeding fishes (Winn and Knott, 1992; Lenihan and Peterson, 1998).

Eutrophication was recognized as a pollution problem in many Western European and North American water bodies in the middle of the twentieth century (Rudhe, 1969). Since then, it has caused deterioration in the aquatic environment globally and serious problems for water use, particularly in drinking water treatment (Codd, 2000). A survey showed that in the Asia Pacific Region, 54% of stagnant water bodies are eutrophic. The proportions for Europe, Africa, North America and South America are 53%, 28%, 48% and 41%, respectively (ILEC/Lake Biwa
Research Institute, 1988-1993). However, technical measures for reduction of nutrients are present for stagnant water bodies, but still these have not been widely applied (Chorus and Mur, 1999).

Wherever, conditions of temperature, light and nutrients status are favourable, increased growth of cyanobacteria is usually seen at the surface of water (Pearson et al., 1990). This proliferation is dominated by a single or a few species, the phenomenon is referred to as cyanobacterial bloom (Hrudcay et al., 1994; Ressom et al., 1994). Problems associated with cyanobacteria are likely to increase in areas experiencing population growth with a lack of concomitant sewage treatment and in regions with agricultural practices causing nutrient losses to water bodies through over-fertilization and erosion.

In recent years, the incidence of harmful Cyanobacterial blooms has increased globally in frequency, severity, and duration (Anderson et al., 1993; Chorus and Bartram, 1999). A widely-used measure of cyanobacterial biomass is the chlorophyll $a$ concentrations. Peak values of chlorophyll $a$ for an oligotrophic pond are about 1-10 µg l$^{-1}$, while in a eutrophic pond they can reach 300 µg l$^{-1}$. However, Zohary and Roberts (1990) reported a very high chlorophyll $a$ content as high as 3,000 µg l$^{-1}$ in the reservoir of South Africa.

Recently cyanobacterial toxins have become widely recognized as a human health problem arising as a consequence of eutrophication. The importance of such toxins, relative to other water-health issues, can currently only be estimated. According to Sivonen and Jones (1999), a significant proportion of cyanobacteria produce one or more of a range of potent toxins. If water containing high concentrations of toxic cyanobacteria or their toxins are ingested (in drinking water or accidentally during recreation), they impart damage to various organs
which affects the human health (Kuiper-Goodman et al., 1999). Some cyanobacterial substances may cause skin irritation on contact.

Cyanobacteria are known to produce a wide range of bioactive and toxic substances (cyanotoxins), which are harmful to aquatic animals and other phytoplanktons used as source of food for fishes and other aquatic animals (Phillips et al., 1985; Rabergh et al., 1991). These toxins are classified into three categories, according to their mode of action: hepatotoxin, neurotoxin and dermatotoxin (Chorus and Bartram, 1999). The hepatotoxins are produced by various species within the genera *Microcystis* (Shirai et al., 1991; Namikoshi et al., 1992; Lukkainen et al., 1994; Lee et al., 1998), *Oscillatoria* (Lukkainen et al., 1993), *Anabaena* (Harada et al., 1991; Sivonen et al., 1992; Namikoshi et al., 1998), *Nodularia* and *Nostoc* (Namikoshi et al., 1990; Sivonen et al., 1990; Beattie et al., 1998) etc. These are also known as microcystins, which are geographically most widely distributed in freshwaters (WHO, 2003). Recently, the microcystins have even been identified in marine environments as a cause of liver disease in net-pen reared salmon. However, it is not clear which organism in marine environments contains these toxins. As with many cyanotoxins, microcystins were named after the first organism found to produce them, *Microcystis aeruginosa*, but later studies also showed their occurrence in other cyanobacterial genera. At least 70 variants of this microcystin have been identified throughout the world till now (Rinehart et al., 1994; Sivonan and Jones, 1999). Three families of neurotoxins, anatoxin-a & homo anatoxin-a, anatoxin-a(s) and saxitoxins have been reported from many countries (Sawyer et al., 1968; Mahmood and Carmichael, 1986; Fawell et al., 1993; Humpage et al., 1994; AWWA, 1995). Some cyanobacteria such as *Lyngbya* produce dermatotoxins, which cause inflammation of the skin (Moikeha and Chu,
1971; Hashimoto et al., 1976; Mynderse et al., 1977). They are also potent tumor promoter (Fujiki et al., 1990).

Cyanotoxins belong to rather diverse groups of chemical substances (Sivonen and Jones, 1999), each of which shows specific toxic mechanisms in vertebrates (Kuiper-Goodman et al., 1999). Theses toxic cyanobacteria have caused fatal poisoning of mammals, birds and fishes (Codd and Poon, 1988; Carmichael, 1992; Kotak et al., 1996; Tenchilla and Dietrich, 1997) and may also have exerted adverse effects on human health (Gorham and Carmichael, 1988; Carmichael, 1994, 1997). These toxins may fall into two of the four groups of water-related diseases. The exposure of cyanotoxins has led to human fatalities (Kuiper-Goodman et al., 1999). These toxins pose a challenge for management. The number of quantitative surveys on cyanotoxin occurrence is low, and the level of cyanotoxin exposure during recreational activities is largely unknown. Surveys on cyanobacteria and cyanotoxins during 1990s have tended to employ more sensitive and definitive methods for the characterization of toxins, such as chromatographic or immunological methods (Sivonen and Jones, 1999). These studies provide an improving basis for estimating the range of concentrations to be expected in given water body and season. However, monitoring cyanotoxin concentration is more difficult than many other waterborne disease agents, because variation in cyanobacterial quantities, in time and space, is substantial, particularly if scum-forming species are dominant. Wind-driven accumulations and distribution of surface scum can result in concentrations of the toxin by a factor of 1,000 or more (or even result in the beaching of scum) and such situations can change within very short time periods, i.e. the range of hours. Very few studies of cyanotoxin removal from water have been
published (Hrudey et al., 1999), although some water agencies have carried out unpublished studies.

In comparing the available indications of hazards from cyanotoxins with other water-related health hazards, it is conspicuous that cyanotoxins have caused numerous fatal poisonings of livestock and wildlife, but human fatalities due to oral uptake have not been documented. Cyanotoxins are rarely likely to be ingested by humans in sufficient amounts for an acute lethal dose. Nevertheless, dose estimates indicate that a fatal dose is possible for humans, if scum material is swallowed. The combination of available knowledge on chronic toxicity mechanisms (such as cumulative liver damage and tumour promotion by microcystins) with that on ambient concentrations occurring under some environmental conditions, shows that chronic human injury from some cyanotoxins is likely, particularly if exposure is frequent or prolonged at high concentrations.

Because of the small number of published studies regarding cyanobacterial toxins and their impact on animal and human health, it was felt desirable to improve the understanding of this topic by conducting a prospective study. The principal aim in conducting this study was to improve the understanding of the problem, and to provide further data and recommendations to allow revision and refinement of recreational water exposure guidelines relating to cyanobacterial toxins.