Water is a renewable resource sustained by the hydrological cycle. The hydrological cycle and services are of prime concern as they move through and define the environment and biology of our planet. The history of human civilisation is replete with the ways humans have learned to manipulate and use the hydrological services. Hydrological services are a diverse group, categorised into five broad groups (Brauman, 2007). They are:

- improvement of extractive water supply,
- improvement of in-stream water supply,
- water damage mitigation,
- provision of water related cultural services,
- provision of water-associated supporting services.

Extractive water uses include municipal, agricultural, commercial, industrial, and thermoelectric power use. *In situ* uses include hydropower generation, water recreation and transportation, as well as freshwater fish production. Globally, freshwater withdrawals have been estimated at 35% of accessible runoff and in-stream uses estimated at about 19% of runoff, though these diversions are not distributed uniformly worldwide (Oki & Kanae, 2006). Water damage mitigation is a regulating service; which includes ecosystem mitigation of flood damage, sedimentation of water bodies, saltwater intrusion into groundwater, and dryland salinisation. Cultural hydrologic services include spiritual uses, aesthetic appreciation, and tourism. The water-related supporting services of terrestrial ecosystems are wide ranging and include the provision of water for plant growth and to create habitats for aquatic organisms. Trade-offs are inherent in the supply of hydrologic services. Under various scenarios of quantity, quality, location, and timing of flow, some services will be improved at the expense of others.
1.1 World water distribution

Water is vital in all components of the environment. Water covers about 70% of earth’s surface. It occurs in all spheres of the environment-in the oceans as a vast reservoir of saltwater, on land as surface water in lakes and rivers, underground as groundwater, in the atmosphere as water vapour, in the polar icecaps as solid ice, and in many segments of the anthrosphere such as in boilers or municipal water distribution systems. Water is an essential part of all living systems and is the medium from which life evolved and in which life exists. The relative water distribution of earth (Mckinney & Schoch, 2003) is given below as percentage.

<table>
<thead>
<tr>
<th>Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt water</td>
<td>97.4</td>
</tr>
<tr>
<td>Ice caps &amp; glaciers</td>
<td>1.98</td>
</tr>
<tr>
<td>Ground water</td>
<td>0.59</td>
</tr>
<tr>
<td>Lakes</td>
<td>0.007</td>
</tr>
<tr>
<td>Soil moisture</td>
<td>0.005</td>
</tr>
<tr>
<td>Atmosphere, rivers</td>
<td>0.001</td>
</tr>
<tr>
<td>Plants, animals</td>
<td>0.001</td>
</tr>
</tbody>
</table>

As human populations and their economies grow, water uses tend to increase although the amount of freshwater in the world remains roughly the same. The amount economically available for human use is only 0.007% of the total, or about 13,500 km³, which is about 2300 m³ per person—a 37% drop since 1970 (Wolf, 2007).

1.2 Water quality degradation

Availability of freshwater of adequate quantity and quality is a prerequisite for sustainable development. Water pollution and wasteful use of freshwater threaten development projects and make water treatment essential in order to produce safe potable water. Discharge of toxic chemicals, over-pumping of aquifers, long-range atmospheric transport of pollutants and
Contamination of water bodies with substances that promote algal growth are some of today’s major causes of water quality degradation. Some problems have been present for a long time but have only recently reached a critical level, while others are newly emerging. To understand the effects of water pollution and technology applied in its control, it is useful to classify pollutants. Based on their environmental and health effects they are classified into:

- Disease causing agents or pathogens, including bacteria, viruses, protozoa and parasites,
- Oxygen demanding organic wastes,
- Water-soluble inorganic chemicals, including acids, salts, and metals,
- Inorganic plant nutrients (nitrates and phosphates) from fertilizers,
- Organic chemicals, including oil, gasoline, plastics, pesticides, solvents and detergents,
- Water-soluble radioactive isotopes,
- Sediment or suspended matter (particulates) from soil and other solids,
- Heat from the cooling of industrial and power plants,
- Oil from petrochemical industry, leakage from pipes and accidental spillage, and
- Genetic pollution caused by the introduction of exotic species.

To a limited extent, streams and rivers have the ability to assimilate biodegradable wastes. Thus, they can recover the effects of pollution naturally, without significant or permanent environmental damage. The capacity for self purification depends on the strength and volume of pollutants and on the stream discharge or flow rate.
1.3 Water on international agenda

The urge to protect hydrosphere resources has been on the main agenda of international conventions and national policies. UN conference on water, 1977 was the first initiative to protect hydrological resources. Following it, water is on international agenda with a number of water conservation and management conferences, polices and action plans. Major international programmes and conferences on pollution prevention, conservation and management programmes and conferences are listed below (www.worldwatercouncil.org).

- UN Conference on Water, Mar del Plata (1977) defined water as a common good and highlighted the right of people to have access to drinking water regardless of the development stage and socio-economic situation.

- International Drinking Water Supply and Sanitation Decade (launched by the UN) 1981-1990, raised its goal as to "Provide every person with access to water of safe quality and adequate quantity, along with basic sanitary facilities, by 1990."

- Global consultation on Safe Water and Sanitation for the 1990’s, New Delhi - organised by UNDP appealed to all nations for concerted action to enable people to obtain two of the most basic human needs - safe drinking water and environmental sanitation.

- In 1992 the International Conference on Water and the Environment held in Dublin, Ireland, produced four key principles to guide policies for water and sustainable development.

- UN Conference on Environment and Development (UNCED Earth Summit, Rio de Janeiro, 1992) action plan-Agenda 21 encouraged the global management of fresh water and the integration of sectoral water plans and programmes within the framework of national economic and social policy.
UN Conference on Human Settlements (Habitat II), Istanbul (1996) advocated the necessity to provide adequate quantities of safe water.

The priorities of the First World Water Forum, Marrakech (1997) were water sanitation, shared water management, ecosystem conservation, gender equality, and efficient use of water.

Second World Water Forum, La Hague (2000) emphasised the need for better governance and an integrated water resources management through sharing water resources and governing water wisely.

United Nations Millennium Declaration (2000) defined its development goal as: "Halve, by 2015, the proportion of people who are unable to reach or to afford safe drinking water."

International Conference on Freshwater, Bonn (2001) recognised water as a key to sustainable development.

According to the report published by third world water forum (2003) significant progress has been made since the second world water forum and it is possible to meet the water challenges.

The International Decade for Action “Water for Life” 2005 to 2015 (launched by the UN) aims to promote efforts to fulfil international commitments made on water and water-related issues by 2015.

Fourth World Water Forum (Mexico), held in 2006 declared its theme as "Local Actions for a Global Challenge", through participation of local actors.

1.4 Water quality management

Water quality management is the practice of planning, developing, distribution and optimum utilization of water resources under defined water polices and regulations, for the protection of water’s quality for various beneficial uses, for the provision of adequate wastewater collection, treatment, and disposal for municipalities and industries, and for the activities
that might create water quality problems. The sustainable management of water quality has policy, technical, institutional and financial components.

Water quality is the physical, chemical and biological characteristics of water in relationship to a set of standards. Water quality standards are limits on the amount of physical, chemical or microbiological impurities allowed in water that is intended for a particular use. Water quality requirements or objectives can be usefully determined only in terms of suitability for a purpose or purposes, or in relation to the control of defined impacts on water quality. Water quality standards are created for different types of water bodies and water body locations as per desired uses. The primary uses considered for such characterization are parameters which relate to drinking water, safety of human contact, and for health of ecosystems. Water quality objectives aim at supporting and protecting designated uses of freshwater, i.e. its use for drinking-water supply, livestock watering, irrigation, fisheries, recreation or other purposes, while supporting and maintaining aquatic life and/or the functioning of aquatic ecosystems. Water quality objectives provide the basis for pollution control regulations and for carrying out specific measures for the prevention, control or reduction of water pollution and other adverse impacts on aquatic ecosystems (Tebbutt, 1998).

Water quality criteria for raw water, used for drinking-water treatment and supply usually depend on the potential of different methods of raw water treatment to reduce the concentration of water contaminants to the level set by drinking-water criteria. Drinking water treatment can range from simple physical treatment and disinfection, to chemical treatment and disinfection, to intensive physical and chemical treatment.

Water quality criteria for irrigation water generally take into account, amongst other factors, such characteristics as crop tolerance to salinity, sodium concentration and phytotoxic trace elements.
Livestock may be affected by poor quality water causing death, sickness or impaired growth. Variables of concern include nitrates, sulphates, total dissolved solids (salinity), a number of metals and organic micro pollutants such as pesticides. In addition, toxic algae and pathogens in water can present problems. Some substances, or their degradation products, present in water used for livestock may occasionally be transmitted to humans.

Water quality criteria for recreational purpose are used to assess the safety of water to be used for swimming and other water-sport activities. The primary concern is to protect human health, by preventing water pollution from faecal material or from contamination by microorganisms that could cause gastro-intestinal illness, ear, eye or skin infections. Criteria are therefore usually set for indicators of faecal pollution, such as faecal coliforms and pathogens.

Water quality criteria for the protection of aquatic life may take into account only physico-chemical parameters which tend to define water quality that protects and maintains aquatic life, ideally in all its forms and life stages, or they may consider the whole aquatic ecosystem. Water quality parameters of concern are traditionally dissolved oxygen (because it may cause fish kills at low concentrations) as well as phosphates, ammonium and nitrate (because they may cause significant changes in community structure if released into aquatic ecosystems in excessive amounts). Heavy metals and many synthetic chemicals can also be ingested and absorbed by organisms and, if they are not metabolised or excreted, they may bioaccumulate in the tissues of the organisms. Some pollutants can also cause carcinogenic, reproductive and developmental effects.

Water quality criteria for commercial and sports fishing take into account, in particular, the bioaccumulation of contaminants through successive levels of the food chain and their possible biomagnification in higher trophic levels, which can make fish unsuitable for human consumption. They are
established at such a concentration that bioaccumulation and biomagnification of any given substance cannot lead to concentrations exceeding fish consumption criteria, i.e. criteria indicating the maximum content of a substance in fish for human consumption that will not be harmful (Helmer & Hespanhol, 1997).

In India, five water quality classes have been designated (A-E) on the basis of the water quality requirements for a particular use (Trivedy, 2004).

<table>
<thead>
<tr>
<th>Water quality classification</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
<td>Drinking water source without conventional treatment but after disinfection.</td>
</tr>
<tr>
<td>Class B</td>
<td>organised outdoor bathing.</td>
</tr>
<tr>
<td>Class C</td>
<td>Drinking water source with conventional treatment followed by disinfection.</td>
</tr>
<tr>
<td>Class D</td>
<td>Maintain aquatic life (i.e. propagation of wildlife and fisheries).</td>
</tr>
<tr>
<td>Class E</td>
<td>irrigation, industrial cooling and controlled waste disposal.</td>
</tr>
</tbody>
</table>

1.5 Management tools

Water quality management provides an integrated approach to the protection, improvement and sustainable use of rivers, lakes, estuaries, coastal waters and groundwater. The main aims are to prevent further deterioration, protect and enhance the status of aquatic ecosystems and associated wetlands, to promote the sustainable consumption of water; to reduce pollution of waters and to reduce the effects of floods and droughts (Pahl-Wostl et al., 2008; Vigil, 2003). The objective of water quality management is to balance the interests of users with the development of the
resource, while at the same time improving and preserving environmental quality. Prior to management, present and potential future beneficial uses of water body have to be identified. In water management, decisions are based on the comparison of water quality data with criteria and standards. Technical feasibility and risk assessment are taken into account before setting criteria and standards. Hydrometric and water quality surveys are conducted as a part of standard setting (Tebbutt, 1998).

Monitoring, as a practical activity, provides the essential information which is required for an assessment of water quality, especially for describing water resources and identifying actual and emerging problems of water pollution, formulating plans and setting priorities for water quality management, developing and implementing water quality management programmes, evaluating the effectiveness of management actions. However, assessments require additional information, such as an understanding of the hydro-dynamics of a water body, information on geochemical, atmospheric and anthropogenic influences and the correct approaches for analysis and interpretation of the data generated during monitoring (Bartram & Ballance, 1996).

1.6 Management of eutrophication

Eutrophication of surface waters is generally considered as a matter for environmental concern. It is the process of nutrient enrichment and gradual filling in of enclosed water body. As it is a natural process it can be thought of as an inevitable and continual ageing of an enclosed water body. The natural process of eutrophication, from the oligotrophic through senescent stages takes thousands of years. Cultural eutrophication is the acceleration and hastening of the natural ageing process because of human activity in the drainage basin of the water body (Nathanson, 2003).

Accelerated nutrient inputs directly affect the population growth of primary producers-phytoplankton, macrophytes and periphyton. Excessive growth of algae increases the amount of organic matter settling to the bottom.
Eutrophication linked changes also affects taxonomic composition, competitive strategy and biodiversity. The increase in oxygen consumption by the settling biomass can lead to oxygen depletion and changes in community structure or death of the benthic fauna. Increased growth and dominance of fast growing filamentous macroalgae in shallow sheltered areas are yet another effect of nutrient overload, which will change the coastal ecosystem, increase the risk of local oxygen depletion, and reduce biodiversity and nurseries for fish (Sigee, 2005; Nathanson, 2003; Wetzel, 2001).

In reality the ecosystems get out of equilibrium with respect to the utilisation values as well. If the lentic water body is a source of drinking water, its value may be greatly impaired because phytoplankton rapidly clogs water filters, and may cause a foul taste. Toxic blooms may cause injury to human health. Eutrophic system is unappealing for swimming, boating and sporting (Wright, 2005).

Various methods for managing algal blooms through physical, chemical (Barroin & Feuillade, 1986; Tucker & Lloyd, 1987; Hawkins & Griffiths, 1987; Oliveira-Filho et al., 2004) or biological means (Sigee et al., 1999; Jeong et al., 2003) do exist. The methods available for reducing algal crops will only succeed if their purpose and effects are understood and their ecological targets are clear.

The repression of eutrophication by reducing nitrogen and phosphorus contents of the water system is the ideal preventive strategy. For the implementation of this long term strategy understanding of the water body, especially interaction of phytoplankton with major plant nutrients and their cycling is of great significance.

However, as an immediate corrective approach, these are not considered practical as it often takes long period of time to take effect. *In situ* treatment of algal blooms to achieve immediate effect, as well as to
maintain long term good water quality is more of an essential option. However chemical treatments have shortcomings, foremost of which is the generation of secondary pollutants and it has undesirable effects on non target organisms. Here comes the use of organisms or compounds having biological origin.

The vast and devastating effect of eutrophication on environment made it a persistent and one of the most challenging problems. Increasing severity of the eutrophication problem necessitates the need to control algal bloom in a sustainable way, as it threatens the environment and livelihood of populations.

Taking into consideration of the aforementioned reasons it was thought worthwhile to design a set of experiments for the evaluation of trophic status of a lentic water body and \textit{ex situ} nutrient enrichment, and to study the interaction of phytoplankton to nutrient enrichment in a eutrophic body, and also to develop an appropriate microbial technology to control algal bloom. This technology precisely consisted of isolation and purification of microorganism associated with declining algal bloom. Besides, another experiment was designed to promote microalgal flocculation by chitosan as an environmental friendly \textit{ex situ} algal removal technique.

The thesis is divided into 5 chapters commencing with an introduction as chapter 1. The chapters 2, 3 and 4 are in the form of scientific papers with an introduction, materials and methods, followed by results, discussion and a list of references. The fifth and final chapter gives a conclusion based on the results of the study, and a summary of the whole work.
1.7 References


http://www.worldwatercouncil.org


