STUDY OF SUSTAINABILITY OF ANASAGAR LAKE, AJMER

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Submitted in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY

to

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY
JAIPUR-302 017 (INDIA)
January, 2018

Dedicated to my parents

CHAPTER-1

INTRODUCTION

1.1 Lakes

A lake is an area of variable size filled with water, localized in a basin and surrounded by land, apart from any river or other outlet that serves to feed or drain it. The word “Lake” is used to describe many types of water bodies such as natural, manmade and ephemeral. Lakes are also defined as inland bodies of water with individual basins or depressions that are formed by natural sinking and rising of land. One of the most unique definition of lake is “a depression or a group of depressions which are partly or fully filled by water, all parts of the water body having the identical surface, apart from temporary variability, resulted by wind or ice, the ratio between in-flow and volume is adequate to let nearly all of the suspended, inflowing material to form bottom sediment and the surface area exceeds a given minimum value” (Kuusisto, 1985**)**. The International Glossary of Hydrology defines a lake as an "inland water body having considerable size” (UNESCO and WMO, 1992). Ministry of Environment and Forest (Govt. of India) define lakes as standing water bodies with a minimum water depth of 3m, generally cover a water reach of more than one lakh square metres and have no or little aquatic vegetation (Protection and Management of Urban Lakes in India, 2010).

Important features of lakes are water body, drainage basin (catchment area), inflow and outflow, nutrient content, dissolved oxygen, pollutants, pH and sedimentation. From a landscape perspective, the drainage basin and the water body of a lake system are two distinct and interrelated parts.

Lakes are essential part of urban ecosystem. Though relatively small in size, lakes carry out considerable environmental, social and economic functions, ranging from serving as a source of drinking water, recharging groundwater, controlling flooding and atmospheric temperature fluctuations, supporting biodiversity and providing livelihoods. Lakes all over the world are facing increasing threats from human activities and have suffered environmental degradation as a result of unplanned urbanization and increased pollution due to input of various kinds of wastes such as municipal waste, sewage, industrial waste, pesticides and fertilizers etc., only the degree of degradation differs (William and Gerald, 1986; Sisodia *et al.,* 2004; Vyankatesh *et al.,* 2013).

1.2 Lake Sustainability

Water resources are the life of agricultural, industrial, household, urban development and recreational activities. Industrialization, globalization, population expansion and amplified human demand for food and energy are straining our planet's limited natural resources including our lake system. Climate change and environmental degradation are likely to place even further pressure on our ecosystems and the need to sustain the lakes comes henceforth. Lake sustainability provides a mechanism through which society can interact with the environment while not risking or damaging these water bodies. The balance between social equity, ecological effectiveness and economic efficiency is vital to sustainability. It includes the concept of sustainable development which defines development as which meets the needs of the present generation without compromising the ability of future generations regarding fulfilling their requirements (Brundtland, 1987).

Lake sustainability recognizes the essential interdependence of community, economic activities and the environment and it is definite that growth or change in any of these areas will affect the others. Researchers justify the values of the urban lakes associated with ecological, economical, social and cultural factors which serve as driving force behind lake sustainability (Anand, 2014). Key elements of lake sustainability are shown in Figure 1.1.

Figure 1.1: Key Elements of Lake Sustainability
(Source: www. The pillars of sustainability)

1.3 Status of Anasagar Lake

Anasagar Lake is an artificial lake situated in Ajmer city of Rajasthan State (Table 1.1). The climate of Ajmer city is semi-arid with dry and hot summer and cool winter. The average temperature of Ajmer city ranges from 25°C (min.) to 47°C (max.) in summers and from 3°C (min.) to 22°C (max.) in winters (De *et al.*, 2005). The average rainfall of the city is about 500 mm (Central Ground Water Board, 2008). The lake was built by King Anaji Chauhan during 1135-1150 AD by raising a dam across Luni River and was used for supply of drinking water in early times. This is the largest and most popular lake in Ajmer. Presently the lake is used for recreation, boating and fishing. The lake receives a huge amount of untreated waste water from surrounding area. Agricultural practice in lake area is common when water recedes. The overflow from lake reaches Khanpura Pond where it is used for irrigation.

Pressures of urbanization and negligence of lake health have caused significant environmental degradation of Anasagar Lake. Due to a large population living around the lake, there is a heavy load on the lake and its catchment. The lake suffers from a severe problem of inflow of untreated waste water and municipal solid waste which find its way directly into the lake from the catchment area. Encroachment and human induced activities in the lake and its catchment area are continuous on increase. The banks around the lake are used by the public for bathing and washing clothes. The pesticides and associated chemicals originating from human activities or agricultural farming are discharged directly or indirectly into the receiving waters (Mathur *et al.*, 2012). Immersion of idols during religious festivals and disposal of flowers and food materials into the lake have worsened the situation.

1.4 Salient Features of Anasagar Lake

Salient features related to Anasagar Lake are shown in Table 1.1. The information and data given in Table 1.1 have been referred in forthcoming chapters for study, analysis and discussion purpose.

Table 1.1: Salient Features of Anasagar Lake

CHARACTERISTICS	DESCRIPTION
Geographic location	26°25’N-26°29’N(Latitude) 74°38’E-74°42’E (Longitude)
Location in Ajmer	North-West of Ajmer, Rajasthan
Lake type	Artificial lake, constructed by damming over Luni River
Lake water spread area	0.97 sq km to 1.87 sq km
Highest flood level	485.305 m above MSL (as revised in 2013)
Catchment area	53 sq km (gross), 20 sq km (intercepted by Lake Foysagar), 5 sq km (built up area)
Topography of lake catchment area	Steep to gentle slope with low vegetal cover
Storage capacity of lake	5.68 Million Cum (at HFL)
Lake circumference	7.3 km (at HFL)

Source of water in lake	Rainfall runoff and overflow from Lake Foysagar through Bandi River
Depth	4.4 m
Overflow arrangements	Four overflow gates (size 1.2m X 1.8m)

(Source: Detailed Project Report, 2007: Lake rejuvenation project, Anasagar Lake, Ajmer and Nagar Nigam: 2013, Land use details in Anasagar Lake catchment)

1.5 Motivation for the Present Study

Anasagar Lake, Ajmer city (India) has been selected as study area for present research work. The lake has undergone considerable changes during past years which are continuous and quite visible. These can be summarized as:

(i) Frequent death of fish is common both in summers and winters. It is observed that the lake has lost a variety of aquatic life and there has been a drastic decline in fish quantity.

(ii) Evolution of foul gases in lake area is common in summers and it has made life miserable in nearby residential areas.

(iii) The stormwater drains can be seen choked due to huge amount of solid waste and silt and frequent flooding arising out of this is common in rainy season. The lake can be seen with huge amount of solid waste floating on water surface near banks.

(iv) The lake shoreline is not protected and human encroachment and interference in lake area are visible. Development of residential settlements and small scale industries are on continuous increase in lake area.

(v) Untreated waste water reach the lake through stormwater drains and it has increased with the increase in population. The population in lake zone is continuous on increase.

(vi) Transparency of lake water has decreased with time and plant growth in lake is visible and on increase.

(vii) There has been a continuous increase of barren land area in lake catchment with continuous reduction in forest area. Human induced activities have increased in lake catchment with time.

(viii) Bathing and washing activities in lake have increased with time and these are observed more during *Urs* and *Pushkar* fair.

(ix) Variety and number of migratory birds to Anasagar Lake have decreased with time.

Following questions arise out of these observations:

(i) What could be reasons of frequent death of fish, evolution of foul gases, increased plant growth and decline of migratory birds in Anasagar Lake?

(ii) Is the lake water polluted? Is it due to entry of untreated waste water into the lake? What could be the other reasons? What could be the measures to control lake water pollution?

(iii) Why human induced activities are continuously on increase in lake area and its catchment? Can increase in barren land and reduction in forest area be related to these activities? How these activities may be controlled?

As an environmental engineer, my vision is that Anasagar Lake is severely polluted and deteriorated and the ecological, cultural and social values of lake are continuously on decline. Hence, it is necessary to investigate the causes of pollution and environmental degradation alongwith remedial measures to restore and sustain the lake.

1.6 Objectives of the Present Study

The present study is aimed to evaluate various socio-economic and environmental factors affecting the sustainability of Anasagar Lake.

The socio-economic factors include increased demands for using lake resources, public awareness and understanding and insufficient governance.

The environmental factors consist of threats arising from within lake drainage basins and threats arising from outside lake drainage basins.

Threats arising from within lake drainage basins include water quality concerns, accumulation of litter and garbage, loss of natural, aesthetic and scenic beauty, loss of aquatic biodiversity and habitat and health risks.

Threats arising from outside lake drainage basins include transport of airborne pollutants and climate change.

1.7 Organization of the Thesis

For the convenience in presentation, the thesis has been divided in six chapters. The chapter wise contents of the thesis are given below:

In Chapter 1, utility of lakes, lake sustainability and status of Anasagar Lake have been discussed. The motivation for study and its objectives and salient features of Anasagar Lake are outlined here.

Chapter 2 deals with the detailed review of literatures of degraded lakes and the lakes restored all over the world. Various socio-economic and environmental factors affecting the lake sustainability are discussed here.

Chapter 3 highlights various issues and activities related to socio-economic and environmental factors that may affect the sustainability of Anasagar Lake.

Chapter 4 deals with the analysis of various issues and activities related to socio-economic and environmental factors discussed in Chapter 3 to ascertain impact over sustainability of Anasagar Lake.

The outcome of study and analysis of various socio-economic and environmental factors together with adaptive management to sustain Anasagar Lake are discussed in Chapter 5.

Conclusions drawn from present study and future scope of the research work are given in Chapter 6.

CHAPTER-2
LITERATURE REVIEW

2.1 General

Various socio-economic and environmental factors affecting the lake sustainability are discussed in following literature reviews. The environmental factors include threats arising from within lake drainage basins and threats arising from outside lake drainage basins.

2.2 Socio-Economic Factors

Various issues related to socio-economic factors affecting the lake sustainability include increased demands for using lake resources, public awareness and understanding and insufficient governance.

2.2.1 Increased Demands for Using Lake Resources

Disposal of untreated or inadequately treated sewage and waste water is a major water pollution issue for lakes in all developing countries, particularly those undergoing explosive urbanization. Increasing economic development pressures due to human settlement around lakes have resulted into more stress on lakes. Increased agriculture, fishing and recreation activities have worsened the situation further.

Columbia Lake, Connecticut (Columbia) was studied to investigate about the impact of urbanization and ways to restore and sustain it (Kennedy *et al.,* 1975). The study was focused on entry of waste water into the lake. The maximum depth of lake is 7.8 metre and it covers 1.15 sq km area. The lake's watershed (4.59 sq km) is entirely within town boundaries. It was found that a part of waste water entered into lake every day from surrounding area. It deteriorated the lake water quality. Informal interviews with citizens and officials at state, regional and local levels were conducted in order to restore the lake. Measures were taken to divert waste water away from the lake. Today the shore area of lake is properly protected and well managed. The water quality of lake has improved.

Major cause of lake pollution in Kerala (India) is entry of untreated municipal waste, sewage and solid waste into the lakes. Kochi has a chain of lakes lying parallel to the Arabian Sea coast. The degradation of lake system was studied and it was found that about 3 million cubic metre of waste water enter into the lakes directly every day through major canals. This has resulted into pollution of lake system (Nair and Unni, 1993).

Chandrasekhar *et al*. (2003) studied and examined the causes of degradation of Bellandur Lake, Bengaluru city (India) due to entry of domestic and industrial effluents. It was found that the addition of effluents from Bangalore city changed the characteristics of the lake. It converted the lake into an artificial reservoir of domestic sewage and industrial waste from a natural ecologically healthy lake. This resulted into decreased dissolved oxygen and increased biochemical oxygen demand for lake water.

Sisodia *et al.* (2004) studied various physico-chemical characteristics of water of the wetland of Jamwa Ramgarh Lake, located at Jaipur (India).The purpose was to see the impact of various domestic and industrial wastes entering into wetland on water quality. Samples were taken once every month from January 2003 to December 2004. The lake water was always alkaline because pH constantly remained above 7. The electrical conductivity values of water samples varied between 500 mmhos/cm and 700 mmhos/cm. The total dissolved solids values of water samples ranged between 305 mg/l and 421 mg/l. The dissolved oxygen of water samples ranged from 4.88 mg/l to 13.4 mg/l. Total alkalinity values fluctuated from 102.6 mg/l to 215 mg/l indicating that the water was hard. Chloride values of the wetland water were found at higher level (82.07 mg/l). Higher concentration of chlorides is considered to be an indicator of pollution due to presence of organic waste of animal origin. The study revealed that entry of domestic and industrial waste into Jamwa Ramgarh Lake has deteriorated the lake water quality.

Photo 2.1: Degraded and Restored Views of Chilka Lake (Orissa)
(Source: UNEP, 2006: Ecological restoration of Chilka Lake)

Chilka Lake is located in the East Coast of Orissa State (India) and is the largest salt water lake in Asia. It was observed that the lake area reduced to 760 sq km by late 1990's which was 1165 sq km in early years of 20th century. The reasons could be attributed to increased agriculture and aquaculture practices and amplified human settlements near lake shoreline. Hydrologically, this lake is influenced by three subsystems namely; Mahanadi River system, rivers flowing in the lake from the western catchment and the Bay of Bengal. The lake served as a vital life line for more than 2 lacs people in 141 villages who lived around the lake and were dependent on aquaculture, agricultural practices and fisheries for their livelihoods. The increased agricultural practices promoted the use of chemical fertilizers and pesticides. The upstream erosion and sedimentation process contributed to lake water deterioration. Decline in salinity was observed with rapid growth of invasive weed species and macrophytes disturbing the delicate ecosystem of the lake. The restoration of Chilka

Lake was started by Chilka Development Authority (CDA). The objectives were to restore the ecological balance of the lake and provide livelihood to the villages surrounding the lake. The activities included control of silt load in catchment area, maintenance of salinity, dredging, weed management and its use in biogas generation, operation of mass awareness and fishery resource development programmes. Outstanding changes in the ecosystem of Chilka Lake were observed such as salinity maintenance, inflated aquatic life, increased income of people dependent on lake resource, enhanced awareness among local population and improved water quality (Ghosh, 2003). Photo 2.1 shows the degraded and restored views of Chilka Lake.

Photo 2.2: Degraded and Restored Views of Hauz Khas Lake (Delhi)
(Source: www.Hauz Khas Lake, Delhi)

Half a decade ago Hauz Khas Lake in Delhi (India) was suffering from a low water table and was almost dry (Protection and Management of Urban Lakes in India, 2010). The sources of water to lake were stormwater and the waste water from a nearby sewage treatment plant. The lake suffered from high organic load due to mass plant growth in and outside it. The lake restoration started in July 2007 and in this process the treated effluent from the nearby sewage treatment plant was diverted to the lake using pipes. Biological treatment practices were applied to reduce biochemical oxygen demand, nitrogen and to improve the levels of dissolved oxygen. Weekly monitoring of lake health was carried out under supervision of Delhi

Development Authority (DDA) with the help of various water quality testing laboratories. Fish species were also introduced in the Hauz Khas Lake to consume the planktons, which depend upon the organic content in water. The lake was found completely free from odour and algal webs and water quality of lake improved significantly. Today, the lake has acquired the character of a natural ecosystem. Photo 2.2 shows the degraded and restored views of Hauz Khas Lake.

Photo 2.3: Degraded and Restored Views of Naivasha Lake (Kenya)
(Source: www. Lake Naivasha, Kenya)

Thomas *et al.* (2011) discussed and investigated about the degradation and restoration of Lake Naivasha (Kenya). The catchment area of lake is around 3,400 sq km. It was found that unsustainable land-use practices within the watershed, unregulated and excessive water use for domestic and agricultural/ horticultural use and increased population pressure resulted into water pollution and loss of biodiversity. The lake restoration project started in year 2008 with various activities for lake restoration that included control over use of lake water and fertilizers and pesticides, diversion of waste water away from lake, planting native and high-yielding fruit trees and crops for improved farm productivity and training of farmers. It resulted into improved lake water quality and increased fodder supply. Photo 2.3 shows the degraded and restored views of Naivasha Lake.

Vijayvergia and Tiagi (2007) studied about physical, chemical and biological characteristics of water of Udaisagar Lake, Udaipur (India) to determine pollution level and restoration measures to sustain the lake. This lake is an important source of industrial and irrigation water supply. It receives inflow of waste water through Ahar River which receives sewage of Udaipur city and industrial effluent of certain industries. It was found that the lake is facing severe water pollution and eutrophication problem with elevated algal bloom. The lake water was found with low transparency and high concentration of chlorides, total dissolved solids and nutrients. The study suggests various restoration measures such as establishment of sewage treatment plant, mechanical harvesting to control nuisance of algal bloom and aeration of lake water for lake sustainability.

Khan (2015) discussed about the causes of degradation of Dal Lake (Jammu and Kashmir, India) and module for lake restoration to sustain it. Dal Lake is a fresh water lake which is main source of attraction for tourists and economy for the people in its catchment area. Due to population explosion, the pressure on the lake and its surroundings has increased alarmingly. The total population within the lake catchment has been estimated as 2 lacs. There has been a significant population growth of the people living in house boats and hamlets within lake. The lake has shrinked to a great extent due to increasing encroachment with time. The increasing discharge of various effluents, sewage and sediments alongwith nutrients has made this lake eutrophic which has resulted into over growth of aquatic plants and decrease in dissolved oxygen. Large areas of the lake have been converted into floating gardens for public use. Urbanization has resulted into growth of residential buildings, restaurants and hotels along the lake front. The suggested restoration measures include afforestation and proper soil conservation and management in catchment, trapping of debris, garbage and sediments from the catchment area using settling basins, dredging, acquisition of land and structures within the lake body, diversion of sewage and drainage from the peripheries and house boats to treatment plant, restrictions over encroachment, development of proper solid waste management system and promotion of mass awareness regarding lake sustainability.

Parashivamurthy (2015) studied about the causes of pollution of Varthur Lake in Bengaluru (India). Water samples of lake were taken and studied by team of Indian Institute of Science (IISc) and it was found that the lake water was severely polluted. Nitrates, potassium, sulphates, phosphates and many other components were found above prescribed levels in lake water. It was concluded that nitrates came from urine and fecal matter and soaps and detergents were the source of sulphates and phosphates. The study revealed that entry of untreated sewage and waste water could be the prime reasons of lake water pollution.

2.2.2 Public Awareness and Understanding

The lake systems of the world have served the population since long. Population around lakes is closely associated with the natural cycle of lakes, seasonal changes in fish distribution and availability, vegetation growth and water levels. The local population uses lakes as direct resources for various purposes. Fishing, use of vegetation for livestock or construction and agricultural practices at lakeshores are common. Hence, appropriate consideration should be given to the needs and attitudes of the local population for long term sustainability of lakes (Hook, 1988).

While discussing the environmental issues, public participation in decision making may serve as an effective and valuable tool. The extent of public participation depends upon the size of participation and degree of actual influence of public in decision making. The lowest level of participation includes informing public about the decision. Higher levels involve public in decision making at different extents that include consultation and public hearings in organized workshops. Administrative agency responsible for decision making, consider public observations, comments and opinions and give feedback. The highest levels of participation allow tight collaboration with public on all levels of decision making and put decision making in the hands of public (NCEIA, 2004).

Jipe Lake (Tanzania) was rich in biodiversity and a huge population of Tanzanians was dependent on it for their livelihood. Major activities of population surrounding the lake included fishing, livestock keeping and agriculture. The lake has been suffering from a number of environmental problems since year 1980. Increased human pressure around lake has resulted into increased siltation, soil erosion, overgrazing and invasion by waterweeds. Waterweeds have covered more than half of Jipe Lake. Due to reduced fishing activities fishermen have migrated to nearby places. Tanzanian Government decided to involve the Jipe Lake stakeholders in management plan for sustainable utilization of the lake. A three year mass awareness strategy have been planned to make greater involvement of stakeholders in planning and implementation of programmes towards controlling the lake degradation (Maembe, 2004).

Kenji *et al*. (2012) studied about the effective restoration of Lake Suwa (Honshu Island, Japan) through efforts of local stakeholders in elimination of blue-green algae and reduction in heavy eutrophication. From1950s to 1960s, the basin area of lake developed with modern industrial and agricultural sector. The residential settlement increased rapidly and the area under forests came down. The silk thread manufacturing industry became a leading industry, bringing prosperity to the Lake Suwa area. As the basin developed economically, Lake Suwa, earlier with safe water, became the final disposal location for various pollutants including contaminated and polluted soil, nutrient salts, heavy metals and other chemicals from industries, waste from households and construction sites. The water quality of Lake Suwa deteriorated and in the late 1970s, major pollutants in the lake including nutrients reached their worst levels. However, the water quality of Lake Suwa was improved to a certain degree due to the setting of strict effluent standards, dredging operation and construction of sewerage system by local administration. Still, blue-green algae did not disappear from Lake Suwa. Finally, a committee consisting of local stakeholders was formed in late 1970s that included persons from various fields. The committee started organizing public seminars and meetings on environmental issues to raise people's awareness regarding lake water cleanup. A future development plan for lake basin was prepared. The committee monitored and assisted in proper implementation of lake restoration programme of local administration with participation of local population. The eurtrophication level of lake reduced considerably with time with the elimination of blue-green algae.

Kaikondrahalli Lake (Bengaluru city, India) has experienced drastic changes in ecology, land use and management over the past decade, converting the lake into a polluted water body. The sustainability of lake was adversely affected. The lake is a unique example which was restored by local stakeholders and non-government organizations when it was on the brink of extinction. The lake was not always a beautiful sheet of water. Till 2009, the water body was a heap of garbage and filled with weeds. The non-government organizations mobilized residents of the locality and made them feel that the lake belonged to them. Activities to save and sustain the lake included protection and management of lake shoreline, stoppage of entry of waste water into the lake and treatment of catchment to reduce soil erosion and increase inflow of water into the lake during rains. Now the residents have a clean and huge water body next to their home that offers biodiversity with a tree park, long walk way and cycle path. Around 37 bird species, including migrant birds, have been spotted at the lake. Provision is also made for local residents to wash cattle in separate ponds. A play area and other facilities are planned in such a way that these can be used by visitors to the lake, as well as by school children (Nagendra, 2016).

2.2.3 Insufficient Governance

According to Reddy and Char (2006), involvement and participation of non-governmental organizations is gaining popularity in lake restoration and sustainability programmes. It could be due to lack of proper governance in maintaining the health of lakes. Non-governmental organizations act as catalysts in such programmes. The examples of non-governmental organizations in India are Peoples Group (Hyderabad), Society of Appeal for Vanishing Environments (SAVE, Nainital), Howrah Democratic People Committee (Howrah), Green Kashmir (Jammu and Kashmir), Ecological Task Force (Harike), User's Committee (Pushkar) and many others. The study shows that these have moved to Judiciary in many cases through Public Interest Litigations (PILs) seeking directions of the courts to restore lakes and proper implementation of environmental laws. In many cases the non-governmental organizations have established information centres to promote mass awareness and public participation in lake restoration programmes. In the high altitude lakes of Leh in Jammu and Kashmir, the local community has established six conservation trusts to undertake conservation measures of the lakes. The Ministry of Environment and Forests (Govt. of India) has also recognized the need of community participation in lake restoration programmes considering the importance of social, economic and ecological aspects.

A strong relation exists between the value of lakes and how the lakes are governed. Several values are linked to lakes such as socio-cultural values, economic values and ecological values. Lake systems offer recreation places, better outdoor environment and technical solutions for infrastructures; regulate property price and many more. Many of lakes in world have reached their ecological limits due to over exploitation by societies. Encroachments by illegal activities and waste dumping in lakes have increased due to poor and inadequate governance. These activities have adversely affected the sustainability of lakes. The ecological performance of lake systems has also diminished with time (Mansee *et al.*, 2011).

A study was made by Chidammodzi and Muhandiki (2015) to understand the state of governance of environment for Malawi Lake Basin (East Africa). The lake has greater fish biodiversity than any other freshwater lake in the world and has over 1000 fish species. It is the third deepest lake in the world with a maximum depth of about 700 m and ninth largest lake in the world with a surface area of 29,500 sq km. The lake is shared among three African countries; Malawi, Tanzania and Mozambique. It was found that over fishing, deforestation, uncontrolled bush fire and poor land use in lake catchment increased with time. It resulted into increased soil erosion, pollution from agricultural activities and over-exploitation of fish. Interviews with officials and local population, field observations and review of existing lake management system revealed that there was a lack of coordination between management plans, strategies and enforcement of environmental laws made for lake sustainability.

Lakes are usually under-valued, poorly managed and governed in most of the countries. Management of lakes requires intense knowledge of their drainage systems, catchment characteristics, precipitation, groundwater inflows, surrounding wetlands and pollutant pathways. Adequate governance is essential for lake basin management, but it is the most challenged task and needs more attention. It needs to be properly designed to measure the progress and impacts of policies and the role of various agencies in ensuring sustainability of lakes. Proper governance becomes necessary with over-emphasis on lake utilization and exploitation. Good governance should involve processes, decisions and outcomes that properly govern, manage and sustain the lake systems (Cookey *et al.,* 2016).

2.3 Threats Arising from Within Lake Drainage Basins

Various issues related to threats arising from within lake drainage basins affecting the lake sustainability include excessive water withdrawals or diversions, water quality concerns, unsustainable fishing practices and aquaculture, accumulation of litter and garbage, loss of natural, aesthetic and scenic beauty, loss of aquatic biodiversity and habitat and health risks.

2.3.1 Excessive Water Withdrawals or Diversions

Bush *et al.* (2007) studied about the sustainability of the Great Lakes (USA). The Great Lakes comprises of Lakes Superior, Michigan, Huron, Erie and Ontario. Theses lakes represent 20 percent of the world’s surface freshwater and 95 percent of the United States water supply. It was found that in recent years the Great Lakes have suffered from a severe problem of withdrawal and diversion of excess water for agriculture, municipal and industrial use. This has adversely affected the sustainability of the Great Lakes. Increased withdrawals and diversions of lake water often lead to adverse ecological and community impacts and heavy pollution.

The study made by Max and Rebecca (2009) revealed that world’s saltiest Dead Sea Lake (Jordan) is a threatened water body due to intense water withdrawals from Jordan River in the north and increasing industrial and agricultural activities in the south. The prime source of water inflow to the lake is Jordan River. As a result, about one-third area of the lake has already been drained and its water level is dropping by about one metre each year. The water quality of lake is deteriorating continuously.

Jones (2010) studied about the impact on sustainability of Aral Sea Lake (Kazakhstan and Uzbekistan, Russia) due to diversion of inflowing tributaries for irrigation purpose during the last half century. It was found that the lake has shrunk significantly in surface area and volume. A major increase in salinity and fundamental changes to its biological communities were observed.

2.3.2 Water Quality Concerns

(i) Excessive Nutrient Loads

Prime sources of lake eutrophication include the use of fertilizers, defective septic systems and soil erosion in catchment. Agriculture, with the use of phosphate enriched fertilizers, is the primary source of excess phosphorus responsible for degradation of lakes (Carpenter, 2008). Even after restrictions and ban, farmers still apply phosphorus fertilizers, even when soils already have a reservoir of this nutrient. The application of chemical fertilizers and phosphorus rich manure result in gradual accumulation of phosphorus in the soil of watershed. This significantly intensifies the amount of phosphorus runoff to lakes (Bennet *et al.,* 2001).

For an eutrophied lake as a drinking water resource, the increased algal growth clogs intakes, increases corrosion of pipes, makes filtration more expensive and often causes taste and odour problems. Algae removal also increases filtration costs for industries using eutrophic waters. In addition, swimming in eutrophic waters causes “swimmer’s itch” and people generally find clear waters more pleasing than turbid waters. Both social impacts and economic losses are important and make eutrophication control necessary (Vollenweider, 1968; Leng, 2009).

Severe eutrophication results into hypoxic conditions and often disrupts normal food web and ecosystem processes by developing dead zones where no animal lives can sustain (Smaya, 2008). In 1960s, Lake Washington (Seattle, USA) was one of the most exposed examples of anthropogenic eutrophication. The lake received 80,000 cum of waste water effluent each day from surrounding area (Edmondson, 1991). About 37,000 kg of phosphates was added from developed agricultural and urban lands, stimulating plant and algal growth that vanished most other species in the lake (Edmondson, 1970).

Eutrophication reduces the resource value of lakes as recreation, fishing and aesthetic enjoyment diminish. The impact of eutrophication on recreation and tourism is perhaps the most sensitive area for the public. Lakes deteriorate through too much addition of plant nutrients, organic matter and silt that jointly result into increased algae and rooted plant biomass, reduced water clarity and usually decreased water volumes (Harper, 1992). In this condition water bodies loose the attractiveness for recreation, as well as their usefulness and safety for industrial and domestic water supplies.

Tippa *et al.* (2007) studied about the extent of pollution due to nitrogen and phosphorous and effect of bioremediation in the ancient Agasthya Lake in Badami (Karnataka State, India). In recent years the pollution of water of lakes has become a leading environmental problem in the world. Eutrophication of lakes is rapidly increasing due to higher sewage discharge and anthropogenic stress. Higher amount of nitrogen and phosphorous, 60 mg/l and 15.5 mg/l respectively, were found in Agasthya Lake. The study shows that use of *Pseudomonas* species (microorganisms) for bioremediation was successful that reduced more than 50 percent of nitrogen and phosphorous concentrations in Agasthya Lake.

A three year study and monitoring of water quality was carried out by Brandvold *et al.* (1976) at different locations in watershed of Bosque Del Apache National Wildlife in New Mexico. Comparisons and analysis were made at upstream and downstream locations of Bosque Del Apache Lake to determine the impact on water quality due to birds. The mean values of total nitrogen, total phosphorus and chemical oxygen demand were found to increase downstream where the birds were roosting. This suggested the potential of the birds to contribute towards eutrophication related problems. The plants subsequently grew in this area due to availability of nutrients.

Welch (1981) observed dilution/ flushing as an effective restoration technique for Moses and Green Lakes in Grant County, Washington State (USA). The dilution water added in both lakes was low in nitrogen and phosphorus content relative to the water of lakes. Flushing rates were about ten times normal in Moses Lake and three times normal in Green Lake during the spring-summer periods. High improvements in water quality (nutrients, algae and transparency) were observed for both the lakes.

William *et al.* (1988) discussed about pollution of Lake Erie (North America) due to phosphorous loading. The Lake Erie basin was found intensively developed with agriculture, urban areas and industries in early 1960's. Severe eutrophication claimed Lake Erie and increased algal growth became the dominant plant species, covering beaches with slimy moss (small flowerless plants) and killing off native aquatic species by consuming oxygen. Pollution filled Lake Erie with nutrients, with phosphorous being the main culprit of eutrophication. The reason could be the use of phosphorous as fertilizer for plant growth in agricultural practices and in many commercial detergents. The process of growing, dying and decomposing of plants resulted into anoxia (severe deficiency of oxygen), thus killing fish and other aquatic species and eruption of foul gases. Later in year 1977, phosphorus in detergents was banned. Control over use of fertilizers resulted into reduction of eutrophication in Lake Erie with time.

A study about efficiency of aeration systems installed in three British Columbia lakes (Black, Glen and St. Mary), suffering from anaerobic conditions due to eutrophication, was carried out by Ashley (1988). It was found that undesirable concentrations of manganese, iron, hydrogen sulfide, carbon dioxide, ammonia and other substances associated with anaerobic conditions were reduced. Aeration systems could be useful to reduce the stress of thermal stratification (Johnson, 1966). Thermal stratification and its associated hypolimnetic oxygen depletion in eutrophic lakes restrict fish and other biota to shallow depths. At some time during summer, there may be no place in the lake with suitable living conditions for fish. Even if thermal stratification is not lethal to the fish, it can severely stress the population. Hypolimnetic aeration, if properly used would create both suitable oxygen and temperature conditions for coldwater fish.

Iron, calcium and aluminum salts combine with phosphorus and remove phosphorus containing matter from the water column as part of a floc (OECD, 1982; Olem and Flock, 1990). This method has been applied successfully in Braakman and Grote Rug lakes in Netherland, where total phosphorus concentration and algal biomass reduced successfully. These treatments are more common for smaller lakes.

Sediment covering materials could be useful to stop plant growth by the fact that plants require light and cannot grow through physical barriers even if the nutrients in soil are present (Olem and Flock, 1990). These materials can be used in specific and small areas such as dock spaces and swimming beaches due to the high costs. Various types of materials may be used for this purpose such as Black Polyethylene, Polypropyl (Typar), Fiberglass PVC (Aqua screen) and Nylon (Dartek).

Prepas *et al.* (1990) studied the impact of aeration system in Amisk Lake (Canada) over lake water quality. In May 1988, the system was installed to introduce pure oxygen into the bottom part of the north basin of Amisk Lake with mean depth as 14.4 m. It was found that during summer, oxygen depletion and total phosphorous accumulation rates in the treated basin were only 42.5% of historic averages and during winter, dissolved oxygen concentrations were maintained at 5 mg/l. The rates in the untreated south basin remained near or above pretreatment rates.

The phosphorous loading by bird dropping was observed and monitored by Scherer *et al.* (1995) in urban Green Lake, Styria (Austria) between January 1992 and December 1994 in order to assess the impact over lake eutrophication. Though various birds were present, the most abundant water birds were American coots (36%), mallards (17%), gadwalls (12%) and various species of gulls (12%). Even though geese were not as plentiful (6%), they were noted as significant contributors of feces. Water birds contributed 87% of the total feces from birds. It was found that in year 1992, about 160 kg (27%) of the total phosphorous loading came from water birds. In year 1993, approximately 159 kg (25%) of total phosphorous was contributed by water birds. It was found that phosphorous loading varied according to migration pattern of birds. The highest loading occurred in January 1994 with 34kg, while the lowest loading rate occurred in May 1994 with 3kg. Under right conditions (low dissolved oxygen or high pH) the phosphorous releases from lake sediment and contribute towards eutrophication.

[illegible]

Severe agricultural practices have increased the input of large quantities of agrochemicals and pesticides in Vembanad Lake in Kumarakom, Kerala State, India (Nair and Unni, 1993). Concentration of dissolved and particulate trace metals (Ni, Pb, Zn, and Mn) in Vembanad Lake were studied by Unnikrishnan and Nair (2004). It was found that lack of proper flushing of backwaters, which received large amount of heavy metals through the application of pesticides and agro-chemicals in surrounding area, adversely affected the water quality of Vembanad Lake.

Abida *et al*. (2008) investigated about the impact of heavy metals like iron (Fe), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), lead (Pb) and cadmium (Cd) on water, plants, sediment and fish of Madivala Lake in Bengaluru (India).The lake was found to be heavily contaminated by certain heavy metals. It was found that untreated industrial, agricultural and domestic wastes were continuously being discharged into Madivala Lake from surrounding industries, agricultural fields and residential colonies which could be a source of heavy metal contamination. The heavy metals were found highest in water sample and least in fish of Madivala Lake. Heavy metals are not biologically degradable and tend to accumulate in aquatic life. The increase in the bioaccumulation levels of heavy metals in fish could be a fatal and it was observed in Madivala Lake.

Marielle *et al.* (2010) studied and investigated about chemical pollution in municipal lake of Yaounde, Cameroon (Africa). It was found that waste water from household and shops with chemicals reached the municipal lake. A large part of catchment area was found being used illegally for various anthropogenic activities. Lack of proper urban planning, demographic pressure and improper rain water and solid waste management were the reasons found for deteriorated stage of municipal lake.

A study of heavy metal contamination in Keenjhar Lake (Sindh, Pakistan) was made by Lashari *et al.* (2012). The tests for heavy metals in lake water were carried out from January 2003 to December 2003. The concentrations of Zn, Cr, Cu, Fe and Mn were recorded lower than permissible limits, whereas Ni and Cd were found higher than permissible limits as recommended by WHO (2004). It was found that domestic waste containing heavy metals entered the lake directly or indirectly. The accumulation of toxic metals in aquatic food chain may cause risk to human health due to water and food consumption offered by lake. Various steps for systematic management of Keenjhar Lake were recommended that included diversion of waste water away from Keenjhar Lake and prohibition of boating activities in lake.

A study was carried out to assess the concentration of heavy metals in Kukshet Lake in Navi Mumbai (India) by Singare *et al.* (2011). Kukshet Lake receives domestic raw sewage from nearby area. Cattle washing, cloth washing, bathing and religious activities like idol immersion etc., were found as the causes of increased concentration of harmful chemicals in the lake water. It was found that the heavy metal concentration in the lake water substantially increased after the religious activities from September to October. These heavy metals adversely affect aquatic flora and fauna.

Vyankatesh *et al.* (2013) analyzed the environmental status of Lonar Lake, Maharashtra (India). The purpose was to assess the impact of use of huge amount of agrochemicals in lake catchment. The lake water was found to be very rich in nutrient content. It was observed that the colour of the lake water changed from pale green to dark green showing dense algal population with predominating *Spriulina* species. The eutrophication of the lake could be due to untreated domestic sewage and garbage coming out from Lonar city that reached the lake and the use of agrochemicals in lake catchment. No fish species was recorded in the lake, could be due to presence of heavy metals. The odour of lake water was found objectionable. The dissolved oxygen was recorded in the range of 1.2 mg/l to 2 mg/l.

(iii) Increased Erosion and Sedimentation

Freshwater lake sediment elimination is usually undertaken to deepen a lake thereby increasing its volume to enhance fish production, remove nutrient enriched sediment, remove toxic or hazardous material and to reduce the abundance of rooted aquatic plants. This technique is recommended for reducing phosphorus release from sediment. Sediment removal to control toxic and hazardous material is possible with minimal environmental impact when proper equipment is used, but it may be extremely costly. Dredging will take out rooted aquatic plants; however, their re-encroachment rate will be depth, sediment texture and nutrient dependent (Peterson, 1981).

The effects of increased flow due to urbanization in terms of increased sedimentation in Lake Mendota (Dane County, Wisconsin, USA) were studied by William *et al.* (1986). A five year data collection and study were made on Pheasant Branch, a stream to Lake Mendota draining a large area of rolling hills, agricultural land and rapidly urbanizing areas around Dane County. It was found that the stream required frequent cleaning because of heavy sedimentation. The surrounding area increased in inhabitants by 44 percent from 1970 to 1980 and was projected to have a population of 18,000 by the end of year 2000. Increased flow resulted into heavy soil erosion in stream, lowering of mean stream bed and widening of width. Increased sedimentation and deterioration of water quality in Lake Mendota could be related to it.

Thouk and Nuov (1996) discussed the sustainability of Cambodia's Great Lake (Tonle Sap Lake) considering massive over exploitation of the forests and destructive human activities in lake catchment. The 3,000 sq km lake water expand to more than 6,000 sq km area inside the inundated forests; draining about 67,000 sq km basin area. The forest that surrounds the lake consists of hundreds of plant species and wildlife. Due to massive over exploitation of the forests and destructive human activities in the inundated lake catchment, increased rate of siltation was identified as a major threat to the lake ecosystem. Afforestation, monitoring and controlling over the exploitation of the forest and adequate management of the lake catchment were recommended to sustain the lake.

Lake Baringo (Kenya) was very rich in biodiversity till 1979. But its richness reduced with time due to growing human and livestock populations, drainage basin destruction and mass deforestation. It changed the flow pattern of rivers into the lake and now only one river flows into the lake while earlier the number was seven. Approximately five million cubic metres of sediment is currently being deposited in the lake each year from the drainage basin and the depth of the lake has reduced to 1.9 metres (2006) from 8.9 metres (1970). It is estimated that if the lake continues to accumulate sediment at the present rate, it will possibly dry up within next twenty years. The impact of sedimentation has adversely affected the fish biodiversity, with extinction of many species that contributed to livelihoods for local population. This has also resulted into degraded water quality of Lake Baringo (UNEP, 2006).

2.3.3 Unsustainable Fishing Practices and Aquaculture

Aquaculture could be a source of degraded water quality, habitat destruction and fish disease. Fossil fuel is used to manufacture fish feed in many areas. The fish feed may be made of corn or wild caught fish. The use of small aquatic species contributes to over-fishing. Water quality can be degraded through the use of automated feed to fish which may increase amount of nutrient in lake water. Biodiversity is threatened when non-native species are used for aquaculture. Use of non-native species could be a source of disease in fish (Marcella and Anna, 2013).

Richard (2003) studied about decline of commercial fisheries in Lake Victoria (Tanzania, Africa) due to over-fishing. The lake originally had a multi-species fishery in which two species *Oreochromis esculentus* and *Oreochromis variabilis* were the most important due to high commercial value. But the pressure on fisheries started due to introduction of efficient gill nets in year 1905 and expansion of market. A general survey in year 1928 revealed that the two prime commercial fish species *Oreochromis esculentus* and *Oreochromis variabilis* became endangered species because of over-fishing. Finally a gill net mesh size restriction was recommended by local authorities, which was implemented in year 1931.

Use of inappropriate fishing gear, poisons and explosives for fishing can cause fish death and breeding problems. It may reduce the self sustaining capability of fish. Over-fishing for a prolonged period can lessen commercial fisheries. Unsustainable aquaculture can degrade water quality due to nutrient pollution and increasing quantities of antibiotics and hormones entering into a lake (UNEP, 2003).

2.3.4 Accumulation of Litter and Garbage

Due to improper collection system, discarded wastes are often dumped into nearby ditches and streams which may find way to lake system. The discarded waste includes various goods, biodegradable items, containers and packing materials etc. It can cause oxygen depletion in bottom waters of lakes. Obstruction to free flow of runoff causing floods, decline of natural beauty of lake systems and problems associated with leaching of chemicals are results of accumulation of litter and garbage. Litter and garbage may contribute to spread of human disease organisms and can adversely affect the aquatic life of lakes (UNEP, 2003).

Tapas *et al.* (2014) carried out study regarding improvement of urban municipal solid waste management in order to minimize the pollution in lakes of Bhopal city (India). Various measures are suggested in this regard to control lake pollution. These include creating public awareness regarding ill effects of solid wastes on lake system, prohibition of littering of solid wastes in areas notified by local administration, house to house collection of municipal solid waste on regular basis, use of properly designed collection bins and proper segregation of municipal solid waste. Formation of a clear policy for proper management and collection of municipal solid waste with the participation of local populace is suggested to sustain the lakes.

Kripa *et al.* (2012) studied about accumulation of litter in Vembanad Lake (Kerala State, India) and suggested preventive measures to sustain the lake. Huge amount of rubber tyres, empty bottles, rubber foot wears, pieces of foam material, synthetic bags, tin cans and glass bottles etc. were observed in lake water. On interacting with the fishermen it was found that the quantity of litter entered in lake ranged between 2 to 18 kg per day. Empty plastic bottles, plastic bags and sachets were the main floating items that formed more than 90 percent of the litter. Plastic sheets and bags were the main items recorded at the lake bottom. Litter found in form of discarded fish nets indicated the lack of awareness of fishermen regarding damages of live nektonic and crawling biota. It was found that most often the fishermen throw the litter collected in the nets back to the lake water which may destroy the habitats, generally used by fish for breeding. It could be a cause of fishery resource decline in lakes. The study suggests that creating awareness among common people about the harmful effects of litter, discouraging littering on private and public places in lake area, placing garbage bins, educating fishermen not to dump the litter collected in the nets back to water, promoting watch groups of local population to maintain cleanliness and punishing the defaulters could be the probable remedial measures to minimize degradation of lake environment due to accumulation of litter.

Pollution by plastic debris has been an environmental concern in the Laurentian Great Lakes (North America) as it affects water, shoreline and benthic environment. Data reveal that more than 80 percent of anthropogenic litter along the shorelines of the Great Lakes is comprised of plastics. Sources of plastic debris to the Great Lakes include microplastic beads from various consumer products, pellets manufactured from the plastic industry and waste from beach-goers, shipping and fishing activities. Generally plastics degrade slowly in the environment and may have long-term adverse ecological and economic impacts, including problems with disposal of organic pollutants. These issues adversely affect the lake sustainability (Alexander *et al.*, 2015).

2.3.5 Loss of Natural, Aesthetic and Scenic Beauty

The Attabad Lake (Gojal, Pakistan) receives water from Hunza River through spillway. The beauty of lake is being spoiled by garbage, human waste and dust. There are no minimum essential facilities like washrooms and toilets required for tourists near spillway including proper garbage collection system. Scraps fall into the lake due to loading and unloading of shipment near spillway. Heavy dust due to traffic on unmetalled road is worsening the situation. Disposal of waste into the lake is common due to lack of awareness. Developing a proper and adequate solid waste collection system, sprinkling water over unmetalled road, providing basic and essential facilities for tourists to maintain hygiene and promoting mass awareness regarding protection of lake environment could be the possible solutions to protect and sustain the beauty of Attabad Lake (Mir, 2011).

Proper protection and management of natural lakeshores enhance the natural beauty of a lake. To protect our lakes, we have to protect our lakeshores. Natural lakeshores provide habitat, filter runoff from the land and create natural protection that absorb wave energy and reduce shoreline erosion. Natural lakeshores lead to a better habitat for fish community and improved water quality. Constructions near lakeshore may endanger the habitat of biotic community in and around lake. Preserving local and native vegetation around lakes is essential for a healthy lake ecosystem. Trees and other vegetation along the lakeshore help protect lakes from the impacts of development. Overhanging trees also provide comfortable environment for aquatic life. During rains, the vegetation along lakeshores reduce the flow velocity of runoff and probability of pollutants reaching the lake reduces. Protection of native vegetation is important as it requires low maintenance. Natural lakeshores contribute to improved water quality that can help increase the value of lakefront property (EPA, 2010).

Unplanned development near the lakeshores degrades the natural and scenic beauty of lake landscapes and may adversely affect the lake water quality. Increasing human settlement and anthropogenic pressure in lake basin diminish the aesthetic quality of a lake. The economic value of a lake reduces due to solid waste floating on lake surface and accumulated near shoreline (UNEP, 2003).

2.3.6 Loss of Aquatic Biodiversity and Habitat

Deutscher (2004) studied and investigated about impacts of socio-economic factors on fishing aspect in Lake Albert (Uganda, Africa). Lake Albert contributes considerably to Uganda's fish production. The local population at the lakeshore depends totally upon fisheries. The fisheries in lake were found no longer sustainable, due to extraction of more fish than produced. The study shows that the problem of over-fishing in Lake Albert is a result of complex socio-economic issues of society. These issues include poverty, lack of economic alternatives, lack of problem awareness, conflicts of interest between rich and poor fishermen as well as between indigenous people and migrants and the lack of enforcement of existing fisheries laws.

Nalawade *et al*. (2008*)* studied about degradation of Salim Ali Lake in Aurangabad city (India) due to entry of waste water and sewage and its impact on habitat of migratory birds. In this process, the physico-chemical parameters of lake water were monitored and effects of increasing human pressure in lake vicinity were studied. The water quality parameters and the migratory birds population were correlated. It revealed that water quality degraded with time and arrival of migratory birds declined consequently. The higher values of total dissolved solids, chemical oxygen demand and biochemical oxygen demand and reduced value of dissolved oxygen in water confirmed the entry of untreated sewage into the lake. The greenish colour of water was observed because of the excess growth of microcystis algae due to addition of sewage (Bhalla *et al.*, 2006). It was found that prime reason for deterioration of water quality and reduction in aquatic diversity of lake was increased human settlement in lake vicinity. It resulted into entry of waste water and sewage from surrounding area into the lake, which degraded the habitat of migratory birds.

The lake is now covered with water hyacinths and Acacia trees because of excess addition of phosphates from detergents and nitrates arising out of excretory waste.

Michael and Christian (2014) studied about the impact of climate change on fish production and their growth in lakes of Arctic region. Many fish species produce only above or below certain temperatures (Mathur *et al*., 2013). For this purpose bioenergetic models were used to simulate changes in *Least Cisco* production. *Least Cisco* is an important commercial fish in Arctic region. First, current temperatures suitable for Least Cisco were used and annual growth of fish was observed. Increased warmer water temperatures resulted in significant reduction in the fish production, particularly for larger size classes, when food availability was held constant. A shorter period of ice cover resulted in increased production of the fish. Prey quality was also altered and it was observed that it had a greater effect on fish production in summer than winter and on relative growth of younger than older age of the fish. The study reveals that change in native temperature affects the production of fish adversely. It may cause fish death also.

2.3.7 Health Risks

Jim B. *et al.* (2010) studied and discussed about the potential of adverse health effects of pesticides on living beings. Pesticides are commonly used in agricultural industry to kill pests. These may find way to lakes directly or indirectly and may harm aquatic life and human beings. A low level of exposure to a very toxic pesticide may not be more dangerous than a high level of exposure to a comparatively low toxicity pesticide. The health effects of pesticides depend upon the type of pesticide used. These may adversely affect the nervous and endocrine system and may generate skin and eye irritation in living beings. Some pesticides may be carcinogenic in nature.

Manisha D. *et al.* (2014) carried out study to evaluate the impact of idol immersion in lakes on human health and fish. The study was conducted for Gandhisagar, Futala and Ambazari Lakes of Nagpur city (India). These lakes are highly involved in idol immersion activity. Water and *Tilapia* fish of these lakes were analyzed for heavy metals. The samples were collected before and after three months of the idol immersion activities. High levels of heavy metals as lead, cadmium, copper, iron and manganese were found in water and fish. Concentrations of lead and cadmium in fish were observed as 0.83 μg/g and 0.47 μg/g respectively which were too high according to WHO standards. Heavy metals may disturb the enzyme and hormone producing capabilities of fish. Humans are exposed to these accumulated metals in fish by ingestion that may result into health hazard. It was investigated that heavy metal concentrations in lake water and muscles of *Tilapia* fish increased after immersion of Idols. The study recommends that idols should be made of natural biodegradable materials instead of organic pollutant materials and government should strictly deal the issue of idol immersion for the sake of the environment and public health.

2.4 Threats Arising from Outside Lake Drainage Basins

Various issues related to threats arising from outside lake drainage basins affecting the lake sustainability include transport of airborne pollutants and climate change.

2.4.1 Transport of Airborne Pollutants

Air pollutants can deteriorate water quality and soil and harm plants and animals of a lake. The atmosphere could be a source of transporting contaminants to lakes from sources outside the basin. Lake acidification could be due to transportation of pollutants from industrial stacks and vehicular emissions. Nitrogen and sulphur compounds deposited from the air are prime sources of acidification of lakes. Although nitrogen is an essential plant nutrient, excess nitrogen could be a source of eutrophication. Fish sensitive to lake acidification may be stressed and adversely affected. Pesticides, agricultural chemicals and eroded soils can be carried to great distances through atmospheric transport (UNEP, 2003). Metals and toxic compounds can be deposited in lake from the atmosphere and bioaccumulate in the food chain. This can cause neurological, behavioural and reproductive change in aquatic life (Mathur *et al.*, 2012).

Radford (2013) studied about severe pollution of Lake Chad (West Africa) due to eruption of smog and soot from factory chimneys and coal-burning power plants situated in far areas. Deterioration in lake water quality was observed. The nitrogen and sulphur compounds deposited on lake surface from air pollution were found as major causes that changed the water chemistry. Earlier, the lake was a giant body of water that nourished the crops in lake region. American scientists found it as an ecological disaster of Lake Chad.

Sandra and Luca (2006) studied about pollution in Alpine Lakes (Washington, USA) due to pesticides transported by air. Alpine Lakes are classified as lakes at high altitudes, usually starting around 1700 metre in elevation above sea level. The study indicated that accumulation of contaminants like DDT (dichloro-diphenyl-trichloro-ethane), PCB (polychlorinated biphenyl) and HCB (hexachlorobenzene) in muscles of fish of lakes could be due to atmospheric deposition of pesticides as there was no other source of pollution. It is estimated that about 70-90 percent of ground applied pesticides and 25-50 percent of aerially applied pesticides reach their target area and the remainder is dispelled into the environment where it exposes to wildlife and people (Mathur *et al.*, 2012). It was found that although pesticidal concentrations in fish muscles of Alpine Lakes were low and not a problem for fish consumption, their occurrence in areas far from local pollution sources clearly indicated that source of these substances was atmospheric deposition.

2.4.2 Climate Change

Vincent (2009) studied about impact of climate change on lake sustainability. The increasing accumulation of greenhouse gases may affect the structure, functioning and stability of lake ecosystems. The continuous increase in temperature of earth may change the distribution and intensity of rainfall and ice containing environments on Earth. Under extreme conditions, lakes may even completely disappear. Lakes at high altitudes and high latitudes and in arid and semi-arid regions may be more sensitive to climate change. Change in the precipitation affects inflow and outflow dynamics and erosion rates. The increased evaporation rates are directly linked to reduction in depth and area of lakes. In arid and semi-arid regions, more heat is trapped in surface water layer of a lake that results into variation in water density and availability of dissolved oxygen for aquatic life. Climate change affects landscape properties, including vegetation and soils, which exert a strong influence on water quality and quantity in the receiving lake basin. Increased temperatures and rainfall can lead to increased rock weathering, thereby affecting composition and concentrations in the runoff and thus water quality of lake. Climate change is accompanied by light and nutrient availability and hence may affect biotic species. Many fish species exhibit dissimilar behaviour with even small climate change and may be driven to even extinction if their thermal tolerance is exceeded. For Toolik Lake (Alaska), an analysis showed that a 3°C rise in lake water temperature caused lake trout to consume eight times more food to maintain the condition, which disturbed the food availability in lake. Hence changes in climate have direct effects on the physical, chemical and biological characteristics of lakes and on surrounding watersheds. It may adversely affect the lake sustainability.

Henry (2015) studied about the change in environment of Lake Erie (North America) due to 51 percent increase in heavy storms since 1960. Lake Erie is the fourth largest lake of the five Great Lakes in North America with 25,744 sq km area. Increase in heavy storms resulted into severe soil erosion in drainage basin that increased nutrient loading, harmful algal blooms, invasive species and oxygen depleted zones and resulted into deteriorated water quality.

Bayer (2013) studied about effect on growth of phytoplankton in Lakes Wanaka and Wakatipu (South Island, New Zealand) due to expected change in climate. For this purpose dynamics of Lakes Wanaka and Wakatipu were modelled under several climate change conditions such as increase in temperature and rainfall. The results from modelling were combined with information on the current dynamics and limits of phytoplankton from field surveys and experimental data. Phytoplankton is a plant like organisms with chlorophyll. Phytoplankton uses sunlight and carbon dioxide for growth and produce oxygen. These are foundation of aquatic food web feeding from zooplankton to big whales. It was found that phytoplankton biomass can increase in lakes in winter also due to increase in temperature. Increase in rainfall could be a source of nutrients input thus increased phytoplankton biomass. Certain species of phytoplankton in lakes were found as powerful biotoxins producers thereby favouring the limited growth of phytoplankton.

Table 2.1 shows the list of socio-economic and environmental factors which have been discussed in literature review to study sustainability of lakes.

Table 2.1: Socio-Economic and Environmental Factors Discussed in Literature Review

S.No.	Reference/Source	Study area	Socio-economic and environmental factors discussed for lake sustainability
1	Kennedy *et al.,* 1975	Columbia Lake, Connecticut (Columbia)	Inflow of waste water from surroundings
2	Nair and Unni, 1993	Lakes in Kerala (India)	Inflow of waste water from surroundings
3	Chandrasekhar *et al*., 2003	Bellandur Lake, Bengaluru city (India)	Inflow of domestic sewage and industrial waste
4	Sisodia *et al.*,2004	Jamwa Ramgarh Lake, Jaipur (India)	Inflow of domestic and industrial wastes
5	Ghosh, 2003	Chilka Lake, Orissa State (India)	Use of chemical fertilizers and pesticides in lake catchment and increased upstream soil erosion
6	Protection and Management of Urban Lakes in India, 2010	Hauz Khas Lake in Delhi (India)	Entry of waste water from a nearby sewage treatment plant
7	Thomas *et al.*,2011	Lake Naivasha (Kenya)	Over use of lake water, use of fertilizers and pesticides in catchment and diversion of waste water into lake
8	Vijayvergia and Tiagi, 2007	Udaisagar Lake, Udaipur (India)	Inflow of domestic and industrial effluent into lake
9	Khan, 2015	Dal Lake (Jammu and Kashmir, India)	Increased discharge of various effluents, sewage and sediments alongwith nutrients
10	Parashivamurthy, 2015	Varthur Lake, Bengaluru (India)	Entry of untreated sewage and waste water
11	Hook, 1988	Lake systems	Fishing, construction and agricultural practices at lakeshores
12	NCEIA, 2004	Lake systems	Public participation
13	Maembe, 2004	Jipe Lake (Tanzania)	Siltation, soil erosion, overgrazing and invasion by waterweeds, mass awareness strategy involvement of stakeholders in planning and implementation
14	Kenji *et al*.,2012	Lake Suwa (Honshu Island, Japan)	People's awareness and participation in lake water cleanup
15	Nagendra, 2016	Kaikondrahalli	Involvement of local stakeholders

		Lake (Bengaluru city, India)	and non-government organizations
16	Reddy and Char, 2006	Lake systems	Involvement of non-governmental organizations as catalysts
17	Mansee *et al.*, 2011	Lake systems	Inadequate governance
18	Chidammodzi and Muhandiki, 2015	Malawi Lake Basin (East Africa)	Inadequate governance
19	Cookey *et al.*, 2016	Lake systems	Poor management and governance
20	Bush *et al.*,2007	Great Lakes (USA).	Excess withdrawal and diversion of water
21	Max and Rebecca, 2009	Dead Sea Lake (Jordan)	Intense water withdrawal
22	Jones, 2010	Aral Sea Lake (Russia)	Diversion of inflowing tributaries
23	Carpenter, 2008	Lake systems	Lake eutrophication due to use of fertilizers, defective septic system and soil erosion
24	Edmondson, 1970 Edmondson, 1991	Lake Washington (Seattle, USA)	Lake eutrophication due to inflow of waste water effluent from surrounding area
25	Harper, 1992	Lake systems	Decline in recreation and aesthetic values of lakes due to eutrophication
26	Tippa *et al.*,2007	Agasthya Lake, Badami (Karnataka, India)	Increase in eutrophication due to sewage inflow and anthropogenic stress
27	Brandvold *et al.*, 1976	Bosque Del Apache Lake (Mexico)	Potential of the birds to contribute towards eutrophication
28	Welch,1981	Moses and Green Lakes, Grant County, Washington (USA)	Improvement in water quality (nutrients, algae and transparency) due to flushing
29	William *et al.*,1988	Lake Erie (North America)	Severe eutrophication due to inflow from agricultural fields, urban areas and industries
30	Ashley,1988	British Columbia lakes (Black, Glen and St. Mary)	Eutrophication and decline in anaerobic conditions due to use of aeration system
31	Prepas *et al.*,1990	Amisk Lake (Canada)	Impact of aeration system over lake water quality
32	Scherer *et al.*,1995	Green Lake, Styria (Austria)	Eutrophication due to phosphorous loading by bird dropping

33	Nair and Unni, 1993	Vembanad Lake, Kumarakom, Kerala (India)	Increase in input of agrochemicals and pesticides due to agricultural practices
34	Abida *et al.*,2008	Madivala Lake, Bengaluru (India)	Heavy metal contamination due to inflow of untreated industrial, agricultural and domestic wastes
35	Marielle *et al.*,2010	Municipal lake, Yaounde, Cameroon (Africa)	Chemical pollution due inflow of waste water from households and shops
36	Lashari *et al.*,2012	Keenjhar Lake,Sindh (Pakistan)	Heavy metal contamination due to inflow of domestic waste
37	Singare *et al.*,2011	Kukshet Lake, Navi Mumbai (India)	Heavy metal contamination due to cattle washing, cloth washing, bathing and idol immersion
38	Vyankatesh *et al.*, 2013	Lonar Lake, Maharashtra (India)	Eutrophication due to inflow of untreated domestic sewage and garbage
39	Peterson, 1981	Lake systems	Elimination of lake sediment
40	William *et al.*,1986	Lake Mendota, Dane County, Wisconsin (USA)	Increased flow and sedimentation due to urbanization
41	Thouk and Nuov, 1996	Great Lake, Cambodia (Tonle Sap Lake)	Increased rate of siltation due to massive deforestation and destructive human activities in lake catchment
42	UNEP, 2006	Lake Baringo (Kenya)	Drainage basin destruction and mass deforestation due to increased human pressure
43	Marcella and Anna, 2013	Lake systems	Aquaculture and degraded water quality
44	Richard, 2003	Lake Victoria, Tanzania (Africa)	Over-fishing
45	UNEP, 2003	Lake systems	Unsustainable fishing practices
46	UNEP, 2003	Lake systems	Improper solid waste collection system
47	Tapas *et al.*,2014	Lakes of Bhopal (India)	Improper solid waste collection system
48	Kripa *et al.*,2012	Vembanad Lake, Kerala (India)	Accumulation of litter and garbage
49	Alexander *et al.*, 2015	Laurentian Great Lakes (North America)	Pollution due to plastic debris
50	Mir, 2011	Attabad Lake, Gojal (Pakistan)	Pollution due to garbage, human waste and dust
51	EPA, 2010	Lake systems	Protection and management of

			natural lakeshores
52	UNEP, 2003	Lake systems	Degradation of natural and scenic beauty of lakes due to unplanned development near the lakeshores
53	Deutscher, 2004	Lake Albert, Uganda(Africa)	Over-fishing due to poverty, lack of economic alternatives, lack of awareness, conflicts of interest between rich and poor fishermen
54	Nalawade *et al*., 2008	Salim Ali Lake, Aurangabad (India)	Impact on habitat of migratory birds due to entry of waste water and sewage
55	Michael and Christian, 2014	Lakes of Arctic region	Impact of climate change on fish production and their growth
56	Jim B. *et al*., 2010	Lake systems	Adverse health effects of pesticides on aquatic life and human beings
57	Manisha D. *et al*., 2014	Gandhisagar, Futala and Ambazari Lakes, Nagpur (India)	Impact of idol immersion on human health and fish.
58	UNEP, 2003	Lake systems	Adverse effects of air pollutants on water quality, soil plants and animals of a lake
59	Radford, 2013	Lake Chad (West Africa)	Deterioration of lake water quality due to eruption of smog and soot from factory chimneys and coal-burning power plants
60	Sandra and Luca, 2006	Alpine Lakes, Washington (USA)	Air transportation of pesticides to lake
61	Vincent, 2009	Lake systems	Impact of climate change on structure, functioning and stability of lake ecosystems
62	Henry, 2015	Lake Erie (North America)	Degradation of lake due to Increase in heavy storms
63	Bayer, 2013	Lakes Wanaka and Wakatipu, South Island (New Zealand)	Impact on growth of phytoplankton due to change in climate.

2.5 Discussion

The literature review clearly reveals that increased human activities due to urbanization around the lakes have severely deteriorated the lake environment. These activities have degraded the lake catchment and deteriorated the lake water quality. It shows that unrestrained dumping of waste and uncontrolled land use change pattern, unsustainable agricultural practices, increased deforestation and industrial activities have adversely affected the sustainability of lakes all over the world. Lack of public awareness and understanding and insufficient governance have further deteriorated the situation.

The literature reviews show that limited numbers of socio-economic and environmental factors have been considered to study the sustainability of lakes (Table 2.1). It cannot provide a broad perspective to understand the sustainability of lakes.

So far no study has been made to discuss sustainability of lakes considering all the socio-economic and environmental factors as mentioned in the literature review. In present research work, all the socio-economic and environmental factors mentioned in the literature review are analysed and discussed together to make the study more comprehensive. Time frame based study and analysis for water quality, population, land use change, lake catchment soil, lake sediment, pesticidal concentration and rainfall have been carried out for better understanding. The objective is to make the study of sustainability of Anasagar Lake more extensive.

Next chapter deals with the study of various issues and activities related to socio-economic and environmental factors that may affect the sustainability of Anasagar Lake.

CHAPTER-3
THREATS TO SUSTAINABLE USE OF ANASAGAR LAKE

3.1 Socio-Economic Factors

3.1.1 Activities Using Lake as a Resource

(i) A huge volume of untreated waste water generated in Anasagar zone finds way to lake through municipal and stormwater drains. The lake is being used to receive waste water since long. It includes waste water from residential areas, hotels, shopping malls, small scale industries and hospitals situated in Anasagar zone besides sewage. Photo 3.1 shows the human settlement around Anasagar Lake. It is estimated that about 0.1 million litres of waste water enter into Anasagar Lake every day from surrounding catchment area (Photo 3.2). The estimated quantity of waste water generation in Anasagar zone is about 22 MLD (2021). This has been calculated on the basis of water supply at the rate of 155 lpcd in the town (CPHEEO, 1999).

(ii) A part of municipal solid waste finds way to Anasagar Lake directly or indirectly. Municipal solid waste contains recyclables substances (paper, plastic, glass, metals etc.), toxic substances (paints, pesticides, used batteries, medicines), compostable organic content (fruit and vegetable peels, food waste) and soiled waste (blood stained cotton, sanitary napkins, disposable syringes) mostly as component of it (Jha *et al*., 2003; Khan, 1994). The physical composition of municipal solid waste in Ajmer city consists of silt and debris (30.44%), clothes (2.56%), metal (2.3%), glass (1.04%), rubber (0.89%), plastics (9.46%), paper (8.62%) and organic matter (45.76%) (Detailed Project Report, 2007: Lake rejuvenation project, Anasagar Lake).

(iii) Agricultural practice in lake area is common when water recedes. The lake water is used for irrigation. Anasagar Lake is also used for recreation and fishing.

(iv) Table 3.1 shows results of seasonal average values of water quality parameters for lake water samples collected and tested in 2012-2013. Table 3.2 shows the values of water quality parameters for lake water samples from year 2006 to 2013.

Table 3.3 shows results of water quality parameters for stormwater samples collected and tested in monsoon period of year 2013. The samples are taken at points where runoff enters into stormwater drains from lake catchment and where storm water drains meet the lake.

Table 3.1: Seasonal Average Values of Water Quality Parameters of Lake Water

Parameters	Unit	Winter season	Summer season	Monsoon season	Average value	Prescribed drinking water standards		Standards adopted from
						Acceptable Limit	Permissible limit	
Ambient temp.	°C	26.45	42.10	31.27	32.27	--	--	--
Water temp.	°C	23.2	36.50	28.40	29.36	25	--	EC(1989)
Colour	Hazen	15.68	30.80	28.75	25.07	5	15	BIS:10500(2012)
pH	--	8.4	8.64	8.75	8.6	6.5-8.5	No relaxation	BIS:10500(2012)
Conductivity	µmho/cm	1397	2687.6	2804.5	2296.36	--	250	WHO(1993)
Turbidity	NTU	4.73	4.77	5.35	4.95	1	5	BIS:10500(2012)
TSS	mg/l	22.75	25.37	19.61	22.57	--	50	EC(1989)
TDS	mg/l	858.3	1610.1	1495.9	1321.43	500	2000	BIS:10500(2012)
Total solids	mg/l	881.05	1635.47	1515.51	1343.98	--	--	--
Chlorides	mg/l	238.07	531.5	482.7	417.42	250	1000	BIS:10500(2012)
DO	mg/l	6.95	5.730	5.797	6.15	--	5	EPA(2011)
BOD	mg/l	4.72	7.44	12.37	8.17	--	3	CPCB(2012)
COD	mg/l	33.73	50.60	87.31	57.21	--	10	WHO(2008)
TOC	mg/l	7.36	9.495	13.12	9.99	3	--	WHO(2008)
Sulphates	mg/l	55.25	106.3	126.8	96.11	200	400	BIS:10500(2012)
Fluorides	mg/l	1.05	1.230	1.157	1.14	1.2	1.5	WHO(2008)
Nitrates	mg/l	9.41	15.74	14.98	13.37	45	No relaxation	BIS:10500(2012)
Nitrites	mg/l	0.879	0.953	0.378	0.736	--	1	EPA(2011)
P	mg/l	0.4537	0.4755	0.2202	0.3831	--	0.1	WHO(2008)
Phosphates	mg/l	0.4035	0.6852	0.3565	0.4817	--	5	WHO(2008)
Oil & Grease	mg/l	1.112	6.115	3.847	3.69	0.5	No	BIS:10500(2012)

Parameters	Unit	Winter season	Summer season	Monsoon season	Average value	Prescribed drinking water standards		Standards adopted from
						Acceptable Limit	Permissible limit	
							relaxation	
Free CO2	mg/l	18.9	ND	ND	9.45	--	--	--
Transparency	m	0.184	0.163	0.157	0.168	< 0.7	Hypertrophic	O.E.C.D.(1982)
						0.7-1.5	Eutrophic	
						1.5-3	Mesotrophic	
						3-6	Oligotrophic	
Total alkalinity	mg/l	430.5	538.325	605.8	524.8	200	600	BIS:10500(1992)
Phenols	mg/l	0.0062	ND	ND	--	0.001	0.002	BIS:10500(2012)
Total hardness	mg/l	326.3	447.3	550.5	441.36	200	600	BIS:10500(2012)
Total coliforms	MPN/100 ml	20950.5	27571.7	22058.2	23526.8	0	No relaxation	BIS:10500(2012)
Fecal coliforms	MPN/100 ml	4534	5532.9	3817.3	4628.4	0	No relaxation	BIS:10500(2012)
Total chlorophyll	mg/l	399.52	462.31	280.65	380.82	< 3	Excellent	VRAP(2008)
						3 – 7	Good	
						7 – 15	undesirable	
						> 15	nuisance	

(*Data Source: Water quality monitoring reports for Anasagar Lake for 2012-2013 by Ajmer Development Authority, Ajmer*)

Table 3.2: Water Quality Parameters Values of Lake Water for Various Years

Parameters	Unit	2006	2007	2008	2009	2010	2011	2012	2013
pH	--	8.35	7.98	8.05	9.8	9.3	9.75	8.6	9,51
Conductivity	µmho/cm	1122.23	1387.9	1876.9	3180	5499.8	3357.5	2296.36	4278
Turbidity	NTU	2.7	3.00	4.56	6.89	3.03	10.31	4.95	5.36
TDS	mg/l	2255	4335.3	3837	1762	3423.19	2378	1321.43	1413
Chlorides	mg/l	360	145.17	202.83	445.98	558.72	695.9	417.42	658
DO	mg/l	3.7	5.88	5.67	9.2	9.23	7.47	6.15	6.11
BOD	mg/l	3.2	5.32	6	8.9	6.36	32.01	8.17	11.305
COD	mg/l	15	43.87	26.76	16.9	375.88	165.74	57.21	74.51
Sulphates	mg/l	43.03	54.98	119.78	78.98	186.19	139.24	96.11	104.17
Fluorides	mg/l	1.05	7.57	3.67	2.45	1.16	1.23	1.14	1.369
Nitrates	mg/l	7.57	9.78	8.24	9.78	10.79	8.74	13.37	13.54
Phosphates	mg/l	0.4023	4.43	3.92	1.8	1.9	4.1	0.4817	1.6136

Oil & Grease	mg/l	2.8	4.2	4.5	11.43	16.41	7.46	3.69	4.80
Transparency	m	0.295	0.285	0.336	0.58	0.139	0.523	0.168	0.160
Total alkalinity	mg/l	882.2	1023.3	182.85	327.3	453.98	487.88	524.8	530.6
Total hardness	mg/l	265	335.33	382.83	476.4	345	441	441.36	445
Total coliforms	MPN/100 ml	11676	12678	10978	13254	17654	19876	23526.8	33000
Fecal coliforms	MPN/100 ml	2400	2300	4500	6981	5000	4532.9	4628.4	20000

(Data Source: DPR, Anasagar Lake, 2007; Sharma et al., 2009; Mathur et al., 2010; Ajmer Development Authority, Ajmer)

Table 3.3: Water Quality Parameters of Stormwater in Monsoon Period of 2013

Parameters	Stormwater (average values)	Unit	Waste water in major drains (average values)		
			Kaji ka nallah	Bandi river nallah	Vaishali Nagar nallah
Ambient temp.	30	°C	31	30.5	30
Water temp.	27	°C	27	29.5	28
Colour	2	Hazen	3	8	7
pH	6.6	--	8.34	8.5	8.6
conductivity	251	µmho/cm	2400	2200	2221
Turbidity	4	NTU	4	5.7	5.23
TSS	trace	mg/l	23	21	43
TDS	153	mg/l	1420	1700	1520
Total solids	151	mg/l	1443	1721	1563
Chlorides	18	mg/l	433	413	312
DO	4.5	mg/l	7.5	8.3	9
BOD	3	mg/l	8.12	9	7
COD	8.2	mg/l	48	47	31
Total organic carbon	12	mg/l	6.12	8	5
Sulphates	15.6	mg/l	108.68	117.3	111
Fluorides	trace	mg/l	1.06	0.88	0.76
Nitrates	22	mg/l	12	9	14
Nitrites	trace	mg/l	0.73	0.53	0.321
Phosphorous	0.13	mg/l	0.19	0.21	.121
Phosphates	0.62	mg/l	0.54	0.57	.54

Oil & Grease	trace	mg/l	1.2	3.4	0.234
Free CO2	5	mg/l	< 0.01	ND	ND
Transparency	0.141	m	0.137	0.167	0.298
Total alkalinity	400	mg/l	573	550	445
Phenols	Trace	mg/l	< 0.01	< 0.01	ND
Total hardness	50	mg/l	454	523	521
Total coliforms	1100	MPN/100 ml	1482	1700	3000
Fecal coliforms	150	MPN/100 ml	359	400	754
Total chlorophyll	32	mg/l	12	23	22

(Data Source: Guru Kripa Test House: 2013, Water quality parameters of stormwater in major drains to Anasagar Lake, Ajmer)

Photo 3.1: The Human Settlement around Anasagar Lake
(Source: www.google earth)

Photo 3.2: Stormwater Drain (Kazi ka nallah) Carrying Waste Water to Anasagar Lake

3.1.2 Activities Related to Limited Public Awareness and Understanding

(i) Activities like washing and bathing are common at the banks of Anasagar Lake (Photo 3.3). The inflow of pilgrims per day in Ajmer is 4000 that increases to 30000 per day during *Urs* fair (Sihara, 2013). The washing and bathing activities at lake banks increase during *Urs* fair. Private owners of land of lake area allow washer-men to use their land pockets for cloth washing.

(ii) Religious rituals, immersion of idols and feeding to fish are common and frequent activities carried out in lake water. Idol production units are established on lake banks since long.

(iii) A part of solid waste reaches the lake thrown by the pubic/ tourists/ vendors due to mismanaged and unprotected shore line of Anasagar Lake (Photos 3.4 and 3.5).

(iv) Average decadal population growth for Ajmer city has been found to be 22.5 percent with corresponding annual growth as 2.05 percent as shown in Table 3.4. Average literacy rate of Ajmer city is 87.53 percent of which, male and female literacy rates are 93.26 and 81.53 percent respectively (*Source*: Census, 2011). The projected population of Ajmer city, for the year 2021 is about 7.20 Lacs. About 30 percent of population of Ajmer city resides in Anasagar Lake zone (Mathur *et al*., 2014). Figure 3.1 shows that the population of city is increasing at an alarming rate.

Table 3.4: Decadal Population of Ajmer City

Year	1941	1951	1961	1971	1981	1991	2001	2011	2021
Population (lacs)	1.47	1.96	2.32	2.65	3.76	4.03	4.86	5.93	7.20
Growth rate (%)	--	33.5	17.6	14.3	42.1	7.2	20.6	22.1	22.5

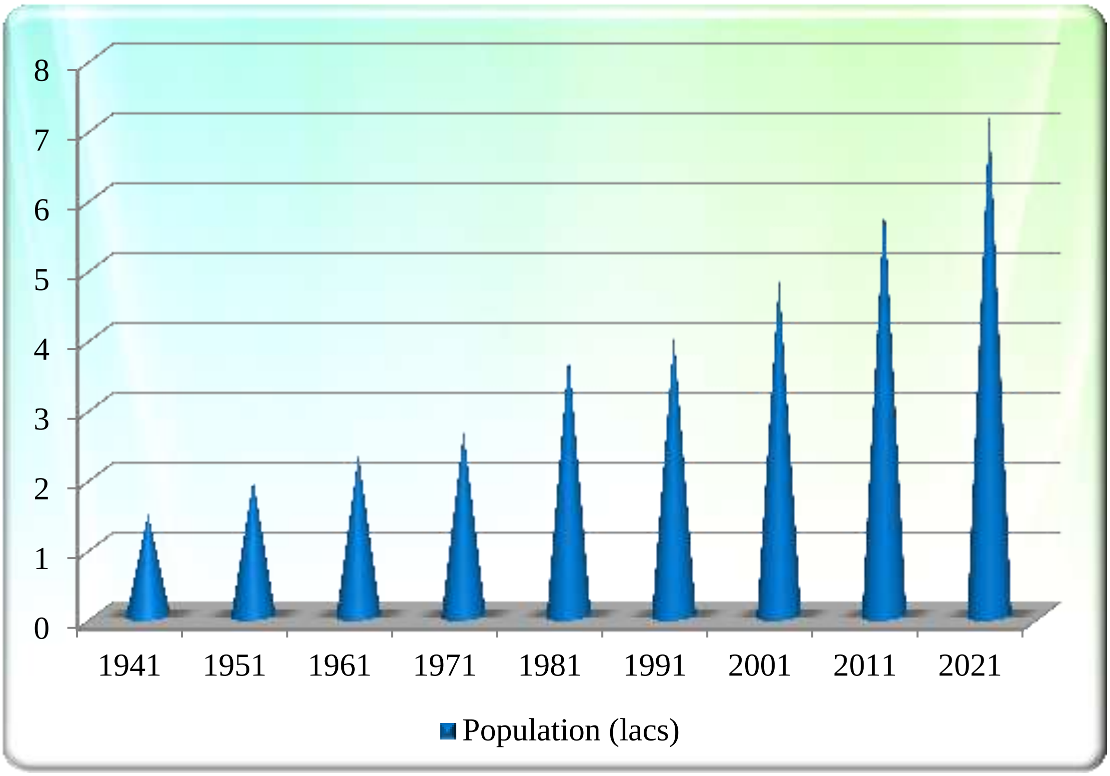


Figure 3.1: Decadal Population (lacs) Variation of Ajmer City (1941-2021)

Photo 3.3: A View of People Bathing and Washing at Lake Bank

Photo 3.4: The Exposed Lake Shoreline behind Vaishali Nagar

Photo 3.5: The Unprotected Lake Shoreline near Regional College

3.1.3 Activities Arising out of Insufficient Governance

(i) The peculiar feature of Anasagar Lake is that there is privately *(Khatedari)* owned land beneath the water. Hence, there are legal claimants to that land of lake area who are still owners of land pockets beneath water. The moment water recedes or abates around the lake; there is claim to the vacated land that is used for agriculture and small scale industries like brick manufacturing.

(ii) Nearly all development that has taken place in the vicinity of Anasagar Lake exists in lake catchment and even in lake water spread area. It includes development of residential colonies, commercial activities such as shops, shopping malls, marriage halls/ gardens, cinema halls, private hospitals, *vishramsthali* for *jayreens* (pilgrims) stay during *Urs* fair and industrial activities such as marble cutting units, idol production and brick manufacturing units, huge road constructions, agricultural activities in and outside the lake area and many more. A shopping mall in water spread area of lake is shown in Photo 3.6. Photo 3.7 shows a brick manufacturing unit in lake reach and Photo 3.8 shows an idol production unit at lake bank.

(iii) A large area of hilly terrain, which is a part of forest land, has been encroached for residential colonies. Cluster of houses, constructed illegally can be seen on hills of forest land in lake catchment area.

Forest land is a large area covered with trees and other woody vegetation. Ministry of Environment and Forest (Govt. of India) defines forest land as an area under government control used for conservation and management of ecological and biological resources.

(iv) Land-use information within Anasagar Lake catchment for various years has been shown in Table 3.5. This shows that land under vegetation cover is reducing continuously and presently it is less than 20 percent of total lake catchment area (53 sq.km) while the area under settlement is increasing and presently it is about 17 percent of the total catchment area (Table 1.1 and 3.5).

Table 3.5: Land-Use Information Within Anasagar Lake catchment

S. No.	Class type	Area (sq km)					
		2000	2003	2006	2008	2012	2013
1	Water body	1.89	1.89	1.875	1.871	1.87	1.87
2	Open/ barren land	0.72	0.88	1.20	1.40	1.82	1.83
3	Agriculture	1.40	1.52	1.68	2.00	2.06	2.06

4	Fallow land	6.42	6.49	6.68	6.80	7.15	7.17
5	Degraded vegetation	2.46	2.46	2.61	2.80	2.91	2.92
6	Vegetation (medium density)	1.027	0.0902	0.785	0.600	0.595	0.595
7	Vegetation (high density)	0.067	0.060	0.042	0.030	0.026	0.026
8	shrubs	8.01	7.62	7.49	7.20	7.16	7.16
9	Marshy land	0.221	0.210	0.201	0.200	0.186	0.186
10	Settlement	5.90	6.00	6.49	7.00	7.26	7.27
11	Industrial area	0.006	0.006	0.007	0.008	0.009	0.011
12	Miscellaneous	24.87	24.96	23.94	23.09	21.94	21.90
	Total	53.00	53.00	53.00	53.00	53.00	53.00

(Source: Nagar Nigam: 2013, Land use details in Anasagar Lake catchment)

(v) The pesticides are of prime choice for farmers of Ajmer due to low cost, high efficacy and easy availability. These are used in agricultural practices.

(vi) Religious rituals, idol immersion and feeding to fish are common in lake water.

(vii) Illegal fishing is common and quite visible in Anasagar Lake throughout the year. Though it is permitted to license holders and restricted from 16 June to 31 July (*Source*: The Rajasthan fisheries rules, 1958).

Photo 3.6: A Shopping Mall in Water Spread Area of Lake at Circular Road

Photo 3.7: A Brick Manufacturing Unit in Lake Reach opposite MPS School

Photo 3.8: An Idol Production Unit at Lake Bank

3.2 Threats Arising from Within Lake Drainage Basin

3.2.1 Issues and Activities Related to Excessive Nutrient and Mineral Load

(i) A part of municipal solid waste finds way to Anasagar Lake directly or indirectly. The chemical composition of municipal solid waste of Ajmer is shown in Table 3.6 (Detailed Project Report, 2007: Lake rejuvenation project, Anasagar Lake).

Table 3.6: Chemical Characteristics of Municipal Solid Waste of Ajmer

pH	6.2-8.3
Organic Matter (%)	20-50
N (%)	0.4-0.9
P (%)	0.29-1.09
K (%)	0.67-2.30

(Source: Detailed Project Report, 2007: Lake rejuvenation project, Anasagar Lake)

(ii) Ajmer belt is a storehouse of deposits of potash, lignite, mica, graphite and many non-metallic minerals and stones. Limestone, feldspathic quartzite, mica, coarse grained marble, lime and building stones are also found in Ajmer (Brief industrial profile of Ajmer District, 2008: MSME, Govt. of India).

(iii) Table 3.7: Average Values of Lake Catchment Soil Analysis

Parameter	Value	Area (2000)	Area (2004)	Area (2006)	Area (2012)	Area (2013)	Unit	Limits (ICAR)	
pH	7-8.5	46%	45%	44%	40%	39%	--	7-8.5	Normal
	>8.5	54%	55%	56%	60%	61%		> 8.5	Alkaline
Conductivity	0-1	28%	27%	26%	20%	18%	mmhos/ cm	< 1	Normal
	1-3	72%	73%	74%	80%	82%		1-3	Medium
Nitrogen	0-0.5	94%	93.8%	93%	90%	89%	Kg/ hectare	< 0.5	Low
	0.5-0.75	6%	6.2%	7%	10%	11%		0.5-0.7	Medium
Phosphorous	0-23	78%	75%	72%	75%	74.5%	Kg/ hectare	< 23	Low
	23-56	22%	25%	28%	25%	25.5%		23-56	Medium
Potash	0-142	24%	23%	20%	15%	14%	Kg/ hectare	< 142	Low
	142-337	49%	50%	52%	55%	56%		142-337	Medium
	>337	27%	27%	28%	30%	30%		> 337	High
SAR	10-18	44%	46%	49%	59%	60%	--	Medium	

(Data Source: Expert Engineers: 2014, Nutrient levels for catchment soil of Anasagar Lake)

Table 3.7 shows the average values of pH, conductivity, nitrogen, phosphorous, potash and soil absorption ratio (SAR) of lake catchment soil samples collected in years 2000, 2004, 2006, 2012 and 2013. According to limits suggested by Indian Council of Agricultural Research (ICAR) a major part of lake catchment soil is alkaline and bears medium values for conductivity and low values for nitrogen and phosphorous. The values of potash vary from low to high. About one third of lake catchment soil bears high values of potash. The soil bears medium range for soil absorption ratio.

(iv) Table 3.8: Average Values of Lake Sediment Analysis

Year	Organic matter (%)	Nitrogen (Kg/ha)	Phosphorous (Kg/ha)	Potassium (Kg/ha)
2000	0.18-0.98	310-1172	16-31	195-280
2004	0.20-1.10	314-1175	17-34	198-285
2006	0.26-1.10	322-1180	20-38	200-291
2012	0.29-1.14	329-1189	21-41	210-299
2013	0.30-1.24	330-1193	21-42	212-300

(Data Source: Expert Engineers: 2014, Nutrients in sediments of Anasagar Lake)

Table 3.8 shows average values of organic matter and N, P and K for lake sediment samples collected in years 2000, 2004, 2006, 2012 and 2013. It shows that the lake sediment is nutrient rich. Photos 3.9 and 3.10 show the vegetation and green algal growth in lake water.

(v) Fertilizers like Super Phosphate and Di-Ammonium Phosphate are used by farmers of Ajmer in agricultural practices (Bhatt, 2006). These may reach into the lake with rain runoff.

(vi) The waste water generated because of bathing and washing activities at lake banks reach the lake directly.

Photo 3.9: The Vegetation Growth in Anasagar Lake

Photo 3.10: Green Algal Growth in water of Anasagar Lake at Baradari

3.2.2 Activities Related to Contamination of Water and Sediment from Toxic and Hazardous Substances

(i) A large area of the catchment of Anasagar Lake is used for agriculture, growing particularly Trapa Bispinosa (*Singhara*) as the primary cash crop and vegetable crops like Cauliflower, Tomato, Cabbage and Brinjal etc. It leads to input of organo-chlorine pesticides (OCPs) in agriculture. Photos 3.11 and 3.12 show the agriculture fields around Anasagar Lake. The production of Trapa Bispinosa has reduced for last few years.

Table 3.9 show average concentrations of organo-chlorine pesticides in lake water samples tested in 2006-2007. Figures 3.2-3.7 show the corresponding monthly variation of organo-chlorine pesticides residues in lake water. Table 3.10 show average concentrations of heavy metals in lake water samples tested in year 2008. The heavy metal containing pesticides may reach the lake with rain runoff or through air.

Table 3.9: Average Concentrations (mg/l) of Organo-Chlorine Pesticides in Lake Water

Pesticides	Heptachlor	β.HCH	pp-DDD	pp-DDE	pp-DDT	Aldrin
Sept. 2006	0.009	0.131	0.010	0.006	0.026	0.005
Oct. 2006	0.018	0.132	0.011	0.009	0.026	0.006
Nov. 2006	0.021	0.139	0.011	0.019	0.029	0.010
Dec. 2006	0.030	0.138	0.012	0.019	0.031	0.012
Jan. 2007	0.029	0.143	0.021	0.023	0.034	0.017
Feb. 2007	0.036	0.152	0.028	0.029	0.040	0.019
March. 2007	0.039	0.151	0.029	0.031	0.048	0.022
April 2007	0.048	0.163	0.036	0.038	0.053	0.026
May 2007	0.057	1.171	0.049	0.035	0.056	0.027
June 2007	0.068	0.174	0.048	0.036	0.055	0.020
July 2007	0.042	0.138	0.021	0.003	0.049	0.022
Aug. 2007	0.004	0.125	0.010	0.019	0.029	0.001
Average	0.0334	0.2297	0.0241	0.0226	0.0402	0.0168
Guideline value (WHO, 2004)	0.00003	0.003	0.001	0.001	0.001	0.00003

(Source: Charan et al., 2008)

Table 3.10: Average Concentrations (mg/l) of Heavy Metals in Lake Water

Metal	Min.	Max.	Mean	Guideline value (WHO, 2008)	Fish culture standards (BIS:13891, 1994)
Fe	0.458	1.031	0.744	0.3	0.05
Zn	0.108	2.096	1.102	3	0.5
Cd	0.036	0.117	0.077	0.003	0.01
Pb	0.092	0.192	0.142	0.01	0.05
Cu	0.038	0.108	0.072	2	0.05
Ni	0.008	0.013	0.010	0.07	0.05
Cr	BDL	BDL	BDL	0.05	0.05

(Source: Datta et al., 2009)

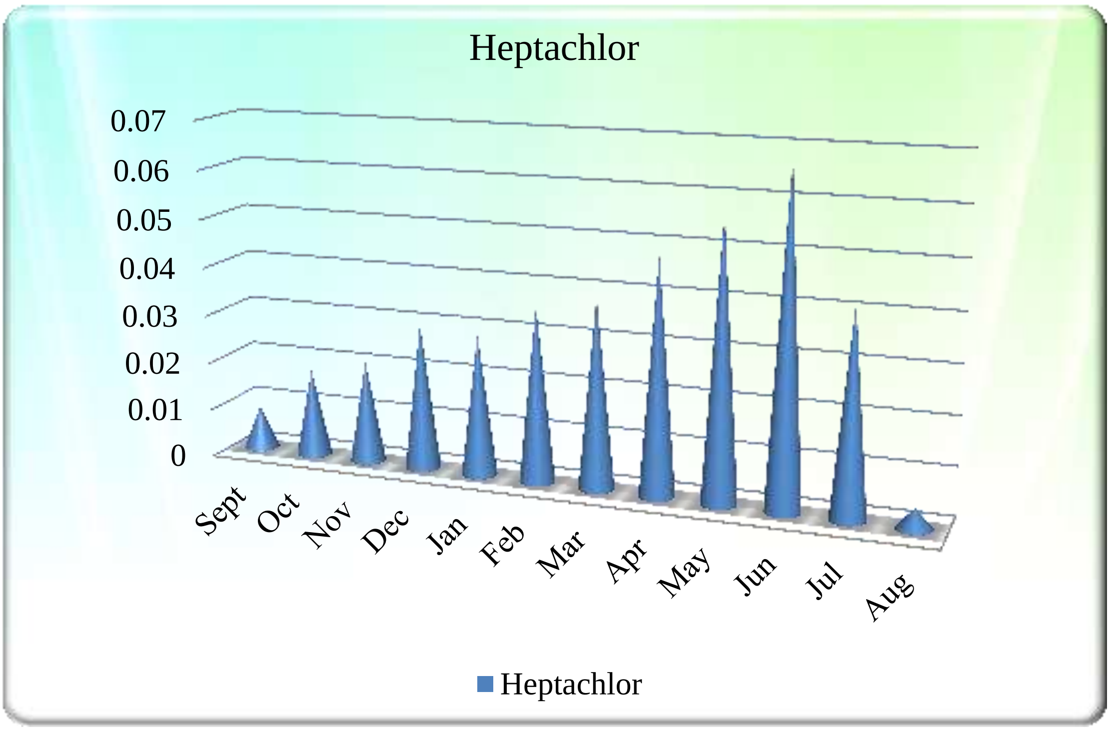


Figure 3.2: Variation of Heptachlor (2006-2007)

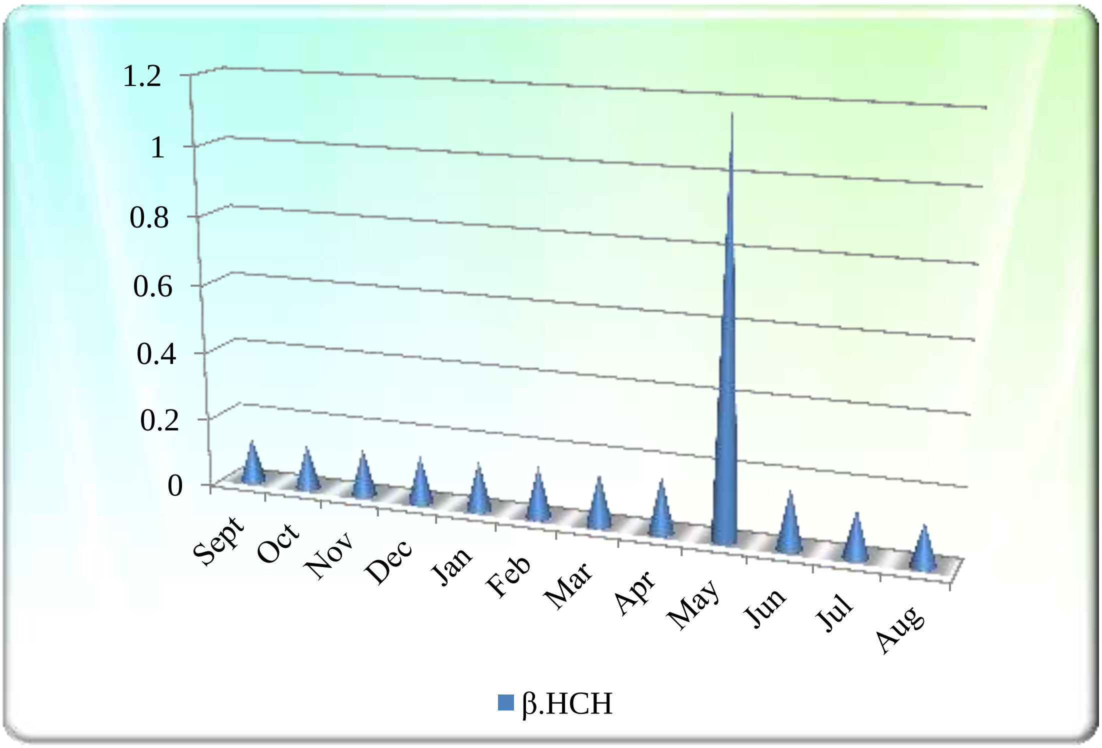


Figure 3.3: Variation of β.HCH (2006-2007)

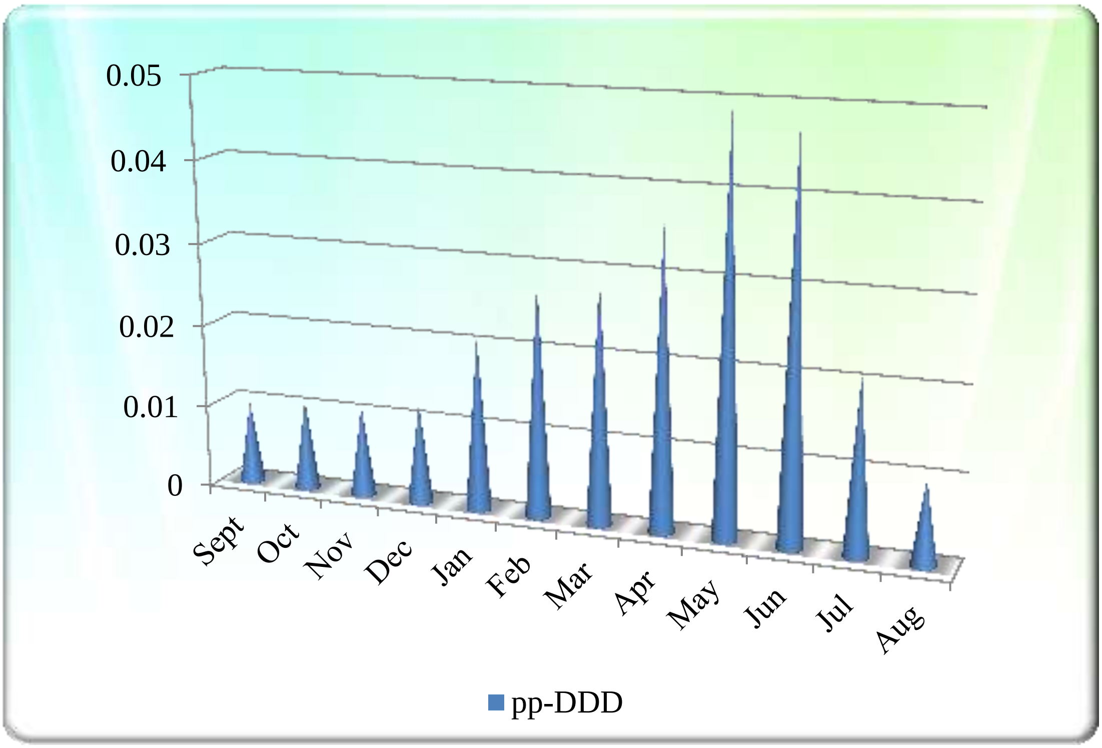


Figure 3.4: Variation of pp-DDD (2006-2007)

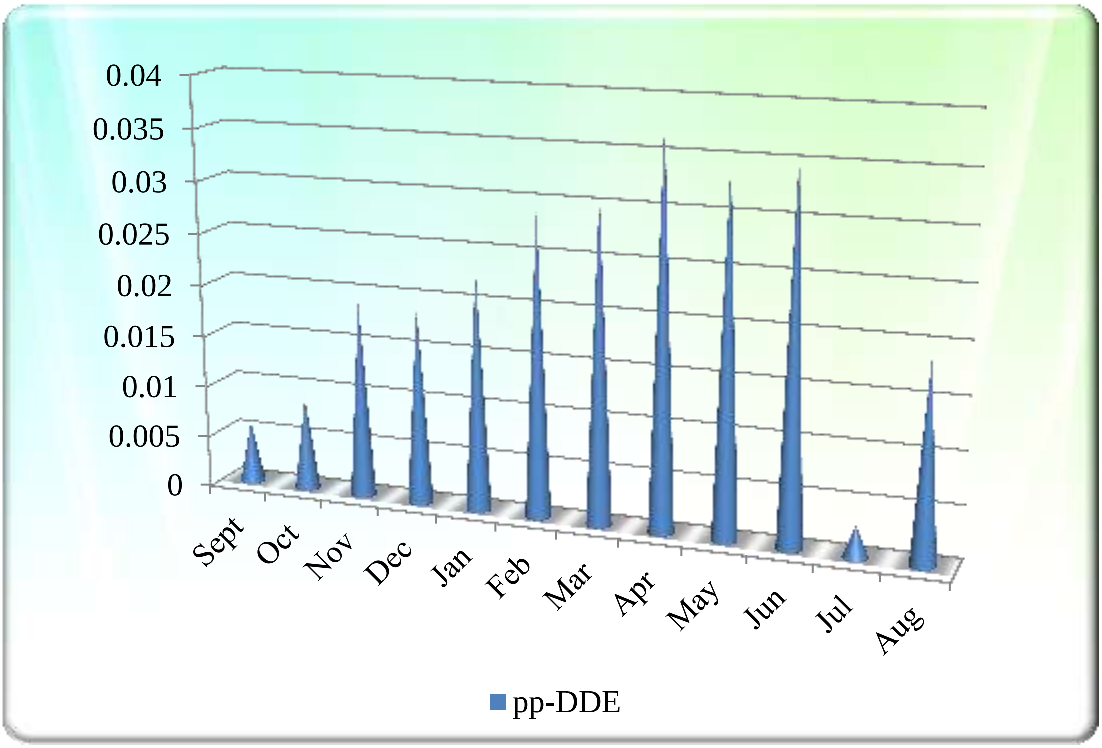


Figure 3.5: Variation of pp-DDE (2006-2007)

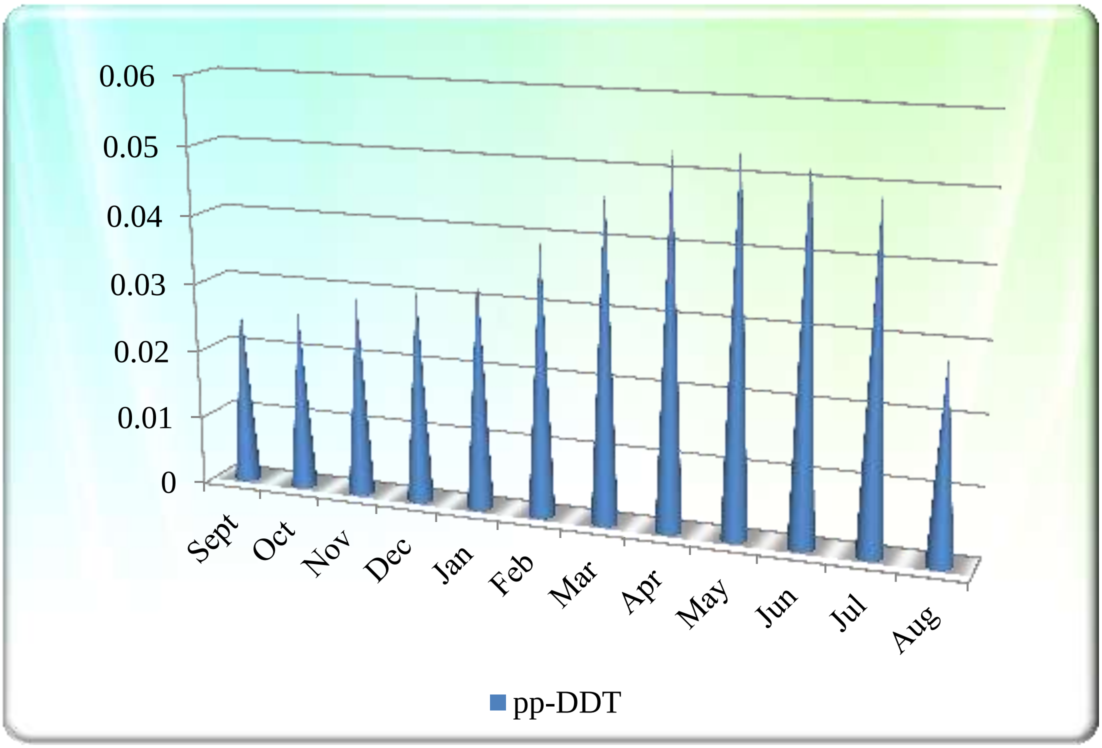


Figure 3.6: Variation of pp-DDT (2006-2007)

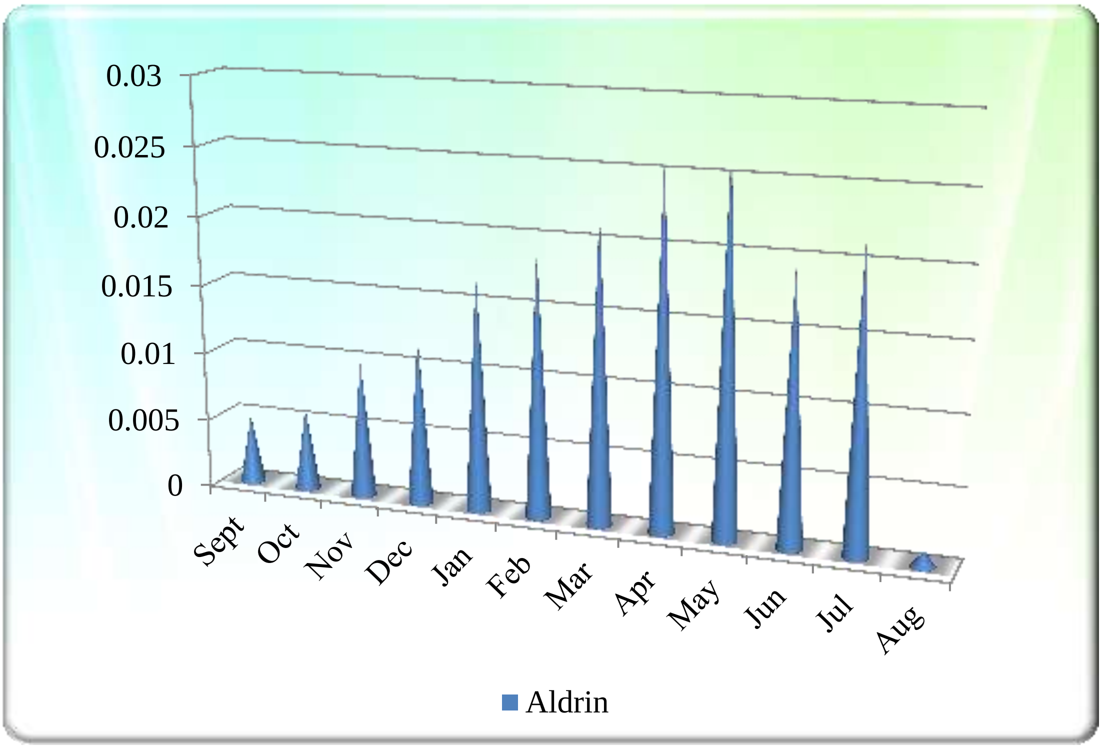


Figure 3.7: Variation of Aldrin (2006-2007)

(ii) A part of municipal solid waste reaches the lake directly or indirectly. It contains many hazardous substances (paints, chemicals, tyres, light bulbs, electric appliances, pesticides, used batteries, medicines and aerosol spray cans etc.) as a component of it (Khan, 1994; Jha *et al*., 2003).

(iii) Cloth washing of medical establishments is being carried out since long time at banks of Anasagar Lake. Idol production units are operating at lake banks since long.

(iv) Ajmer belt is metal enriched with deposits of copper, lead and zinc (Brief industrial profile of Ajmer District, 2008: Ministry of MSME, Govt. of India).

(v) Marble cutting units, automobile industries and workshops, shops for repair of electric appliances, welding work units and many more small scale industries have developed around Anasagar Lake.

Photo 3.11: The Agricultural Fields on Banks of Anasagar Lake
(Source: www.google earth)

Photo 3.12: The Agriculture Fields in North-West of Anasagar Lake
(Source: www.google earth)

3.2.3 Issues and Activities Related to Increased Erosion and Sedimentation

(i) Anasagar Lake receives rain runoff from Nagpahar, Anted and Taragarh hills in catchment area. These hillocks are characterized with steep slopes (>45 degree). Presently the depth of lake is 4.4 m at highest flood level (Table 1.1). Interviews with old residents of lake area revealed that the lake depth was 6.7 m in early sixties. In 1987, de-silting activity was carried out and the collected silt from the lake was dumped in the centre of lake resulting in the formation of one small island (Sharma *et al.,* 2009). Photo 3.14 shows the small island in Anasagar Lake.

(ii) Table 3.5 clearly shows that the vegetation cover over land of lake catchment is reducing continuously with increasing human settlement. Photo 3.13 shows the deforestation in lake catchment near Regional College, Ajmer.

(iii) The general soil structure in lake catchment is well drained, calcareous, fine loamy (fertile) on very gently sloping surface and moderately eroded (Detailed Project Report, 2007: Lake rejuvenation project, Anasagar Lake).

(iv) Table 3.11: Laboratory Test Results for Lake Catchment Soil

Soil Parameters	Near Mittal hospital			Behind Baldeo Nagar		
	At GL	1.2m below GL	1.5m below GL	At GL	1.2m below GL	1.5m below GL
Silt (%)	16.51	15.34	14.23	8.74	9.35	7.65
Fine sand (%)	32.51	32.05	31.87	23.05	22.60	35.80
Medium sand (%)	16.91	17.05	19.21	27.15	29.15	22.60
Coarse sand (%)	14.81	14.95	14.99	11.50	10.55	12.30
Fine gravel (%)	16.75	16.85	17.32	12.50	16.40	12.15
Coarse gravel (%)	2.55	3.46	3.25	15.85	11.95	9.50
Liquid Limit (%)	27.70	26.70	25.22	25.71	27.22	24.44
Plastic Limit (%)	22.70	23.45	20.65	19.86	22.30	18.71
Plasticity Index (%)	5.00	3.25	4.57	5.85	4.92	5.73
Bulk density(gm/cc)	1.73	1.74	1.79	1.63	1.69	1.70
Moisture Content (%)	6.62	6.32	5.78	5.11	5.62	4.42
Dry density (gm/cc)	1.62	1.63	1.89	1.55	1.60	1.63
Sp. Gravity	2.48	2.51	2.56	2.55	2.58	2.54
C (kg/cm^2)	0	0	0	0	0	0
ϕ (Degree)	22.37	21.34	23.45	23.67	24.34	23.12

(Data Source: Expert Engineers: 2012, Engineering properties of catchment soil of Anasagar Lake)

Table 3.11 shows the engineering properties of soil samples of lake catchment collected and tested in April 2011. It shows that the soil of lake catchment contains silt (0.002mm - 0.06mm) and sand (0.06mm - 2mm) as major constituents. The sand is more than 50 percent of total soil constituents of lake catchment. Rocks can be seen at ground level and 1.5m to 1.8 m below substrata. A major part of lake catchment has rocks at ground level to 1.5 m below ground level. The values of sodium absorption ratio (SAR) fall between 10 to18 (Table 3.7).

(v) The major source of water in Anasagar Lake is rain runoff. The average rainfall of Ajmer city is about 500 mm (Central Ground Water Board, 2008). Table 3.12 shows the year wise rainfall received in past 24 years (1990-2013) in Ajmer city and corresponding rainfall variation pattern is shown in Figure 3.8. The city observed heavy rainfall in year 2012 and 2013 that flooded many land areas in lake vicinity as shown in Photos 3.15 and 3.16.

Table 3.12: Rainfall Data of Ajmer City from Year 1990 to 2013

S.No.	Year	Rainfall	S.No.	Year	Rainfall
1	1990	840.7 mm	13	2002	305.8 mm
2	1991	468.6 mm	14	2003	500.6 mm
3	1992	656.8 mm	15	2004	334.2 mm
4	1993	562.1 mm	16	2005	475.2 mm
5	1994	551.0 mm	17	2006	510.8mm
6	1995	745.2 mm	18	2007	474.7mm
7	1996	769.4 mm	19	2008	305.5mm
8	1997	993.7 mm	20	2009	335.9mm
9	1998	576.5 mm	21	2010	480.3mm
10	1999	375.5 mm	22	2011	552.2mm
11	2000	295.0 mm	23	2012	589.2mm
12	2001	377.5 mm	24	2013	634.8mm

(Source: Detailed Project Report, 2007: Lake rejuvenation project, Anasagar Lake and Meteorological Department, Ajmer)

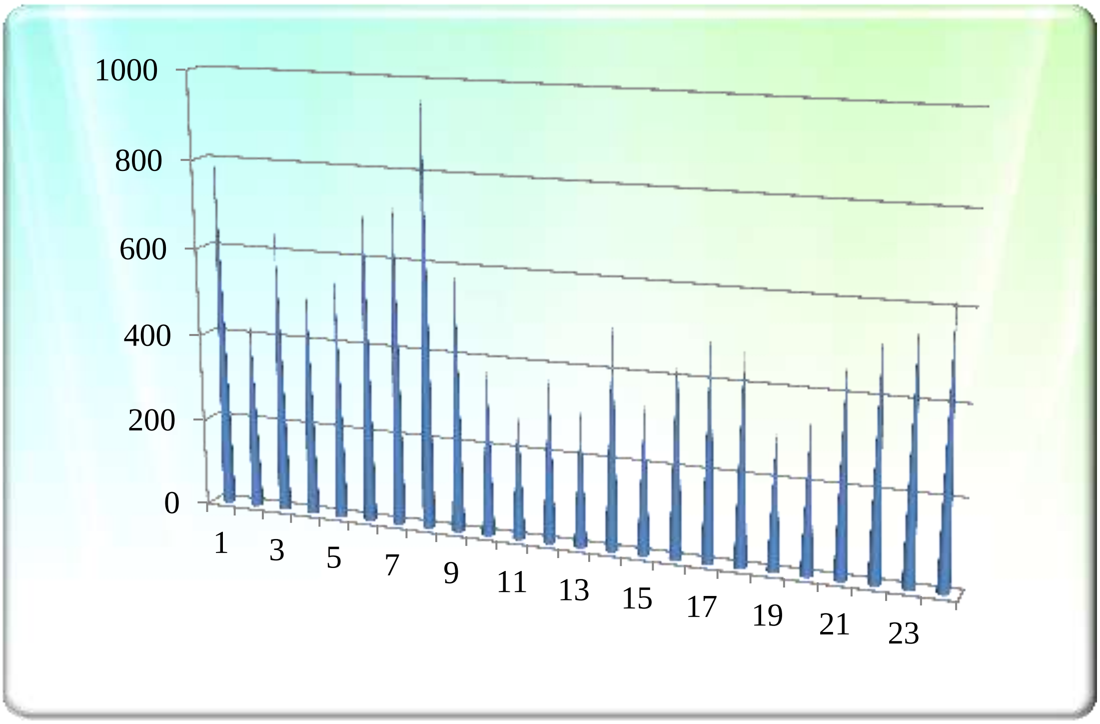


Figure 3.8: Rainfall (mm) Pattern in Ajmer City from 1990 to 2013

(vi) Most of the stormwater drains carrying rain water to Anasagar Lake are in deteriorated condition due to lack of proper supervision and maintenance. The sides and bottoms of these stormwater drains are broken and eroded.

(vii) Municipal solid waste of Ajmer city contains 30.44 percent silt and debris (Detailed Project Report, 2007: Lake rejuvenation project, Anasagar Lake). A part of it enters into lake through unprotected lake banks and open municipal and stormwater drains.

Photo 3.13: Deforestation in Lake Catchment near Regional College, Ajmer

Photo 3.14: Small Island in Anasagar Lake Made Up of Lake Sediment

Photo 3.15: The Inundated Area near Mittal Hospital after Rains in Year 2012

Photo 3.16: The Flooded Anasagar Circular Road after Rains in Year 2013

3.2.4 Activities Related to Accumulation of Litter and Garbage

(i) The estimated quantity of municipal solid waste generated is 76 MT/day for Anasagar Lake zone by the end of year 2021, assuming the generation rate of municipal solid waste as 355 gm/capita/day (CPCB, 2000).

(ii) The collection system of municipal solid waste in Ajmer city is not efficient and regular. Garbage can be seen littered all around easily (Photo 3.17). Dumping of municipal solid waste near lake shoreline is common. The rain runoff carries litter and garbage to lake from unprotected and illegal dumping sites of municipal solid waste in lake vicinity (Photos 3.19, 3.21 and 3.22).

(iii) Blockage of municipal and stormwater drains is frequent due to entry of municipal solid waste (Photos 3.18 and 3.20).

Photo 3.17: Unattended and Broken Bin for Municipal Solid Waste Collection

Photo 3.18: View of Choked Drain in Anasagar Lake Zone

Photo 3.19: Drain Carrying Municipal Solid Waste from Foysagar Lake Area

Photo 3.20: A Choked Minor Drain at G-Block Area, Mankarwali Road

Photo 3.21: A Solid Waste Dumping Site in Lake Reach near Regional College

Photo 3.22: A Solid Waste Dumping Site in Lake Basin near Panchsheel Colony

3.2.5 Activities Related to Loss of Natural, Aesthetic and Scenic Beauty of Lake

(i) Unplanned constructions and haphazard growth of buildings in the lake basin, lake area and along lake shoreline are quite visible and continuous. The land under vegetation cover is reducing continuously at the rate of 1.38 % per year (sq km) while the area under settlement is increasing at the rate of 4.34 % (sq km) per year (Table 3.5).

(ii) A huge amount of municipal solid is generated in Ajmer city. It is estimated that municipal solid waste generation would be 76 MT/day for Anasagar Lake zone by the end of year 2021(CPCB, 2000).

Municipal solid waste can be seen floating on lake water surface particularly at places where stormwater drains meet the lake and near unprotected lake shore line. Tourist spots like *Chaupati and Baradari* developed on lake banks could be seen littered with solid waste.

(iii) Eruption of foul gases from lake water is common around lake during summers due to increased anaerobic decomposition.

(iv) Dead fish could be seen floating on lake water surface throughout the year. These are collected by employees of Nagar-Nigam using boats (Photo 3.23).

(v) Visually the lake water seems to be greenish and turbid with very low transparency. Green algae are visible on lake water surface (Photo 3.10).

(vi) There was a time when Anasagar Lake was a centre for migratory birds. But since last few years these birds have almost disappeared (Gaur, 2014).

Photo 3.23: Dead Fish Collection at Chaupati by Nagar-Nigam in Summers

3.2.6 Issues and Activities Related to Loss of Aquatic Biodiversity and Habitat

(i) Fish death is common in Anasagar Lake which is frequent in summers and sometimes in winters also (Photo 3.23).

(ii) Illegal fishing is common and quite visible in Anasagar Lake. Though it is permitted to license holders and restricted from 16 June to 31 July every year (*Source*: The Rajasthan fisheries rules, 1958).

(iii) The density of rooted macrophytes (*Trapa bispinosa)* in Anasagar Lake has decreased with time (Pandey *et al.,* 2012).

(iv) Huge number of migratory birds like common crane, ducks, coots, pelicans, sand grouse, falcons, buzzards flock, flamingos and the rare Siberian ducks could be seen floating on lake water surface in winters in early times. These have almost disappeared since last few years.

(v) The frontage of Anasagar Lake near shoreline area has undergone huge changes with time due to increasing human pressure (Photos 3.6, 3.8 and 3.11). Agricultural and various construction activities in lake frontage have increased with time (Photos 3.11, 3.12 and Table 3.5).

3.2.7 Issues and Activities Related to Health Risks

(i) Whenever lake water recedes, the vacated land is used for agriculture and the lake water is used for irrigation. Photo 3.11 shows the agricultural fields on banks of Anasagar Lake. The overflow of lake water is used for irrigation near Khanpura Pond over a large area. Photo 3.25 shows a large cultivated area near Khanpura Pond. The lake is being used for recreation and fishing since long.

(ii) Table 3.13 shows the results of seasonal average values of selected water quality parameters for lake water samples collected and tested in 2012-2013. These results are compared with prescribed water quality standards for various lake uses such as recreation, propagation of fisheries and irrigation.

Table 3.13: Seasonal Average Values of Selected Water Quality Parameters of Lake Water

Parameters	Unit	Winter	Summer	Monsoon	Average value	Prescribed water quality standards			Standards adopted from
						Recreational use	Propagation of fisheries	Irrigation	
pH	--	8.4	8.64	8.75	8.6	6.5-8.5	6.5-8.5	6.5-8.5	CPCB (2012)
DO	mg/l	6.95	5.730	5.797	6.15	>5	>4	--	
BOD	mg/l	4.72	7.44	12.37	8.17	<3	<2	--	
Conductivity	µmho/cm	1397	2687.6	2304.5	2296.36	--	1000	2250	
Turbidity	NTU	4.73	4.77	5.35	4.95	5	50	--	AWWA (1990)
Fluorides	mg/l	1.05	1.230	1.157	1.14	1.5	--	--	BIS 2296: (1992)
TDS	mg/l	858.3	1610.1	1495.9	1321.43	--	2000	2100	CPCB (2012)
Chlorides	mg/l	238.07	531.5	482.7	417.42	--	--	600	
Sulphates	mg/l	55.25	106.3	126.8	96.11	--	--	1000	
Total coliforms	MPN/100 ml	20950.5	27571.7	22058.2	4628.4	<500	--	--	

(*Data Source: Water quality monitoring reports for Anasagar Lake for 2012-2013 by Ajmer Development Authority, Ajmer*)

(iii) Seasonal average values of water quality parameters for lake water samples are shown in Table 3.1. Figures 3.9-3.19 show the variation of various water quality parameters (2006-2013) given in Table 3.2. Table 3.9 and 3.10 show the pesticidal and heavy metal concentrations in lake water.

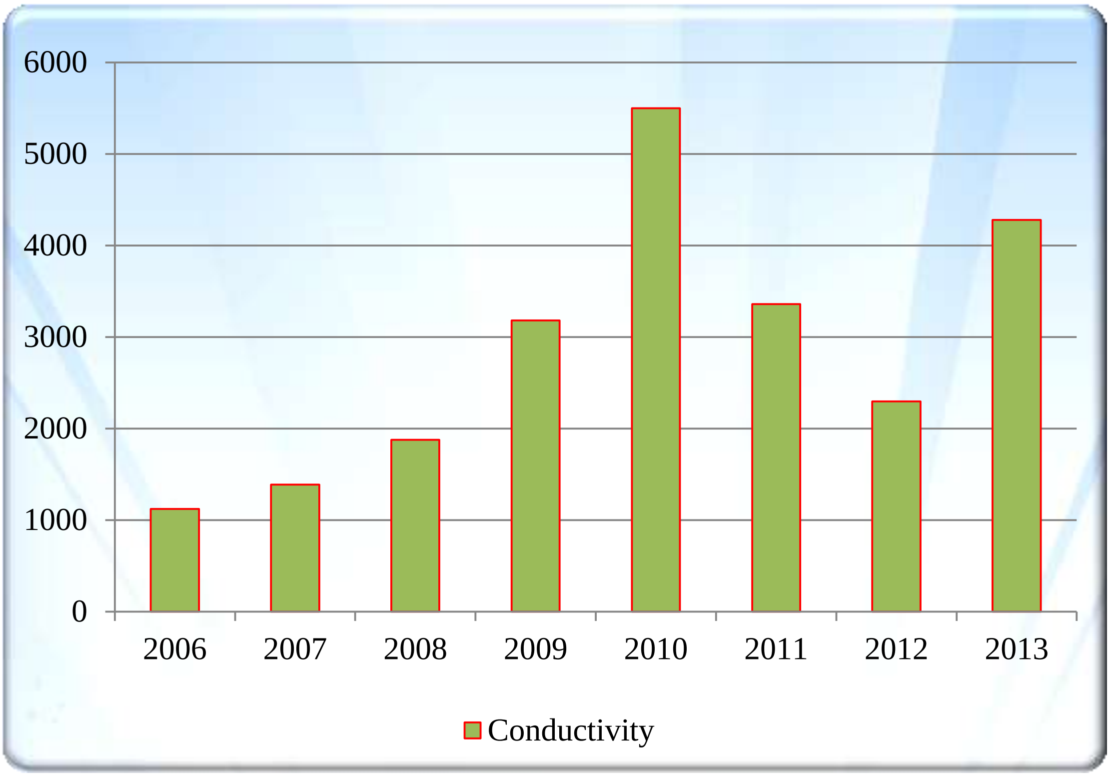


Figure 3.9: Variation of Conductivity in lake water (2006-2013)

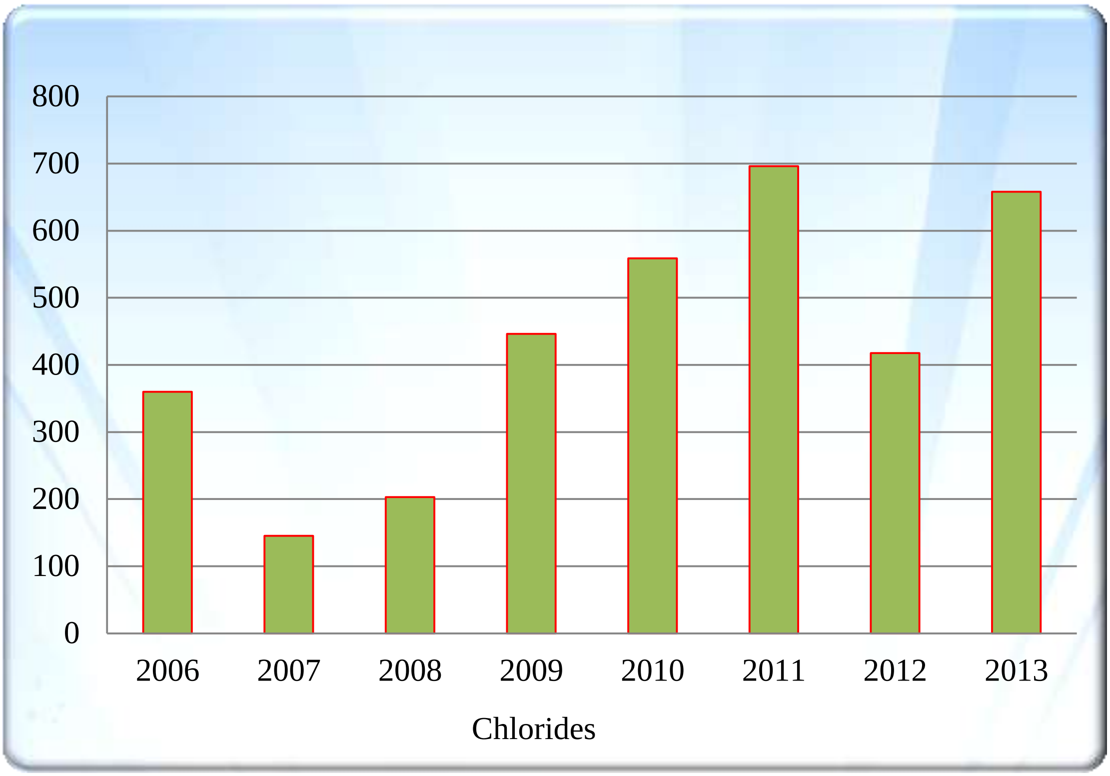


Figure 3.10: Variation of Chlorides in lake water (2006-2013)

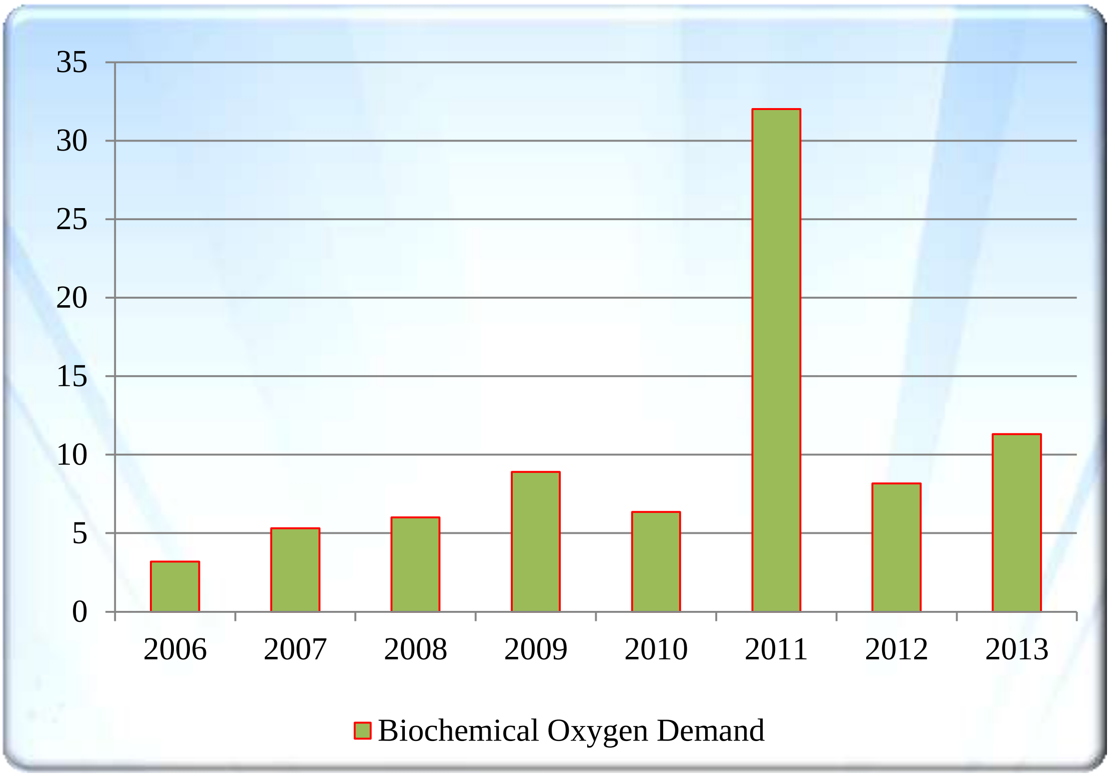


Figure 3.11: Variation of Biochemical Oxygen Demand in lake water (2006-2013)

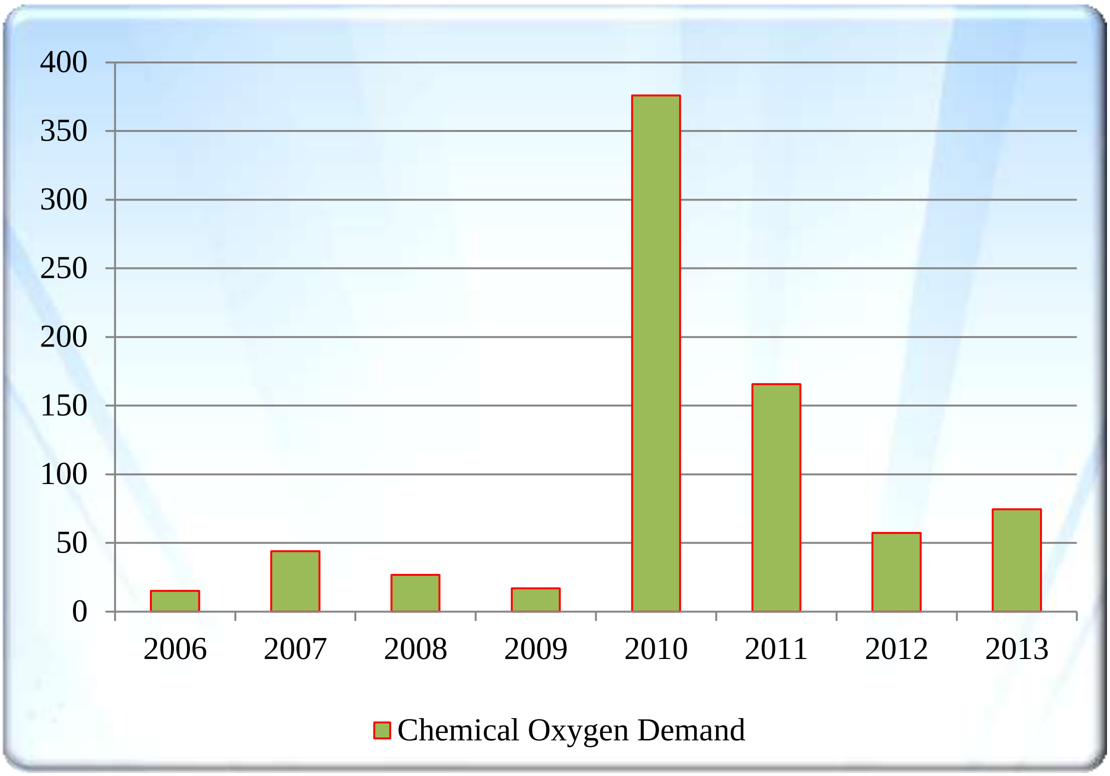


Figure 3.12: Variation of Chemical Oxygen Demand in lake water (2006-2013)

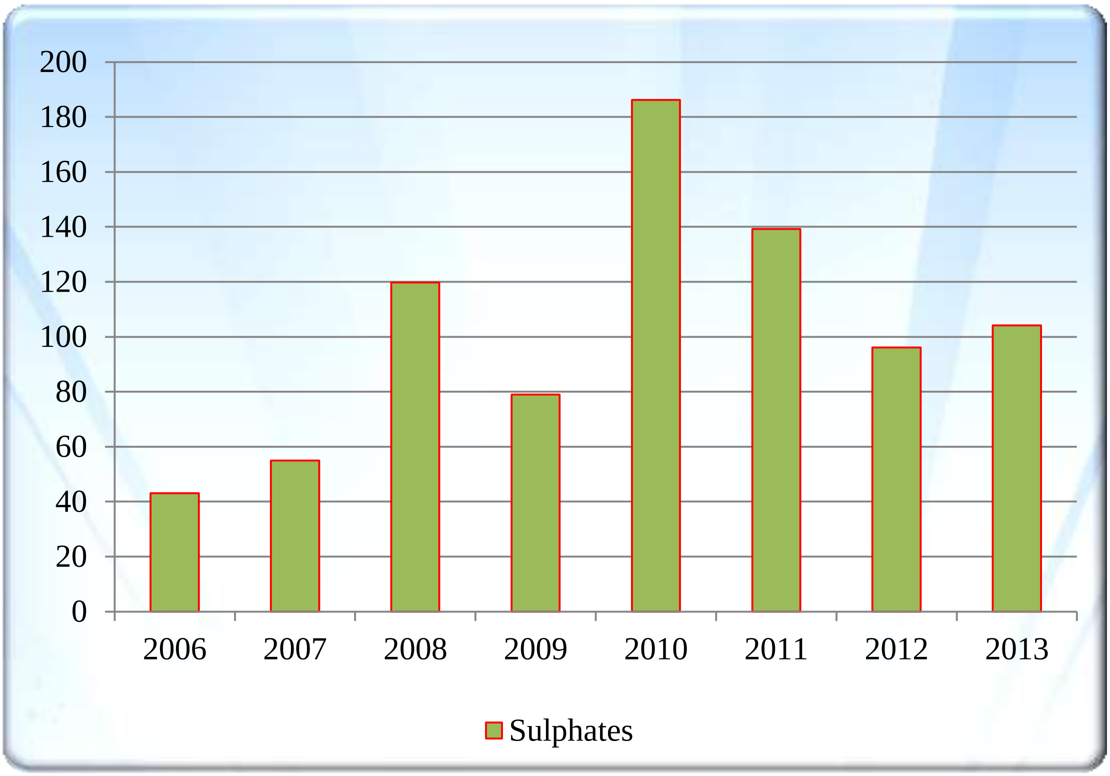


Figure 3.13: Variation of Sulphates in lake water (2006-2013)

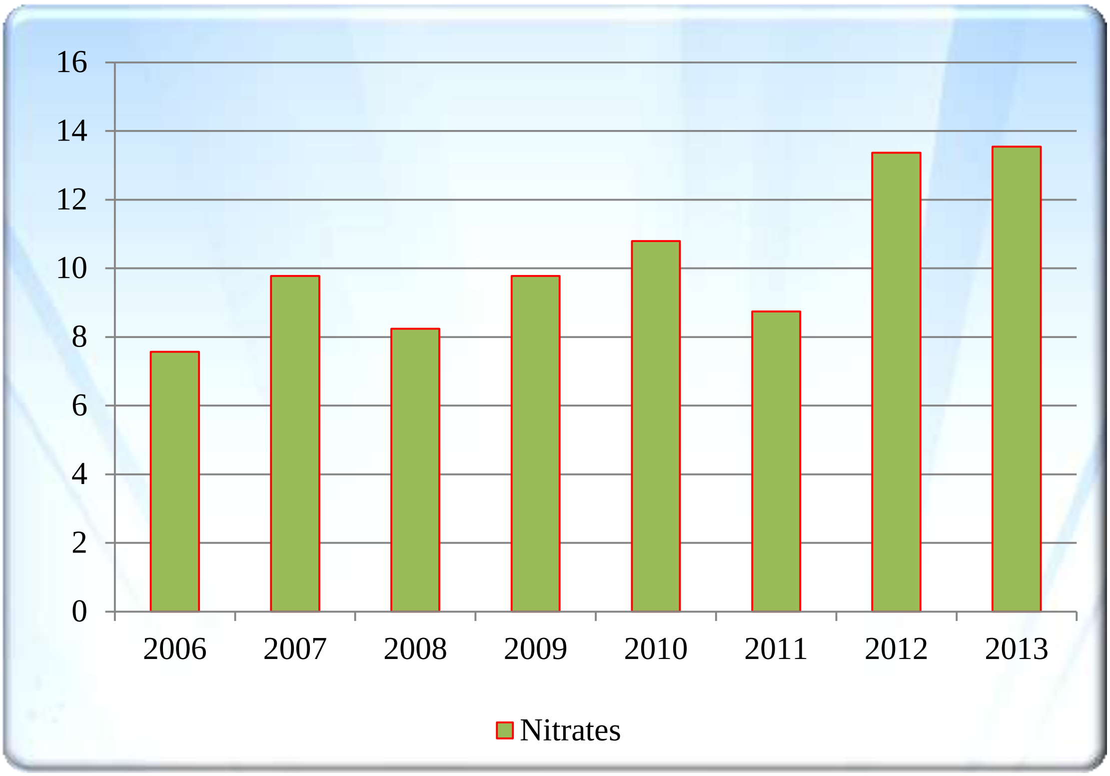


Figure 3.14: Variation of Nitrates in lake water (2006-2013)

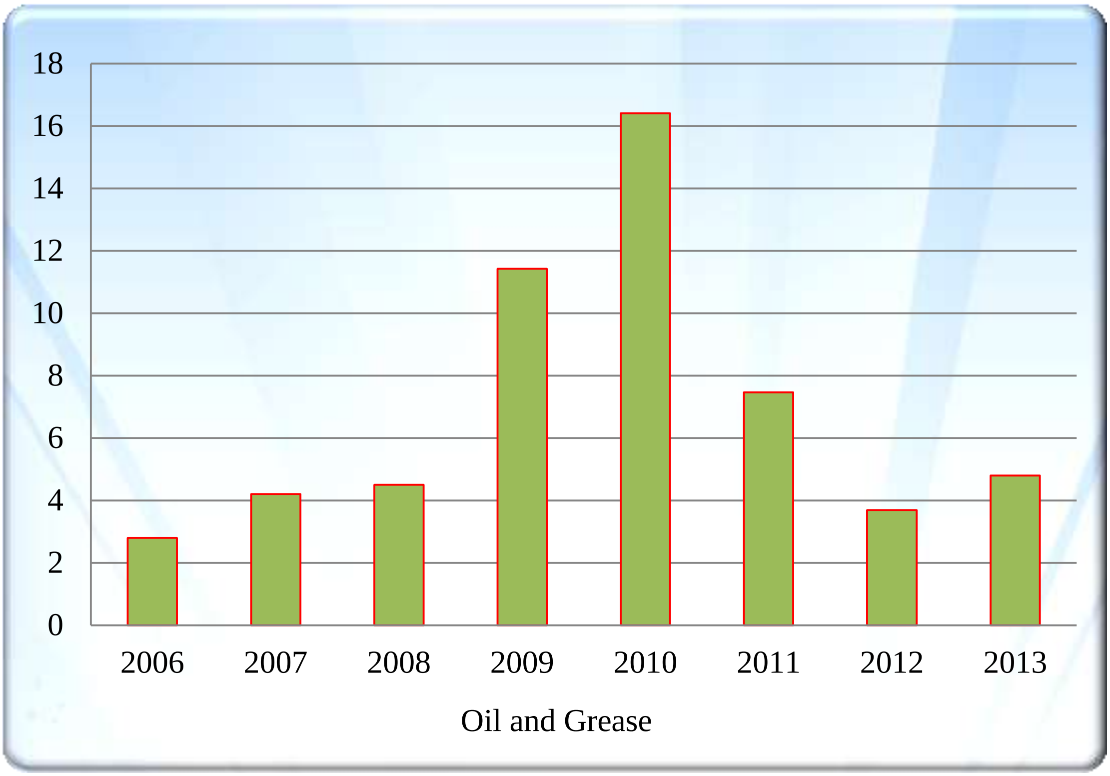


Figure 3.15: Variation of Oil and Grease in lake water (2006-2013)

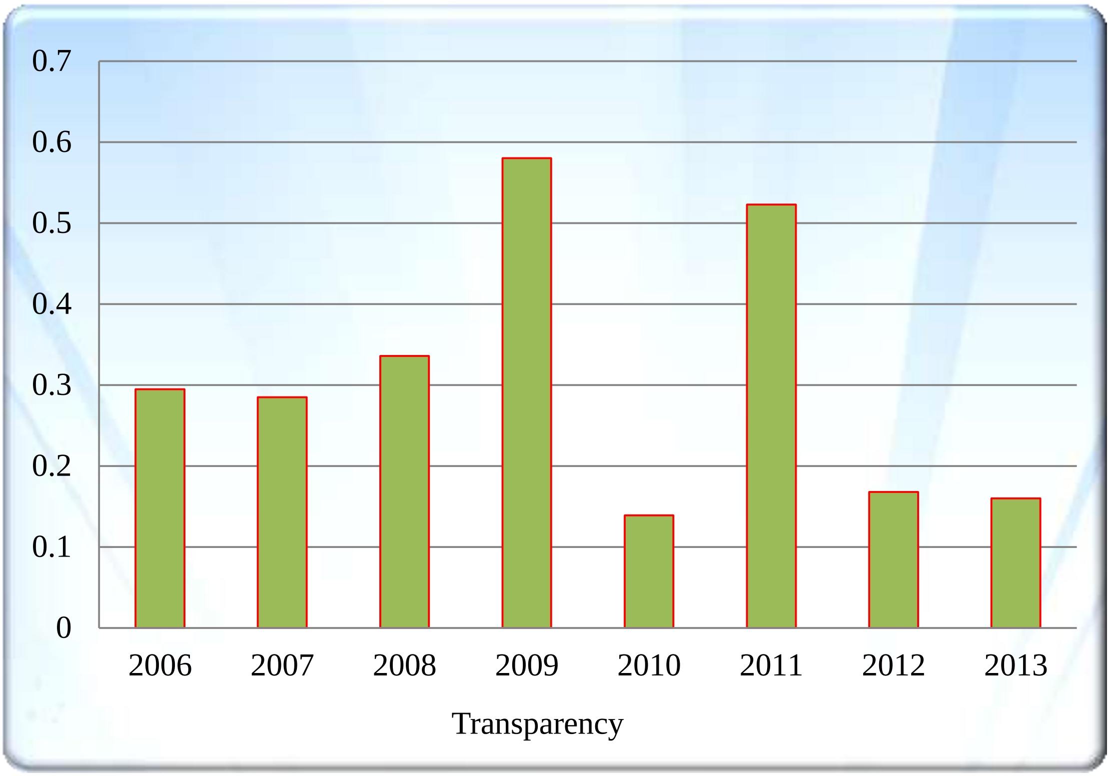


Figure 3.16: Variation of Transparency in lake water (2006-2013)

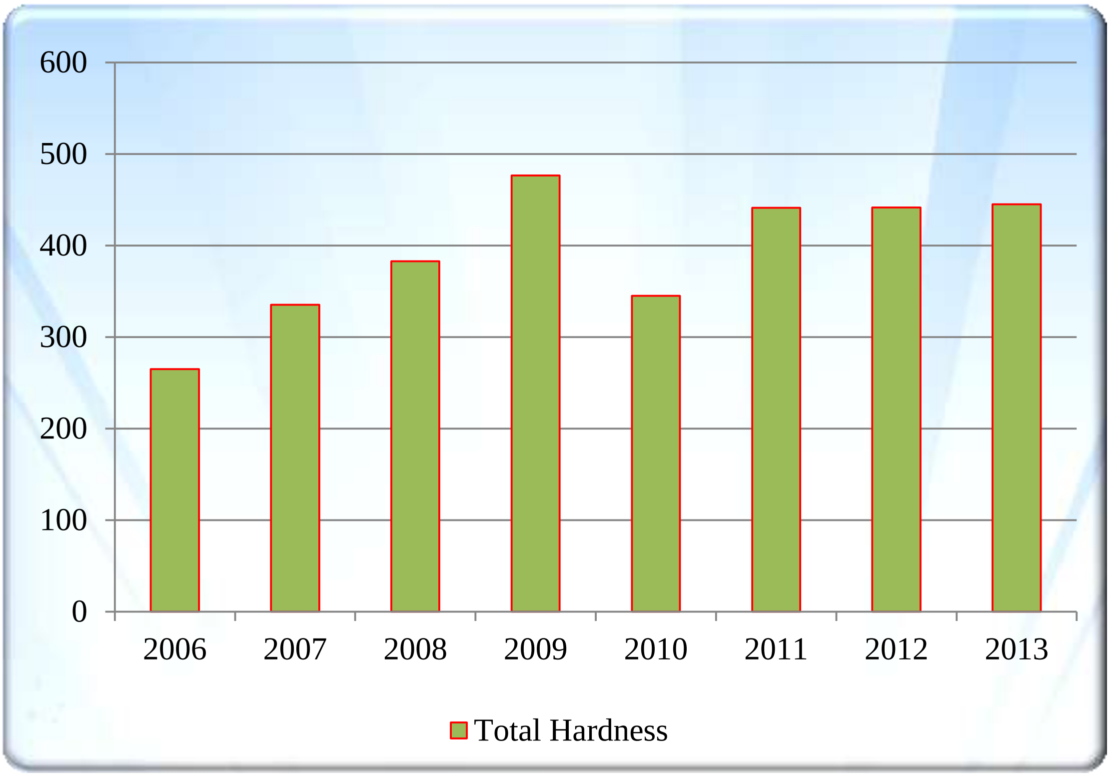


Figure 3.17: Variation of Total Hardness in lake water (2006-2013)

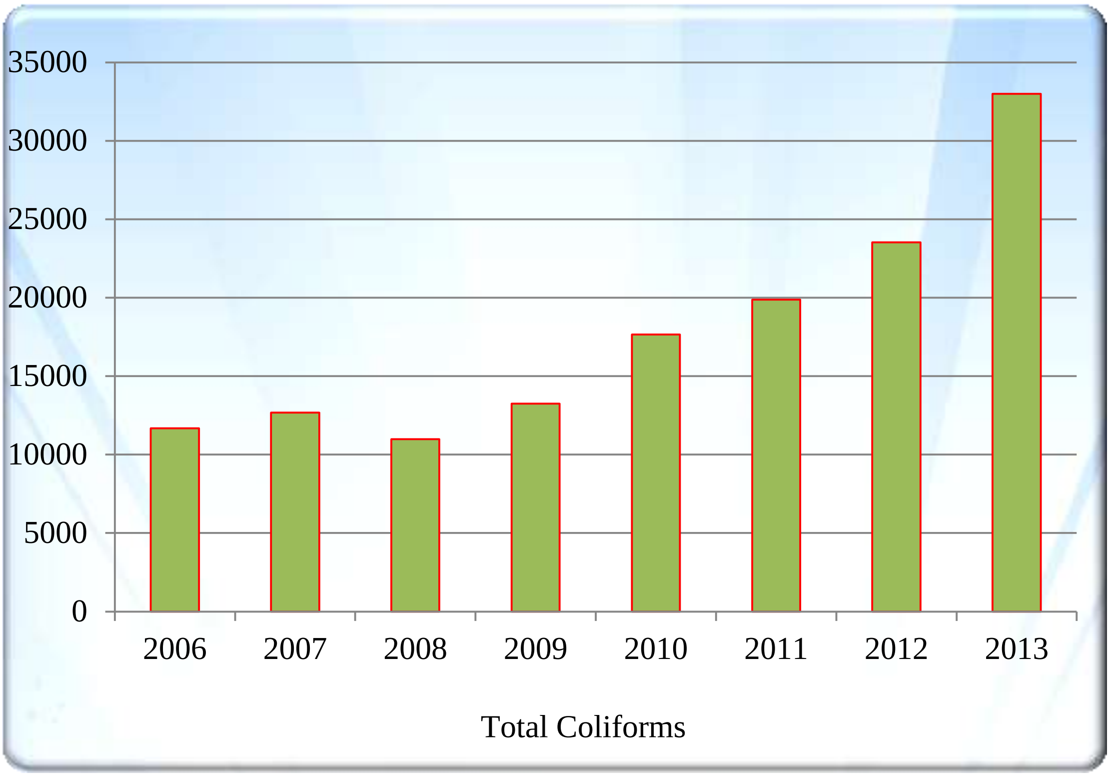


Figure 3.18: Variation of Total Coliforms in lake water (2006-2013)

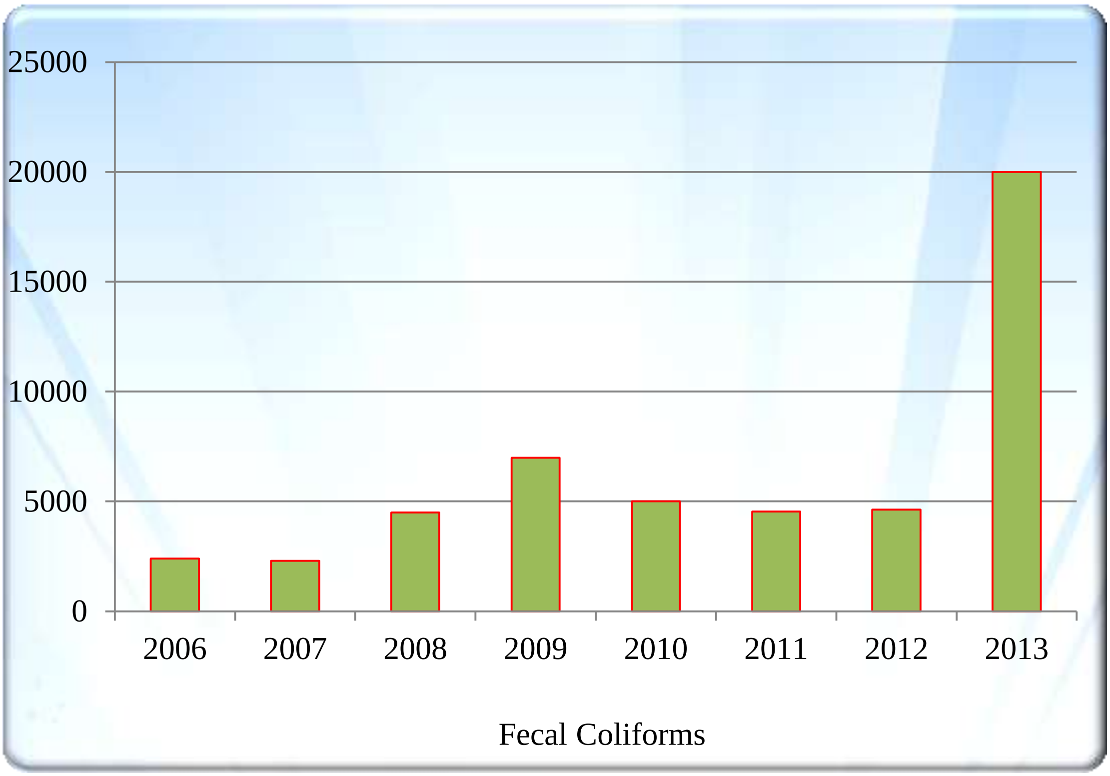


Figure 3.19: Variation of Fecal Coliforms in lake water (2006-2013)

(iv) The fisheries of Anasagar Lake are sold in market. These are used for public consumption.

(v) Water quality parameters for stormwater samples collected and tested in monsoon period of year 2013 are shown in Table 3.3. Frequent flooding takes place due to blockage of municipal and stormwater drains and the polluted water comes out on roads (Photo 3.24).

Photo 3.24: Flooding in Vaishali Nagar Due to Blockage of Stormwater Drains

Photo 3.25: Khanpura Pond and Surrounding Cultivated Area

(Source: www.google earth)

3.3 Threats Arising from Outside Lake Drainage Basin

3.3.1 Activities Related to Transport of Airborne Pollutants to Lake

(i) Various small scale industries such as brick manufacturing units, marble cutting units and mining activities (stone crushers) near Anasagar Lake could be a source of pollutants into atmosphere.

(ii) Petrol/ diesel driven motor boats are used in Anasagar Lake for recreational purpose. These are operated by Nagar Nigam, Ajmer.

(iii) Table 3.4 shows that annual population growth of Ajmer city is 2.05 percent. This shows that population of Ajmer city is increasing at an alarming rate (Figure 3.1). Rapid growth of population together with increased economic activities favours growth of motor vehicles. There has been more than two fold increment in number of registered motor vehicles in major cities of Rajasthan (India) including Ajmer from 2001 to 2011. It shows that number of vehicles per person have increased (Khan S., 2014). It could be related to increased air pollution due to rise in traffic volume (Cox, 2003). Severe air pollution levels and high population densities are more associated in developing countries in Asia (Bingheng and Haidong, 2008).

(iv) A variety of pesticides are used by farmers for agriculture in the basin of Anasagar Lake.

3.3.2 Issues Related to Climate

(i) The climate of Ajmer city is semi-arid with dry and hot summer and cool winter. The average temperature in the summers ranges from 25°C (min.) to 47°C (max.) and from 3°C (min.) to 22°C (max.) in winters (De *et al.,* 2005). The atmospheric pressure varies from 575mm-736mm of Mercury. The prevailing wind velocity ranges between 7 km/hr and 20 km/hr.

(ii) Dead fish in Anasagar Lake could be seen in summers and sometimes in winters also.

(iii) Study of data of rainfall show that rainfall in Ajmer city was near to or above average (500 mm) for a major part of past 24 years (Table 3.12).

(iv) The annual evaporation losses are as high as 3.25 m over Rajasthan. During summer, Rajasthan and parts of central India register a sharp increase in evaporation rates. Though Rajasthan fall under the belt of high evaporation in winter months too, the magnitude of increase in rate of evaporation during summer months is quite high (Central Water Commission, 2006). Photo 3.26 shows the dried Anasagar Lake in year 2004.

Using empirical formula E = 4.57 T + 43.3, given by U.S. Geological Survey and mean annual temperature as 25.13°C, the calculated value of annual evaporation losses for Ajmer city is 1.59 m.

Photo 3.26: The Dried Anasagar Lake in Year 2004

(Source: www.google earth)

3.4 Environmental cum Social Survey

As a part of environmental cum social survey, interactions with 400 number of persons (sample size) were carried out. In calculating the value of sample size, the population of Ajmer city is considered as 7.20 Lacs (2021). The values of confidence level and margin of error are used as 95 and 5 percent for this purpose (Fox *et al.*, 2009; Krejcie and Morgan, 1970).

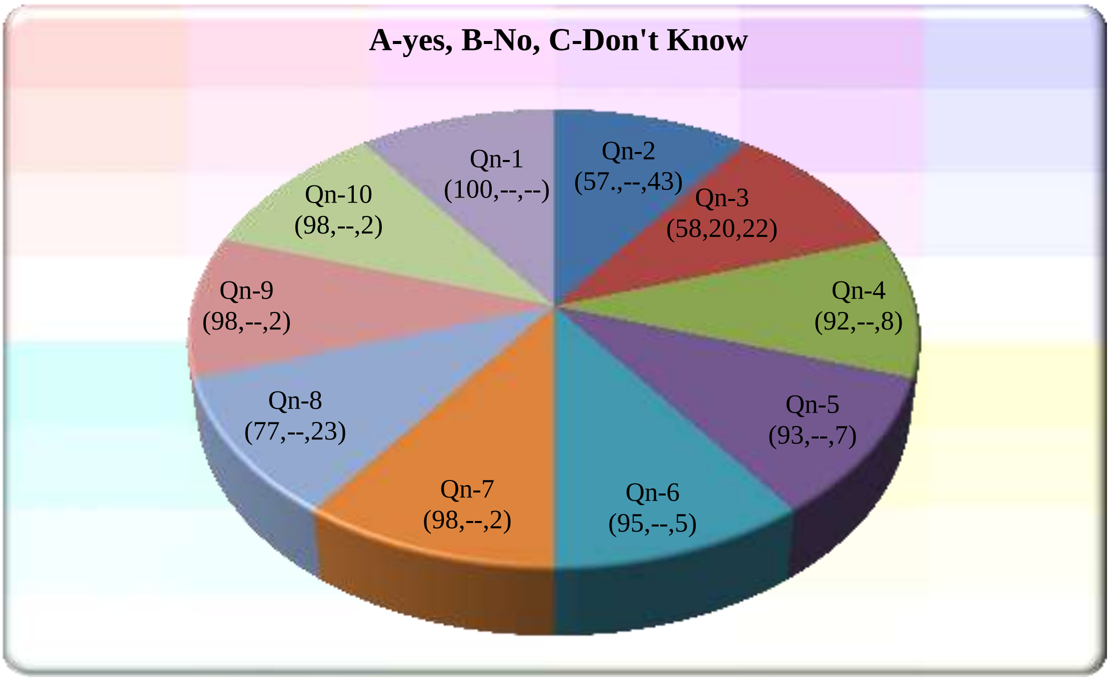
Three study groups were formed in order to understand overall environmental status of Anasagar Lake, which are:

1. Public representatives at Ajmer
2. Officials of executive agencies related to Anasagar lake, Ajmer
3. Residents of Ajmer city

These study groups were formed in order to know about:

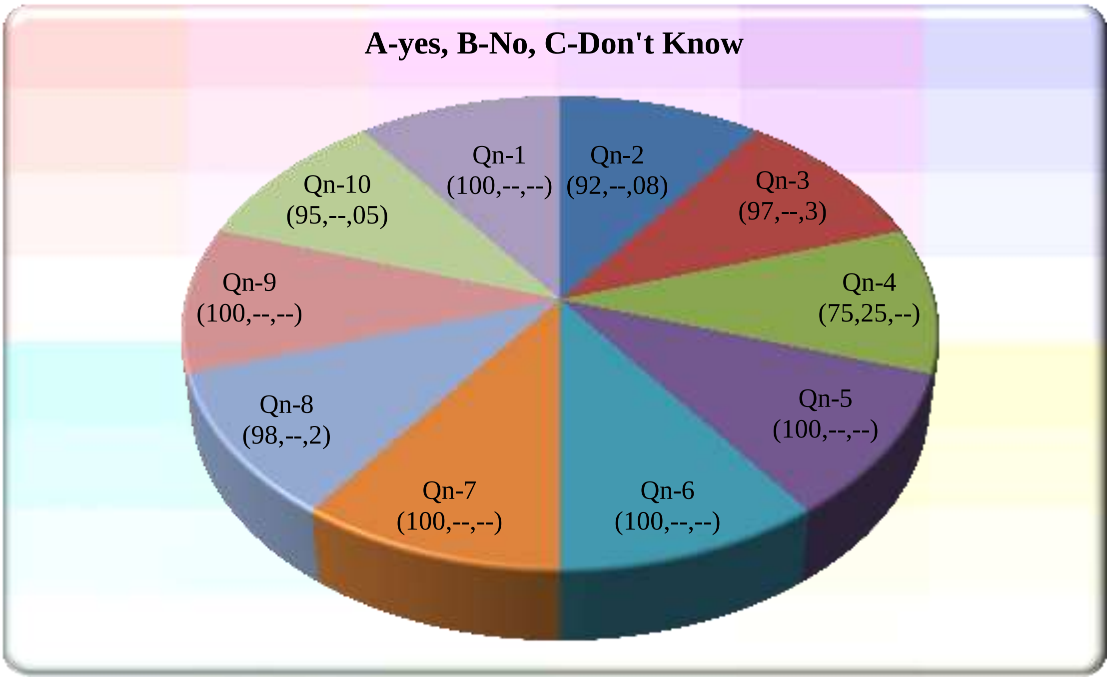
1. The present status of policies and environmental laws related to Anasagar Lake
2. Causes of degradation of environment of Anasagar Lake
3. Views of residents of Ajmer city regarding lake degradation and its impact.

For this purpose questionnaires were prepared accordingly and information gathered is shown here. Symbols A, B and C denote yes, no and don’t know respectively.



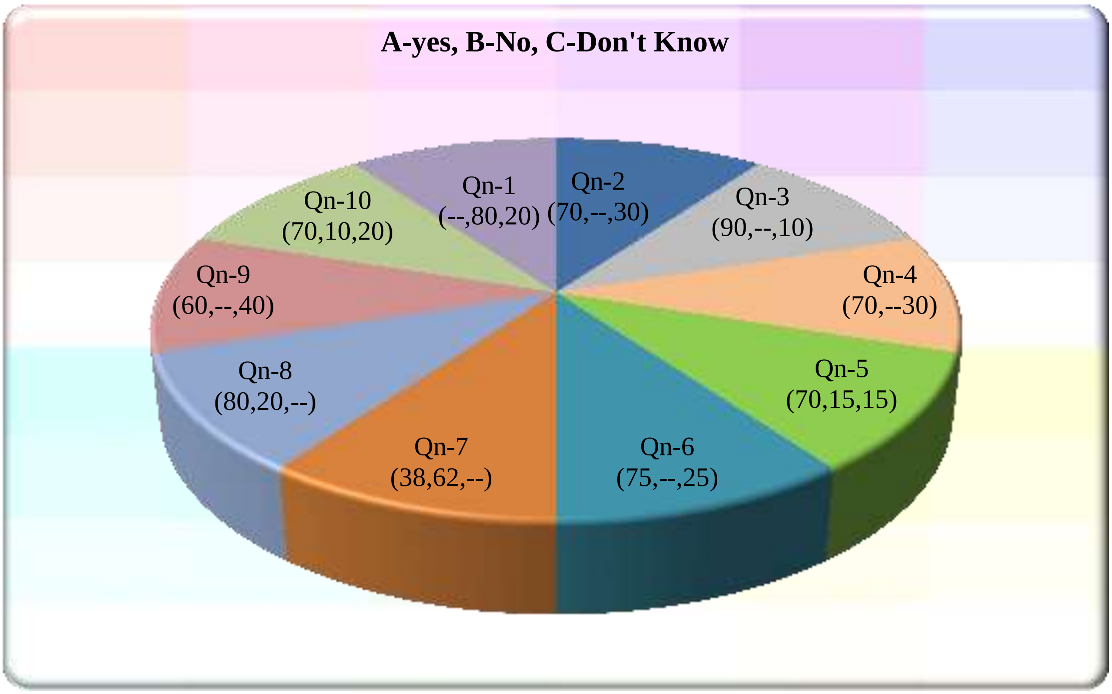
Group I: Public representatives at Ajmer
(Sample size 84)

S.No	Questions	%		
		A	B	C
1	Anasagar Lake is a degraded water body today. Do you agree?	100	--	--
2	Pesticides are being used in nearby agricultural fields around Anasagar Lake. Should it be stopped?	57	--	43
3	Do you think that the solid waste collection system of Ajmer should be improved?	58	20	22
4	Should the shoreline of the lake be well protected?	92	--	8
5	Proper law enforcement and policy implementation are needed to save the lake. Do you agree?	93	--	7
6	The construction and encroachment activities have increased in lake catchment and the land under vegetation is decreasing day by day. Do you think strict laws are needed against it?	95	--	5
7	Do you agree that a team of politicians, engineers, doctors, scientists, officials of government organizations attached with Anasagar Lake and local residents should be formed to monitor the lake environment regularly?	98	--	2
8	Public participation and mass awareness programmes could be helpful in lake sustainability. Do you agree?	77	--	23
9	If the lake is properly developed for tourism, it can be a source of revenue generation. It would help to raise funds for lake maintenance programmes. Do you agree?	98	--	2
10	Strong political will is need of the time to protect and sustain Anasagar Lake. Do you agree?	98	--	2



Group II: Officials of executive agencies related to Anasagar Lake, Ajmer
(Sample size 40)

S.No	Questions	%		
		A	B	C
1	Do you agree that Anasagar Lake is polluted primarily due to entry of municipal waste water and sewage?	100	--	--
2	Do you suggest that bathing and washing activities in lake should be stopped immediately?	92	--	08
3	Pesticidal contamination of lake water may affect the aquatic life adversely. Do you agree?	97	--	3
4	Do you think that the solid waste collection system in Ajmer should be improved?	75	25	--
5	Do you agree that increasing human induced activities along lake shoreline should be controlled?	100	--	--
6	Do you think that local administration should take strong actions to control construction and agricultural activities in lake area?	100	--	--
7	Do you agree that a team of politicians, engineers, doctors, scientists, officials of government organizations attached with Anasagar Lake and local residents should be formed to monitor the lake environment regularly?	100	--	--
8	Public participation and mass awareness programmes could be helpful in lake sustainability. Do you agree?	98	--	2
9	Do you agree that sufficient funding is required to maintain and sustain Anasagar Lake?	100	--	--
10	Do you agree that proper management of lake catchment may reduce the problem of siltation in lake?	95	--	05



Group III: Residents of Ajmer city
(Sample size 276)

S.No	Questions	%		
		A	B	C
1	Can we use the lake water for drinking?	--	80	20
2	Do you know that pesticides are being used in nearby agricultural fields?	70	--	30
3	Do you feel bad smell around the lake in summers?	90	--	10
4	Should the shoreline of the lake be well protected?	70	--	30
5	Does the waste water and sewage from surrounding area reach Anasagar Lake finally?	70	15	15
6	Do you think that the depth and area of lake has reduced with time?	75	--	25
7	Are you satisfied with the formal solid waste collection system by Nagar Nigam in Ajmer city?	38	62	--
8	Fish death is frequent in Anasagar Lake. Is it true?	80	20	--
9	Do you feel that construction and encroachment activities have increased with time in lake catchment?	60	--	40
10	Do you agree that the land under vegetation in lake catchment is decreasing day by day?	70	10	20

The views of majority of public representatives reveal that lack of proper policies and strict laws and paucity of funds have resulted Anasagar Lake into a polluted water body with degraded lake catchment. Funds can be generated by properly developing the lake for tourism. Public participation and mass awareness programmes should be promoted.

Majority of officials of executive agencies related to Anasagar Lake suggest that increased human induced activities have degraded the lake environment. Proper enforcement of environmental laws and rules and regulations is required. Financial assistance is necessary to maintain and sustain the lake. Regular monitoring of lake environment is required. Public participation and mass awareness programmes could be helpful to sustain the lake.

The views of majority of residents of Ajmer city reveal that Anasagar Lake is no more a fresh water body due to entry of waste water, sewage and pesticides into the lake. Increased human activities are responsible for deterioration of water quality and degradation of lake catchment. The lake shoreline should be well protected and the solid waste collection system of Ajmer city needs to be improved.

Next chapter deals with the analysis of various issues and activities related to socio-economic and environmental factors discussed in this chapter.

CHAPTER-4
ANALYSIS

4.1 Socio-Economic Factors

4.1.1 Impact of Using Lake as a Resource

(i) Study and analysis of water quality parameters of Anasagar Lake have been discussed below (Table 3.1). It clearly shows that the lake water is severely polluted.

The colour of lake water was found towards higher side and ranged from15.68 hazen to 30.80 hazen (BIS: 10500, 2012). It indicates that lake water is polluted. A variety of dissolved organic substances originating from anthropogenic sources can contribute to water coloration (Borgerding and Hites, 1994).

The pH values of lake water were found towards higher side and ranged from 8.4 to 8.75, indicating the water as alkaline (BIS: 10500, 2012). The high values may be attributed to sewage input in Anasagar Lake. pH is an important parameter for aquatic life growth (Chisty, 2002). According to Umavathi *et al.* (2007), pH in range of 5 to 8.5 is best for aquatic life growth but harmful when more than 8.8. High pH indicates increased photosynthesis by a large quantity of algae causing removal of carbon dioxide.

The conductivity of lake water varied between 1397 µmho/cm and 2804.5 µmho/cm which is too high (WHO, 1993). It could be due to runoff passing over rocks and carrying input of sewage, fertilizers, pesticides and minerals.

The turbidity of lake water ranged from 4.73 NTU to 5.35 NTU which is high (BIS: 10500, 2012). Sources of turbidity are erosion from catchment area and algal growth. Turbidity may lead to problems associated with increased water temperature.

Elevated values of total dissolved solids (TDS) were observed that varied from 858.3 mg/l to 1610.1mg/l (BIS: 10500, 2012). The total suspended solids (TSS) were found within the prescribed limits and varied from 19.61 mg/l to 25.37 mg/l (EC, 1989). Water with high total dissolved solids may induce an unfavourable physiological response (Basheer *et al.*, 1996).

The chloride content varied from 238.07 mg/l to 531.5 mg/l for lake water. These were found towards higher side (BIS: 10500, 2012). The most important source of chloride is discharge of domestic sewage, hence the concentration of chloride serve as an indicator of sewage pollution.

Dissolved oxygen (DO) is regarded as one of the best indicators to evaluate the health of a water body (Edmondson, 1961). It varied from 5.73 mg/l to 6.95 mg/l in lake water. Lower values of dissolved oxygen in summer months may be due to higher rate of decomposition of organic matter, limited inflow of water and low oxygen holding environment due to high temperature.

Biochemical oxygen demand (BOD) of lake water ranged from 4.72 mg/l to 12.37 mg/l, which is high (CPCB, 2012). The entry of municipal waste water, sewage, industrial effluents and the agricultural runoff might be responsible for the increased levels of biochemical oxygen demand (Kaur *et al.*, 1996). Increased biochemical oxygen demand values during summer may be due to higher microbial activities (Thomas and Abdul, 2000).

The chemical oxygen demand (COD) of lake water varied from 33.73 mg/l to 87.31 mg/l that was too high (WHO, 2008). Table 3.1 shows that BOD/ COD ratio in this study is less than 0.3, showing that the organics in waste water may be refractory and toxic (Khaled and Hammam, 2014).

Total organic carbon (TOC) is a measure of dissolved and particulate organic carbon in water. It varied from 7.36 mg/l to 13.12 mg/l in lake water showing elevated values (WHO, 2008). The sources of total organic carbon are humic substances, partly degraded plant and animal materials.

The sulphates in lake water varied from 55.25 mg/l to 126.8 mg/l. The values fall within the acceptable limit but towards higher side (BIS: 10500, 2012). Sulphates in lake water may find way from numerous minerals, industrial waste and through atmospheric deposition.

The fluoride values in lake water were observed varying from 1.05 mg/l to 1.23 mg/l, which were towards higher side (WHO, 2008). Sources of fluorides are dental products, processed beverages and foods, pesticides, tea drinks, fluorinated drugs and teflon pans entering into the lake through waste water and municipal solid waste.

Nitrates fluctuated between 9.41 mg/l and 15.74 mg/l for lake water, well below the prescribed levels (BIS: 10500, 2012). Nitrites in lake water varied from 0.378 mg/l to 0.953 mg/l and were found below the prescribed levels (EPA, 2011). Presence of nitrates and nitrites in lake water show pollution by organic waste and domestic sewage (Umavathi *et al.,* 2007). It shows the eutrophic state of lake (Sultan *et al.,* 2003).

Phosphorous is a vital nutrient and a limiting factor in preservation of lake fertility. It ranged from 0.2202 mg/l to 0.4755 mg/l in lake water showing higher concentrations (WHO, 2008). The phosphate levels for lake water varied from 0.3565 mg/l to 0.6852 mg/l, well below the permissible value (WHO, 2008). Washing and bathing activities on banks of Anasagar Lake could be a source phosphorous input. Use of fertilizers such as super phosphate and di-ammonium phosphate in agricultural activities may be the major sources phosphates and phosphorous in Anasagar Lake. These are used by farmers of Ajmer (Bhatt, 2006).

The oil and grease concentrations in lake water varied from 1.112 mg/l to 6.115 mg/l, higher than the prescribed level (BIS: 10500, 2012). Sources of oil and grease in lake water are mainly anthropogenic. Waste water from residential colonies, hotels and restaurants and automobile garages around Anasagar Lake could be the prime source of oil and grease in lake water. Use of motor boats in Anasagar Lake for recreation could be a source too.

Free carbon dioxide in lake water was found as 18.9 mg/l in winters. It could not be detected in summer and monsoon period, probably due to high alkalinity. Fish death in Anasagar Lake in winters may be correlated to high carbon dioxide content. Concentrations of carbon dioxide above 20 mg/l may cause death of sensitive species in lakes. Free carbon dioxide in excess of 20 mg/l may be injurious to fish in normal fresh water, but when the dissolved oxygen content drops to 3 to 5 mg/l, lower free carbon dioxide concentrations may also be detrimental (Gupta *et al*., 2013).

The transparency of lake water ranged from 0.157 m to 0.184 m, indicating productive nature and severe eutrophic condition of Anasagar Lake (O.E.C.D., 1982).

Total alkalinity of lake water ranged from 430.5 mg/l to 605.8 mg/l. The values are quite higher than the acceptable values and near to permissible values (BIS: 10500, 1992). Lake water containing total alkalinity as 40 mg/l or more is considered as more productive (Moyle, 2011). The high value of alkalinity indicates the presence of weak and strong bases such as carbonates, bicarbonates and hydroxides in the water body (Jain *et al.*, 1997).

The phenol concentration was found as 0.0062 mg/l in winters and was almost absent in summers and monsoon, probably due to phenol evaporation and dilution of lake water. It was higher than the prescribed levels (BIS: 10500, 2012). The sources of phenol in lake water are plastics and disinfectants used in household cleaning and consumer products such as gargles, mouthwashes and throat sprays etc. Release of phenol into air occurs from automobile exhaust, cigarette smoke and wood burning. It may be transported to lake water through atmosphere.

Total hardness of lake water ranged from 326.3 mg/l to 550.5 mg/l. These values are quite higher than the acceptable value and near to permissible value (BIS: 10500, 2012). These high values in lake water may be due to the addition of calcium and magnesium salts alongwith runoff.

Total coliforms in lake water varied from 20950.5 MPN/100 ml to 27571.7 MPN/100 ml while the fecal coliforms varied from 3817.3 MPN/100 ml to 5532.9 MPN/100 ml, indicating severe fecal pollution due to inflow of sewage in Anasagar Lake coming from areas around.

Total chlorophyll in lake water ranged between 280.65 mg/l and 462.31 mg/l. These values are too high indicating the eutrophic and nutrient rich condition of lake (VRAP, 2008). The concentration of chlorophyll in lake water gives an estimation of concentration of algae and other water plants. Existence of green algae in Anasagar Lake could be correlated to it. The major factor affecting the algal growth in aquatic ecosystem is nutrient enhancement, mainly due to rise in phosphate and nitrate concentrations.

(ii) The waste water generated from agricultural practices reaches the lake. It adds to lake water pollution. Recreational activities and fishing may further pollute the lake water and degrade the lake environment.

(iii) Table 3.2 shows the increasing deterioration of lake water quality with time. Table 3.3 shows that stormwater gets polluted as it travels into stormwater drains due to entry of untreated waste water from surrounding areas. This stormwater finally reaches to Anasagar Lake.

4.1.2 Impact of Activities Related to Limited Public Awareness and Understanding

(i) Washing and bathing activities at lake banks add soap and detergents and thus increase phosphorus into the lake (Sharma *et al.*, 2009). These activities may result into water coloration accompanied by increased levels of pH, turbidity, biochemical oxygen demand, chemical oxygen demand, fluorides, total hardness, total chlorophyll and total suspended solids and reduced levels of dissolved oxygen and transparency. Increased plant growth and hence eutrophication could be related to washing and bathing activities.

(ii) Immersion of idols increases the input of chemicals, heavy metals and organic content in lake water (Manisha D. *et al.*, 2014). Religious rituals and feeding to fish in lake increase the organic matter. Higher values of biochemical oxygen demand, chemical oxygen demand and reduced dissolved oxygen in lake water could be related to these activities.

(iii) Increased values of biochemical oxygen demand, chemical oxygen demand, total organic carbon and reduced dissolved oxygen in lake water could be related to presence of solid waste thrown by public/tourists/vendors in Anasagar Lake.

(iv) The population of city is increasing at an alarming rate. It may adversely affect the lake sustainability directly or indirectly due to increased anthropogenic activities in and around lake area and hence increased lake use.

4.1.3 Impact of Insufficient Governance

(i) Process of acquisition of land beneath lake water by state government and providing land to legal claimants at suitable places is under process (*Ref:* Judgement of Rajasthan High Court 1536/2003). Due to delay in execution of orders, human induced activities are continuously increasing in lake area.

(ii) Illegal constructions and encroachments in lake basin and forest area are continuously on increase. It could be a reason of reduction of land under vegetation and increased area under human settlement (Table 3.5). Rajasthan High Court (India) has banned illegal constructions in catchment area of Anasagar Lake and has issued directions to remove encroachments in Anasagar Lake zone (*Ref*: Case No. CW- 883, 2015).

(iii) Organochlorine pesticides such as Heptachlor, Dichloro-diphenyl-trichloro-ethane (DDT), Dichloro-diphenyl-dichloro-ethylene (DDE), Dichloro-diphenyl-dichloro-ethane (DDD) and Aldrin are being used by farmers of Ajmer, though these are banned for agricultural use in India (Pesticides/ formulations banned in India, 2014). These pesticides may reach Anasagar Lake with rain runoff or through air and increase pollution.

(iv) Idol immersion and feeding to fish are frequently visible in Anasagar Lake, though warning signals are displayed by local administration around the lake. These activities degrade the water quality of lake.

(v) Lack of control over fishing may result into decline of fish variety.

4.2 Threats Arising from Within Lake Drainage Basin

4.2.1 Impact of Issues and Activities Related to Excessive Nutrient and Mineral Load

(i) Table 3.6 shows that municipal solid waste of Ajmer is nutrient rich. Table 3.7 shows the presence of nutrients in lake catchment soil which are continuously increasing with time. Conductivity values of lake catchment soil shows that the soil is mineral rich.

Municipal solid waste and lake catchment soil may add organic matter to lake sediment (Table 3.6 and 3.8). Organic matter is a storehouse of nutrients. When organic matter decomposes, these nutrients are released to plants in the form the plants can absorb (McCauley, 2009). Hence, entry of municipal solid waste and lake catchment soil into lake due to soil erosion may increase the nutrients level in lake sediment as shown in Table 3.8.

Because Ajmer belt is a storehouse of mineral deposits, the soil erosion of geological matrix in lake catchment may increase the mineral level in lake water. Municipal solid waste and lake catchment soil may increase the pH of lake water (Table 3.1, 3.6 and 3.7).

(ii) Use of fertilizers like Super Phosphate (SP) and Di-Ammonium Phosphate (DAP) by farmers of Ajmer may increase the phosphorous level in lake water. In Rajasthan, the consumption of chemical fertilizers per hectare varies from 2.16 kg to 399.90 kg, towards higher side (*Source*: Department of Agriculture, Ajmer).

(iii) The bathing and washing activities at lake banks may be a source of presence of phosphorous in lake water due to use of soap and detergents.

4.2.2 Impact of Activities Related to Contamination of Water and Sediment from Toxic and Hazardous Substances

(i) Table 3.9 shows that the lake water is contaminated with organochlorine pesticides residues. Figures 3.2-3.7 clearly show that contamination due to pesticides in lake water is highest in rainy season, could be due to increased addition of pesticides in lake water with runoff. BIS: 13891(1994) suggests that pesticides should be absent in lake water for fish culture.

Farmers use about 6000 tonnes of pesticides in agricultural practices every year in India (Mohan and Gujar, 2003). Personal interviews with cultivators and pesticide shopkeepers reveal that about 95 percent of farmers in Ajmer use synthetic pesticides (Charan *et al.*, 2010).

(ii) Table 3.10 shows that the lake water is contaminated with heavy metals. Iron, cadmium and lead were found above the prescribed concentration levels while zinc, copper and nickel were within the limits. Chromium was found well below the detectable limit (WHO, 2008). Tolerance limits of heavy metals for fish culture as suggested by BIS: 13891(1994) are shown in Table 3.10. It shows that levels of heavy metals in lake water exceed the tolerance limit except for nickel and chromium.

(iii) The entry of municipal solid waste could be a source of hazardous substances in Anasagar Lake. The sources of hazardous substances are dry cleaners, automobile repair shops, hospitals, photo processing and electroplating units etc.

4.2.3 Impact of Issues and Activities Related to Increased Erosion and Sedimentation

(i) Steep slopes (>45 degree) of hillocks in lake catchment of Anasagar Lake could be a reason of increased soil erosion and sedimentation due to increased velocity of rain runoff.

(ii) Continuous reduction in vegetation cover and increase in human settlement in lake catchment favour soil erosion and sedimentation (Table 3.5). Lack of vegetation cover favours different types of soil erosion (Ramezanpour and Smaelnejad, 2008). Moderately eroded soil structure in lake catchment could be due to well drained and gently sloping earth surface, favouring soil erosion. Since a major part of soil content in lake catchment is sand and silt, it can easily be eroded (Table 3.11).

(iii) As shown in Table 3.7, medium values of sodium absorption ratio (10-18) were observed (BIS: 11624, 1986). These values of sodium absorption ratio favour increased soil erosion (Shahrivar *et al.,* 2012). Aggregate stability is an important physical property that influences soil erosion. Presence of increased amount of sodium adversely affects the aggregate stability. Sodium ions cause more erosion associated with loamy soil (Giglao *et al.*, 2014).

(iv) Table 3.12 shows that the rainfall received in Ajmer city was near to or above average for a major part of past 24 years. Reduction in pesticidal concentrations due to dilution in monsoon period could be related to it (Table 3.9). Heavy rainfall may intensify the erosion and sedimentation (Sharma *et al.*, 2009). Increased soil erosion could be related to it (Henry, 2015). Desilting operation and formation of small island in lake made up of lake sediment could be related to adequate rainfall in Ajmer and hence significant sedimentation (Table 3.12).

(v) Deteriorated and poorly maintained stormwater drains could be a source of increased soil erosion and sedimentation in Anasagar Lake.

4.2.4 Impact of Accumulation of Litter and Garbage

(i) A huge amount of municipal solid waste is generated in Ajmer city every day. Due to inadequate municipal solid waste management and collection system it reaches the lake directly or indirectly.

(ii) Frequent flooding due to blockage of municipal and stormwater drains results into spread of municipal solid waste over large areas. Blocking of drains may prevent and divert runoff reaching the lake (UNEP, 2003).

4.2.5 Impact of Activities Related to Loss of Natural, Aesthetic and Scenic Beauty of Lake

(i) Anasagar Lake is facing the adverse impacts of uncontrolled construction activities that have degraded the natural beauty of lake and landscape (UNEP, 2003). Continuous reduction in land area under vegetation cover with increased area under settlement could be correlated to it (Table 3.5).

(ii) The aesthetic and scenic beauty of lake is adversely affected due to floating of municipal solid waste on lake surface. The littered solid waste around the lake banks further deteriorates the situation.

(iii) Table 3.1 shows that the lake water quality is severely deteriorated due to input of waste water. The greenish colour of water shows the excess growth of microcystis algae due to addition of sewage (Bhalla *et. al*, 2006). Anasagar Lake has been found to be rich of algae comprising of 123 species belonging to 60 genera. Species such as *Achnanthes hungarica*, *Ankistrodesmus falcatus*, *Chlorella vulgaris*, *Chlorococcum infusionum*, *Pandorina morum*, *Pediastrum tetras*, *Scenedesmus quadricauda* and *Stigeoclonium tenue* are found in Anasagar Lake (Sharma and Sharma, 1992).

Eruption of foul gases and floating of dead fish could be related to polluted lake water. These activities diminish the scenic and aesthetic beauty of lake.

(iv) Disappearance of migratory birds to Anasagar Lake could be due to degraded lake habitat resulting into loss of scenic beauty.

4.2.6 Impact of Issues and Activities Related to Loss of Aquatic Biodiversity and Habitat

(i) Fish death in summers in Anasagar Lake could be due to increased bacterial activities decomposing organic content and low oxygen holding environment resulting into dissolved oxygen depletion. Table 3.1 shows that free carbon dioxide in lake water in winters is 18.9 mg/l, that is towards higher side. Reduced photosynthesis in winters may increase free carbon dioxide resulting into increased lake acidity. Increased acidity of lake water due to increase in free carbon dioxide in winters could be a reason of fish death (Gupta *et al*., 2013). Lime is added to Anasagar Lake when there is fish death in winters. Table 3.9 and 3.10 show that lake water is contaminated with toxic and hazardous substances. It could be related to fish death (Mathur *et al.,* 2013). Illegal and over-fishing could be reasons of depletion of commercial fisheries like Common Corp, Silver Corp, Grass Corp, Katla, Tiger and Rohu in Anasagar Lake (Richard, 2003; UNEP, 2003; Deutscher, 2004).

(ii) Eutrophication in Anasagar Lake could be related to reduction in density of rooted macrophytes (*Trapa bispinosa).* It may alter their composition also (Pandey *et al.,* 2012). Input of nitrogen and phosphorous in fresh water lakes enhance algal growth and that may cause suppression or disappearance of macrophytes.

(iii) Since last few years only a small number of birds including local hens and black ducks can be seen and Siberian ducks and flamingos have totally disappeared in Anasagar Lake, though there is a good amount of water in lake (Gaur, 2014). Disappearance of migratory birds in Anasagar Lake could be related to deteriorated lake water quality and lake environment that have resulted into degradation of lake habitat for birds (Nalawade *et al*., 2008).

(iv) The frontage of Anasagar Lake near shoreline area has undergone decline in diversity of trees (*Phllanthus emblica*, *Syzgium cumini*, *Ficus bengalensis*, *Acacia tortilis* and *Magnifera indica*), shrubs (*Calotropis procera* and *Ziziphus mauritiana*), herbs (*Acacia arabica*, *Citrus limon* and *Datura innoxcia*) and grasses (*Saccarum munja* and *Lasiurus hirsutus*). It could be due to uncontrolled and increased human pressure in lake frontage as shown in Table 3.5 (Mathur *et al.,* 2010).The lakeshore flora provides shelter, food and habitat for birds and aquatic life (EPA, 2010).

4.2.7 Impact of Issues and Activities Related to Health Risks

(i) The analysis of water quality parameters shown in Table 3.13 reveals that:

(a) Increased values of pH and conductivity restrict the use of lake water for irrigation.

(b) The lake water is not suitable for recreational use due to high values of pH, biochemical oxygen demand, turbidity and total coliforms.

(c) Increased values of pH, biochemical oxygen demand and conductivity restrict the use of lake water for propagation of fisheries.

(ii) Higher values of water quality parameters such as colour (15.68-30.80 hazen), pH (8.4-8.75), conductivity (1397-2804.5 µmho/cm), turbidity (4.73-5.35 NTU), total dissolved solids (858.3-1610.1mg/l), chlorides (238.07-531.5 mg/l), biochemical oxygen demand (4.72-12.37 mg/l), chemical oxygen demand (33.73-87.31 mg/l), total organic carbon (7.36-13.12 mg/l), fluorides (1.05-1.23 mg/l), phosphorous (0.2202-0.4755 mg/l), oil and grease (1.112-6.115 mg/l), total alkalinity (430.5-605.8 mg/l), phenol (0.0062 mg/l), total hardness (326.3-550.5 mg/l), total coliforms (20950.5-27571.7 MPN/100 ml) and fecal coliforms (3817.3-5532.9 MPN/100 ml) together with reduced values of dissolved oxygen (5.73-6.95 mg/l) and transparency (0.157-0.184 m) indicate that the water of Anasagar Lake is severely polluted (Table 3.1). Values of sulphates (55.25-126.8 mg/l) and free carbon dioxide (18.9 mg/l), towards higher side favour the lake water pollution. Figures 3.9-3.19 show that water pollution of Anasagar Lake is increasing with time.

Table 3.9 show the higher concentrations of various organo-chlorine pesticides such as Heptachlor (0.0334 mg/l), β.HCH (0.2297 mg/l), pp-DDD (0.0241 mg/l), pp-DDE (0.0226 mg/l), pp-DDT (0.0402 mg/l) and Aldrin (0.0168 mg/l) in lake water (WHO,2004). This shows that the lake water is contaminated with pesticides.

Table 3.10 shows that the concentrations of iron (0.744 mg/l), cadmium (0.077 mg/l) and lead (0.142 mg/l) exceed the prescribed levels in lake water (WHO, 2008). It shows that concentrations of iron (0.744 mg/l), zinc (1.102 mg/l), cadmium (0.077 mg/l), lead (0.142 mg/l) and copper (0.072 mg/l) exceed the tolerance limit required for fish culture (BIS: 13891, 1994). This shows that the lake water is contaminated with heavy metals.

(iii) As the lake water is severely polluted and contaminated and unfit for fisheries propagation, probability of health problems due to consumption of fish cannot be denied (Novoton and Dvorska, 2004; Manisha D. *et al.*, 2014). Consumption of fish of severely polluted and contaminated water of Anasagar Lake may adversely affect the health.

(iv) Table 3.3 shows that stormwater gets polluted as it travels into the stormwater drains due to entry of untreated waste water from surrounding areas. Hence, flooding of these stormwater drains may develop unhygienic conditions.

4.3 Threats Arising from Outside Lake Drainage Basin

4.3.1 Impact of Activities Related to Transport of Airborne Pollutants to Lake

(i) The brick industries emit toxic fumes with high concentrations of carbon monoxide and oxides of sulphur and nitrogen. About 28.8 percent of oxides of sulphur and 8.8 percent of oxides of nitrogen in atmosphere are because of emissions from brick industries (Menon and Shahanas, 2011). Marble dust from marble industries could be a source of calcium carbonate, clay, sand and silt into atmosphere (Rani, 2011). Stone crushers give rise to dust emissions in air. Emissions from marble industries and mining activities may add minerals to lake water.

Use of petrol/ diesel driven motor boats in Anasagar Lake could be a source of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), oxides of nitrogen (NOx), non-methane volatile organic compounds (NMVOCs), sulphur dioxide (SO_2) and oil and grease in lake water (Paul J. *et al.*, 1998). The emissions from motor boats may enter into lake water and increase pollution.

The air pollutants from vehicular emissions could be a source of increased water pollution in Anasagar Lake. About 55.8 percent of oxides of sulphur and 54.5 percent of oxides of nitrogen in atmosphere are because of vehicular emissions (Menon and Shahanas, 2011). Increase in number of vehicles in Ajmer city could be related to it (Khan, 2014). The oxides of sulphur and nitrogen emitted from vehicular traffic and brick industries may get transported by air and deposited on surface of lake water. Atmospheric nitrate and sulphate deposition may increase the lake water acidity (UNEP, 2003). This is toxic to fish and other aquatic life (Simonin and Kretser, 1997). Nitrogen and sulphur compounds can change the water chemistry of lake (Radford, 2006).

Levels of oxides of sulphur and nitrogen varied from 4-6 µg/m3 and 20-40 µg/m3 in air of Ajmer city in year 2013. The air pollution in Ajmer city was found from moderate to heavy range (Sharma, 2016).

The atmosphere could be a source of transporting pollutants to Anasagar Lake emitted from industrial activities and vehicular traffic. Higher values of sulphates (55.25-126.8 mg/l), conductivity (1397-2804.5 µmho/cm), oil and grease (1.112-6.115 mg/l) and phenol (0.0062 mg/l) and presence of nitrates (9.41-15.74 mg/l), nitrites (0.378-0.953 mg/l) and free carbon dioxide (18.9 mg/l) in lake water could be related to it (Table 3.1).

(ii) Pesticides are used by farmers of Ajmer in agricultural practices. These may be transported to Anasagar Lake by air and contaminate it (Sandra and Luca, 2006; Mathur *et al.*, 2012). Presence of pesticides and heavy metals in lake water could be related to it (Table 3.9 and 3.10).

4.3.2 Impact of Issues Related to Climate

(i) Bacterial activities increase in summers decomposing organic content. This reduces dissolved oxygen required for aquatic life. Similarly, sudden increase in free carbon dioxide may increase the acidity of lake water in winters. Free carbon dioxide exceeding 20 mg/l is injurious to fish in normal fresh water. At reduced levels of dissolved oxygen (3-5 mg/l), lower free carbon dioxide concentrations may also be detrimental (Gupta *et al*., 2013). Free carbon dioxide in lake water was found as 18.9 mg/l in winters, which is towards higher side (Table 3.1).The climatic conditions of Ajmer city could be the reasons of fish death in Anasagar Lake in summers and winters (Michael and Christian, 2014).

(ii) Table 3.9 shows that pesticidal concentrations in lake water increased in summer period. It could be due to heavy evaporation losses in Ajmer city, resulting into increased pesticidal concentrations. The calculated value of annual evaporation losses for Ajmer city is 1.59 m. High temperature and wind velocity together with reduced barometric pressure at water surface could be related to heavy evaporation losses. Extreme temperatures may result into disappearance of lakes (Vincent, 2009).

(iii) Heavy rainfall may intensify erosion and sedimentation (Sharma *et al.,* 2009; Henry, 2015). Formation of small island in lake made up of lake sediment could be related to sufficient rainfall in Ajmer and hence significant sedimentation (Sharma *et al.,* 2009). Dilution may cause reduction in pesticidal concentrations (Table 3.9).

Table 3.1 shows that levels of various water quality parameters such as colour (30.80 hazen), pH (8.64), conductivity (2687.6 µmho/cm), turbidity (4.77 NTU), total suspended solids (25.37 mg/l) , total dissolved solids (1610.1mg/l), chlorides (531.5 mg/l), biochemical oxygen demand (7.44 mg/l), chemical oxygen demand (50.60 mg/l), total organic carbon (9.495 mg/l), sulphates (106.3 mg/l), fluorides (1.23 mg/l), nitrates (15.74 mg/l), nitrites (0.9533 mg/l), phosphorous (0.4755 mg/l), phosphates (0.6852 mg/l), oil and grease (6.115 mg/l), total alkalinity (538.32 mg/l), total hardness (447.3 mg/l), total coliforms (27571.7 MPN/100 ml), fecal coliforms (5532.9 MPN/100 ml) and total chlorophyll (462.31mg/l) increased in summers. It could be due to heavy evaporation losses. It worsens the lake water quality in summers. Reduced transparency (0.163 m) in summers could be related to it. Lake Anasagar reduced to a small area in year 2004 (Photo 3.26). Heavy evaporation losses and less rainfall could be related to it (Table 3.12).

The outcome of study and analysis of various socio-economic and environmental factors related to Anasagar Lake and required adaptive management for lake sustainability are discussed in next chapter.

CHAPTER-5
DISCUSSION

5.1 Discussion

The outcome of study and analysis of various socio-economic and environmental factors related to Anasagar Lake has been discussed below.

(i) Use of Anasagar Lake as a resource has made the lake severely polluted and eutrophied. Huge volume of untreated waste water entering into Anasagar Lake could be a source of severe water pollution and eutrophication (Kennedy and Zwerling, 1975; Nair and Unni, 1993; Vijayvergia, 2009; Khan, 2015; Chandrasekhar *et al*., 2003; Sisodia *et al.*, 2004; Parashivamurthy, 2015). This waste water originates from a combination of domestic, industrial, commercial, agricultural and recreational activities and sewage. Entry of a part of municipal solid waste into lake has further increased the pollution level.

Higher values of water quality parameters such as colour (15.68-30.80 hazen), pH (8.4-8.75), conductivity (1397-2804.5 µmho/cm), turbidity (4.73-5.35 NTU), total dissolved solids (858.3-1610.1 mg/l), chlorides (238.07-531.5 mg/l), biochemical oxygen demand (4.72-12.37 mg/l), chemical oxygen demand (33.73-87.31 mg/l), total organic carbon (7.36-13.12 mg/l), fluorides (1.05-1.23 mg/l), phosphorous (0.2202-0.4755 mg/l), oil and grease (1.112-6.115 mg/l), total alkalinity (430.5-605.8 mg/l), phenol (0.0062 mg/l), total hardness (326.3-550.5 mg/l), total coliforms (20950.5-27571.7 MPN/100 ml) and fecal coliforms (3817.3-5532.9 MPN/100 ml) together with reduced values of dissolved oxygen (5.73-6.95 mg/l) and transparency (0.157-0.184 m) indicate that water of Anasagar Lake is severely polluted (Table 3.1). Values of sulphates (55.25-126.8 mg/l) and free carbon dioxide (18.9 mg/l), towards higher side add to lake water pollution.

(ii) Washing and bathing activities at lake banks, immersion of idols, religious rituals, feeding of fish and disposal of solid waste in lake add to deterioration of lake water quality. Input of phosphorous, chemicals, heavy metals and organic content in lake water could be related to these activities (Table 3.1 and 3.10).

(iii) Due to insufficient governance there is a lack of administrative control on part of local administration in proper enforcement of rules and regulations and environmental laws. It has resulted into increased unsustainable human induced activities in lake catchment and even in lake area (Table 3.5). These activities are continuously on increase with time and have resulted into shrinkage of lake area, degradation of lake catchment, increased lake water pollution and loss of aquatic life. The lake area has reduced to 1.87 sq km in year 2013 which was 1.89 sq km in year 2000 (Table 3.5). Encroachments, illegal constructions and degradation of lake catchment may result in diversion of runoff reaching the lake.

(iv) Entry of municipal solid waste into lake, soil erosion, use of fertilizers by farmers in lake catchment and bathing and washing activities at lake banks have increased nutrient and mineral load in lake (Table 3.6, 3.7 and 3.8). It results into increased eutrophication and thus reduced transparency. Increased levels of total chlorophyll, turbidity, total suspended soilds and conductivity in lake water could be related to it. Absence of free carbon dioxide in summers could be related to increased eutrophication in lake water (Table 3.1). Addition and decay of organic matter could result into increased levels of biochemical and chemical oxygen demand and total organic carbon with reduced level of dissolved oxygen. Both social impacts and economic losses are important that make eutrophication control necessary (Leng, 2009; Vollenweider, 1968).

(v) Pesticides residues and heavy metals (iron, cadmium and lead) are in higher concentration in water of Anasagar Lake (Table 3.9 and 3.10). Presence of toxic and hazardous substances in Anasagar Lake could be due to use of organochlorine pesticides in agricultural practices, entry of municipal solid waste, inflow of waste water generated from cloth washing of medical establishments at the lake banks, idol production units and small scale industries in lake catchment alongwith erosion of metal enriched rocks in lake catchment (Mathur *et al.*, 2010).

The organochlorine pesticides and heavy metals may adversely affect the neuro-physiological, behavioural and reproductive systems of aquatic life in lakes. The enzyme and hormone disrupting capabilities of pesticides and heavy metals may contribute to decline of fish of water bodies (Mathur *et al.*, 2013). These pollutants adversely affect brain, spinal cord, nervous system, skin, eyes, kidney and lungs of humans and aquatic life (Jim B. *et al.*, 2010). It could be related to frequent fish death in Anasagar Lake. This hazardous waste poses substantial or potential threat to public health and environment (*Source*: US EPA, Resources conservation and recovery act)

(vi) Magnified human induced activities around Anasagar Lake have severely degraded the catchment area, thus increasing the soil erosion (Table 3.5). Various features such as steep slopes of catchment (>45 degree), catchment soil with sand and silt as a major part with medium values of sodium absorption ratio, deteriorated stormwater drains and adequate rainfall favour increased soil erosion (Table 1.1, 3.11, 3.7, 3.12). This soil erosion has resulted into increased sedimentation thus reducing the lake depth. Reduction of lake depth from 6.7 m to 4.4 m in last fifty years indicates heavy sedimentation in Anasagar Lake. The study shows that entry of municipal solid waste may increase siltation in lake as it contains silt and debris

(30.44 %) as major parts. Reduction in fish biodiversity and degraded water quality could be related to heavy sedimentation in Anasagar Lake (UNEP, 2006).

(vii) Inadequate municipal solid waste management and collection system, open municipal and stormwater drains and unprotected and mismanaged lake shoreline could be major reasons of entry of municipal solid waste into Anasagar Lake (Photo 3.4, 3.5, 3.17, 3.18, 3.19, 3.20, 3.21 and 3.22).

(viii) Increased anthropogenic activities and uncontrolled land use change pattern in lake catchment, inadequate municipal solid waste management and collection system and deteriorated lake water quality have diminished natural, aesthetic and scenic beauty of Anasagar Lake (Photo 3.10 and 3.23).

(ix) Increased anthropogenic activities in and around Anasagar Lake and deteriorated lake water quality have degraded the lake environment. It has resulted into depletion of commercial fisheries (Common Corp, Silver Corp, Grass Corp, Katla, Tiger and Rohu), reduction in density of macrophytes (*Trapa bispinosa),* disappearance of migratory birds (Siberian ducks and flamingos) and decline in diversity of trees (*Phllanthus emblica*, *Syzgium cumini*, *Ficus bengalensis*, *Acacia tortilis* and *Magnifera indica*), shrubs (*Calotropis procera* and *Ziziphus mauritiana*), herbs (*Acacia arabica*, *Citrus limon* and *Datura innoxcia*) and grasses (*Saccarum munja* and *Lasiurus hirsutus*).

(x) Untreated waste water entering into lake from surrounding area has severely deteriorated the lake water quality (Table 3.1). The waste water has polluted the stormwater also (Table 3.3). Flooding of stormwater drains may create unhygienic conditions. Input of toxic and hazardous substances into lake from catchment has worsened the situation (Table 3.9, 3.10). These activities have restricted the lake use for irrigation, recreation and propagation of fisheries (Table 3.13). Lake use for these purposes could be a source of health hazard.

(xi) Emissions from brick manufacturing units, marble cutting units, mining activities (stone crushers), petrol/ diesel driven motor boats and vehicular traffic may get transported to lake by air and deteriorate the lake water quality. Pesticides and heavy metals from lake catchment may be transported to Anasagar Lake by air.

(xii) The climatic conditions of Ajmer city (extremes of temperature in summer and winter, heavy evaporation losses and sufficient rainfall in monsoon) have direct impact on fish life and quality and quantity of water in Anasagar Lake.

Fish death in summer and winter, increased erosion and sedimentation and higher concentrations of pesticides and lake water quality parameters in summer could be related to it.

The discussions reveal that various issues and activities related to socio-economic and environmental factors have resulted into severe water pollution and degradation of catchment of Anasagar Lake, thus adversely affecting the lake sustainability. These issues and activities have restricted any direct or indirect use of Anasagar Lake.

5.2 Adaptive Management to Sustain Anasagar Lake

Strong adaptive management framework is needed to construct Anasagar Lake a self-sustaining aquatic ecosystem capable of supporting biodiversity, performing ecosystem functioning and providing ecosystem services to society. The techniques related to adaptive management are discussed below.

- Establishment of sewage treatment plant (STP) to treat waste water and sewage from lake catchment is necessary to limit the pollution as these are the prime sources of pollution in Anasagar Lake (Nair and Unni, 1993;

Chandrasekhar et al., 2003; Sisodia *et al.*, 2004; Vijayvergia and Tiagi, 2007; Thomas *et al.*, 2011; Parashivamurthy, 2015). It would reduce external input of phosphorus to lake water and control eutrophication (Tippa *et al.*, 2007). The waste water should be collected at the sewage treatment plant through closed conduits and given adequate treatment so as to conform to prescribed standards. The waste water after treatment may be diverted to the lake, with proper quality monitoring of the effluent.

- Bathing and washing activities, religious rituals, idol immersion and feeding to fish in lake should be strictly prohibited. Use of idols made of natural biodegradable materials instead of organic pollutant materials should be promoted (Manisha D. *et al.*, 2014). It is suggested that small ponds are made for these activities which are isolated from the main water body. Proper management and protection of shoreline around the lake is essential to reduce the waste thrown by the pubic/tourists/vendors into the lake (EPA, 2010).
- The land beneath lake area still lies with private owners used for unsustainable agricultural practices, cloth washing and running small scale industries. Speedy measures should be taken to acquire this private owned land by local administration.
- Strict enforcement of rules and regulations and environmental laws is necessary to control human induced activities like illegal constructions, encroachments, use of organochlorine pesticides in agricultural practices and illegal fishing responsible for degradation of lake environment (Richard, 2003; Khan, 2015; Mansee *et al.*, 2011; Chidammodzi and Muhandiki, 2015; Cookey *et al.*, 2016). Control over human induced activities in lake catchment would also help maximum runoff reaching the lake.

- The farmers should be promoted to practice organic farming and use organic pesticides and fertilizers. It would reduce entry of toxic and hazardous substances and nutrient load in lake (William *et al.*, 1988). Applications of manure and chemical fertilizers increase nutrient input in catchment soil (Bennet *et al.*, 2001). It releases nutrients into receiving lake for decades even after external nutrient additions are reduced or discontinued (Schindler and Smith, 2009). Waste from small scale industries should be treated as per guidelines established by pollution control authorities.
- The lake is suffering from heavy siltation resulting from soil erosion. Afforestation, construction of check dams at appropriate locations, appropriate maintenance of storm water drains and control over increasing anthropogenic activities in lake catchment would help in reducing siltation, lake pollution and eurtophication (Thouk and Nuov, 1996).
- The sediment of Anasagar Lake is rich in nutrients (N and P). Periodic deweeding and desilting in lake at regular interval is suggested to reduce the eutrophication level and the sediments collected may be utilized as fertilizers in agricultural fields (Peterson, 1981; Vijayvergia and Tiagi, 2007). In 1987, a part of removed sediment from Anasagar Lake was used in agricultural fields by the farmers. The crop yield of these fields was noted to be considerably high as compared to nearby fields not using the sediment (Sharma *et al.*, 2009). Sediment removal increases the storage capacity of a lake. It helps to reduce phosphorus recycling and save the lake from anoxic state at the bottom (Reddy and Char, 2006). Sediment removal had been a common practice in maintenance of lakes and ponds in India (Pandey, 2000).

- The study shows that illegal constructions in basin of Anasagar Lake and encroachment in forest area have resulted into reduction of land under vegetation. Reduction in vegetation cover causes increase in the loss of nutrients of lake catchment soil (Solim and Wanganeo, 2008). Vegetation in the lake watershed act as soil binder and trap for nutrients. Afforestation of native species of trees, shrubs and herbs would improve the commercial, social and ecological usefulness of lake catchment. It would help in reducing soil erosion and hence sedimentation and entry of nutrients in Anasagar Lake. Micro catchments around saplings and V-ditches can be used to harvest rainwater to conserve soil and improve growth of plants in degraded catchment of Anasagar Lake (Singh *et al.,* 2012). Harvesting of rainwater in lake catchment can enhance the biomass growth by 24-71 percent (Singh, 2012). Rainwater harvesting enhance soil water content, nutrients, vegetation cover and plant growth.
- Macrophytes (*Trapa Bispinosa*) restoration is necessary in Anasagar Lake as reduction in macrophytes promotes algal growth (Qiu *et al.,* 2001). This technique has been used in China in reducing the nutrient loading and controlling algal bloom in freshwater lakes (Qin, 2009). Periodic harvesting of macrophytes is necessary to take out large amounts of nutrients incorporated in macrophytes (Vijayvergia and Tiagi, 2007). This also reduces the chances of water body re-pollution due to decomposition.
- The lake is eutrophic with low dissolved oxygen; hence mechanical aerators are suggested to be used as an immediate measure of aeration to improve the water quality of lake (Ashley, 1988; Prepas *et al.,* 1990; Vijayvergia and Tiagi, 2007). Cascade aerators may also be used for this purpose as these are

most widely used. (Thakrey and Hedaoo, 2000).

- Integrated solid waste collection, treatment and disposal system needs to be developed in Ajmer city. It is suggested that safe collection and disposal of hazardous waste needs to be taken into account (Mir, 2011; Kripa *et al.*, 2012; Tapas *et al.*, 2014).
- Proper canalization and lining of stormwater drains is suggested to make maximum runoff reach the lake and reduce water losses and siltation. Covering and regular cleaning of storm water drains would help in reducing municipal solid waste reaching the lake and frequent flooding due to blockage of drains.
- Use of motor boats in lake should be prohibited being a source of oil and grease, free carbon dioxide and heavy metals in lake water (Lashari *et al.*, 2012). Manually, paddle and battery operated boats could be the alternate.
- In order to ensure the continuous functioning of Anasagar Lake, recovery of the cost of services such as waste water treatment, municipal solid waste and lake basin management is essential. The money so recovered can be used for the proper functioning and maintenance of these systems (Pandey, 2001). A lake beautification plan is suggested to be developed that include development of thematic gardens, amusement parks, path ways and other features that will increase the beauty of the lake area and generate revenue.
- An institution is suggested to be formed comprising of experts from different fields with essential facilities. These experts may be selected from local bodies on temporary or permanent basis. This institution is recommended to operate and monitor environmental education and awareness programmes for local

population to enhance their knowledge regarding sustainable use of lakes (Ghosh, 2003; Maembe, 2004; Mir, 2011). It would promote the participation of local population in measures towards lake sustainability (Kenji *et al*., 2012; NCEIA, 2004; Nagendra, 2016; Kennedy *et al.*, 1975).

- Regular monitoring and assessment of major lake components such as catchment area, water quality and social aspects is essential to keep a continuous watch over environmental health of Anasagar Lake (Protection and Management of Urban Lakes in India, 2010). It should be specifically designed to cover physical, chemical, biological and hydrological features of Anasagar Lake. It is a continuous process and the institution formed of experts from different fields and equipped with all facilities could be given this responsibility. It can be undertaken by individuals, governmental agencies, non-governmental organizations, corporations and academic institutions (UNEP, 2003).
- The existing Indian Environmental Legislation about lake pollution control need certain enhancement. A comprehensive and an integrated law on environmental protection of lakes for meaningful enforcement is needed. It is not enough to enact the legislations. Environment studies along with laws shall be made a compulsory subject at school and college levels so that there should be general growth of awareness. It is imperatively necessary to give more powers to the executive agencies to enforce the environmental laws effectively. Environment Courts may be set up for speedy disposal of the cases ensuring uniformity of standards all over the country. A long-term planning must be undertaken by the Central and State Governments to protect and improve the environment laws to keep up and sustain the lakes.

CHAPTER-6

CONCLUSION

6.1 Conclusions

Following conclusions can be drawn from the present study:

(i) The literature reviews show that unsustainable agricultural practices, increased deforestation and soil erosion, industrial activities, unrestrained dumping of waste and uncontrolled land use change pattern arising from urbanization have adversely affected the sustainability of lakes all over the world and have degraded the lake environment.

(ii) Study, analysis and discussion of socio-economic and environmental factors and the environmental cum social survey related to Anasagar Lake reveal that increased anthropogenic pressure in lake catchment as a result of urbanization have severely degraded the lake environment and adversely affected the lake sustainability. The lake has been transformed into a polluted and contaminated water body and any direct or indirect use of lake has been restricted. The lake catchment has undergone severe degradation and the lake has almost lost its natural, aesthetic and scenic beauty.

It is suggested that proper management of waste water and solid waste, vegetation restoration and rainwater harvesting in the lake catchment, periodic sediment removal from lake, macrophyte restoration in lake, efficient governance and strict enforcement of rules and regulations, revenue generation for lake management systems and environmental education and awareness programmes for local population could be the measures to sustain Anasagar Lake.

6.2 Future Scope of Work

In the light of conclusions drawn from this study, following suggestions are made for future research work in this area:

(i) Remote Sensing and Geographical Information Systems (GIS) can be used to provide a data bank of catchment of Anasagar Lake for rapid and large scale understanding of change and in developing management strategies. The study shows that Anasagar Lake is severely eutrophied. Hence a continuous monitoring and analysis of lake eutrophication can be carried out using Remote Sensing and Geographical Information Systems as eutrophication and increase in productivity are associated with change in optical properties of the water mass. It would enable to capture and update all water quality parameters and plan, compare, visualise and evaluate the outcome resulting from simulating various management scenarios.

(ii) Sewage treatment plant (STP) to treat waste water may start functioning in near future, allowing the treated effluent entering into Anasagar Lake. Hence, analysis of lake pollution can be revised later on and identification of lake use can be ascertained on the basis of treatment cost/ benefit ratio and other aspects considering various lake uses.

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PUBLICATIONS AND INTERNATIONAL CONFERENCES

Following papers have been published/ accepted for publication/ communicated out of this thesis work.

International Journals:

1 Mathur, Y. P., Sharma, G., and Jain, S. K. (2012). "Effects of Pesticides on Hormone and Enzyme Systems of Aqua Population: A View Over Anasagar Lake, Ajmer", Journal of Environmental Science, Toxicology and Food Technology, 1(5), 24-28.

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International Conferences:

1. Mathur, Y. P., Sharma, G., and Jain, S. K. (2012): "Effects of Pesticides on Hormone and Enzyme Systems of Aqua Population: A View Over Anasagar lake, Ajmer": International Conference in Advance Trends in Engineering and Technology (ICATET-2013):19-20 Dec. 2013, Arya old campus, Jaipur (was awarded for best paper presentation**).**

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Certificate

It is certified that:

(i) The thesis has not been submitted in part or full to any other University or Institute for the award of any degree.

(ii) I, **Sunil Kumar Jain, Institute ID 2009RCE105,** have fulfilled the requirements for submission of the thesis.

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Declaration

I, **Mr. Sunil Kumar Jain (ID 2009RCE105)** declare that the work presented in the thesis entitled **"Study of Sustainability of Anasagar Lake, Ajmer "** is my own work. I further declare that:

(i) The work has been done while in candidature for Ph.D. degree at MNIT.

(ii) Where I have consulted the published work of others, the same has been clearly attributed.

(iii) Where I have quoted from the work of others, the source has been given, with the exception of such quotations; this thesis is entirely my own work.

(iv) I have acknowledged all main sources of help.

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Acknowledgement

With great delight, I would like to express my deep sense of gratitude towards my supervisors Dr. Y. P. Mathur and Dr. Gunwant Sharma, Professors, Civil Engineering Department, MNIT, Jaipur. I found their physical presence very strong and transforming on my research and personal fronts. They meticulously designed series of research targets and continuously motivated me in achieving a higher level of excellence. This thesis could not have attained its present form both in content and presentation without their active interest, direction and help.

I extend my deep sense of gratitude to Prof. Udaykumar Yaragatti, Director, MNIT, Jaipur for strengthening the research environment of institute by providing all necessary facilities to research scholars. I am also grateful to Dean Academic Affair's office staff, especially Prof. Ravindra Nagar (Ex. Dean) and Prof. B.L. Swami (Dean), for their cooperation in academic work and help throughout the course of the study. I express my gratitude to members of my doctoral guidance committee Dr. A. K. Vyas, Dr. Y. P. Mathur, Dr. Mahesh Jat and Dr. Sumit Khandelwal, Civil Engineering Department, MNIT, Jaipur for providing valuable suggestions and words of encouragement. I am also thankful to Dr. Gunwant Sharma, Professor and Head of Civil Engineering Department, MNIT, Jaipur who has provided valuable suggestions and keen support during the completion of my research work.

I am especially thankful to officials of various government and non-government organizations at Ajmer for providing field data for this research work. I am also thankful to Mr. Rajesh Saxena, Civil Engineering Department, MNIT, Jaipur for his help during my research work.

I am indebted to the Department of Technical Education, Government of Rajasthan, Jaipur for allowing me to pursue my doctoral study at MNIT, Jaipur. I would also like to express my thanks to Principal and colleagues of Government Polytechnic College, Ajmer for their kind cooperation during period of this work.

I also thank my parents, brother Er. Anil Jain, father-in-law and mother-in-law for their constant support and encouragement in accomplishing this work.

I specially thank my wife Dr. Seema Ajmera, son Akshay and daughter Akshita for their hearty support, patience and loving participation in accomplishing this work, which would not have been possible otherwise.

(Sunil Kumar Jain)

ABSTRACT

The objectives of this thesis were to study and investigate social, economic and environmental factors responsible for degradation of environment of Anasagar Lake, Ajmer and draw conclusions to sustain the lake.

To understand and ascertain the sustainability of Anasagar Lake, study and analysis of various issues and activities associated to lake sustainability were carried out which included use of Anasagar Lake as a resource, limited public awareness and understanding, insufficient governance, excessive nutrient and mineral load, contamination of water and sediment from toxic and hazardous substances, increased erosion and sedimentation, accumulation of litter and garbage, loss of natural, aesthetic and scenic beauty of lake, loss of aquatic biodiversity and habitat, health risks, transport of airborne pollutants to lake and climate.

Relevant data and information related to salient features of Anasagar Lake, inflow to Anasagar lake, water quality parameters of lake and stormwater, demography, land-use information in lake area and catchment, rainfall records, physical and chemical characteristics of municipal solid waste, nutrient levels for lake catchment soil and sediment, stormwater drains, lake shoreline, heavy metal and pesticidal contamination in lake, soil characteristics of lake catchment, flora and fauna and climate were collected and investigated in respect of lake health and present environmental status with the help of pictorial views and graphs.

It was found that municipal solid waste and untreated waste water entering into the lake are the prime causes of lake deterioration. This waste water arises from a combination of domestic, industrial, commercial and agricultural activities, surface runoff and from sewer inflow generated around the lake area. A part of municipal

solid waste finds way to lake directly or indirectly. Data based study and analysis of water quality parameters, land-use change, nutrient levels in lake catchment soil and sediment and pesticidal and heavy metal contamination were carried out to assess continuously increasing disturbances to lake functioning. The lake water was investigated and it was found that most of the water quality parameters of lake were on higher levels as compared to prescribed standards. The stormwater analysis revealed that it gets highly polluted when it enters into the drains reaching lake because of mixing with polluted waste water originating from surrounding area.

The literature reviews revealed that increased human pressures due to urbanization around the lakes have adversely affected the lake sustainability all over the world. Environmental cum social survey disclosed that the environment of Anasagar Lake has undergone severe degradation with time due to inadequate policies and strict laws and lack of their enforcement. The increased anthropogenic pressure has converted Anasagar Lake into a threatened water body of Ajmer city.

The study reveals that treatment of waste water originating from lake surrounding before entering into lake, proper management of catchment area, proper shoreline management and strict implementation of environmental laws would serve as prime measures in order to sustain Anasagar Lake.

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LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
AWWA	American Water Works Association
BIS	Bureau of Indian Standards
BOD	Biochemical Oxygen Demand
CDA	Chilka Development Authority
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
CSE	Centre for Science and Environment
DAP	Di-Ammonium Phosphate
DDD	Dichloro-Diphenyl-Dichloro-Ethane
DDE	Dichloro-Diphenyl-Dichloro-Ethylene
DDT	Dichloro-Diphenyl-Trichloro-Ethane
DO	Dissolved Oxygen
DPR	Detailed Project Report
EC	European Community
EPA	Environmental Protection Agency
HCB	Hexachlorobenzene
HCH	Hexachlorocyclohexane
ICAR	Indian Council of Agricultural Research
IISc	Indian Institute of Science
JDA	Jaipur Development Authority
MSME	Ministry for Micro, Small and Medium Enterprises
MSW	Municipal Solid Waste

NCEIA	Netherlands Commission for Environmental Impact Assessment
NMVOCs	Non-Methane Volatile Organic Compounds
OCPs	Organo-Chlorine Pesticides
OECD	Organisation for Economic Co-operation and Development
PCB	Polychlorinated Biphenyl
PIL	Public Interest Litigations
PVC	Polyvinyl Chloride
SAR	Sodium Adsorption Ratio
SAVE	Society of Appeal for Vanishing Environment
SP	Super Phosphate
STP	Sewage Treatment Plant
SWM	Solid Waste Management
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
VRAP	Volunteer River Assessment Program
WHO	World Health Organisation
WMO	World Meteorological Organization

LOCATION PLAN OF ANASAGAR LAKE AT LOCAL LEVEL

LOCATION PLAN OF ANASAGAR LAKE AT STATE LEVEL