SR-6/97-98

STATUS REPORT ON SAGAR LAKE

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NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN
ROORKEE - 247 667 (UTTARANCHAL)

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ABSTRACT

There are a number of major problems that the lakes, all over the world are facing. The Sagar lake is also, not an exception. Though, geographically the lake is small and situated in the region where normal annual rainfall is more than the national average. The shallower part of the lake generally dries up during summer season. This is due to a very small catchment area contributing insufficient runoff water to the lake. The lack of vegetative cover in the catchment area causes severe problem of sedimentation to the lake. The catchment of the lake is full of built-up areas, building stone quarrying, crop fields etc. As time passed by, inflow from these crops fields and a number of domestic and industrial effluents joining the lake have degraded its water quality to an unusable extent. The yield of fish is also reduced to a great extent as abundance of carnivorous and local minor fishes spoil the fish seed of major Carps. Population residing around the lake is also found suffering from various diseases due to lake-water. In nutshell, it can be said that the domestic use of lake-water has been ceased.

In this report, efforts are made to compile all possible published work on the Sagar lake in one place. This includes brief description of the historological and the geographical background of the lake, details of water quality analysis carried out in various years, present position of the lake and various schemes proposed and implemented for the improvement of pathetic condition of the lake. Further, this report is a first step of N.I.H. Regional Centre Sagar to understand the present conditions of Sagar lake in order to plan and conduct the hydrological studies in future.

A number of analytical studies have been carried out on biological aspect of the Sagar lake. The general observations of these studies show a high trophic status and a high organic pollution level of the Sagar lake. Also, a number of proposals and schemes from various Government agencies have been offered for the renovation of the lake, but due to lack of public awareness as well as scientific approach, the lake is still to get its golden period.

1.0 INTRODUCTION

1.1 General

Lakes are inland depressions containing standing enclosed bodies of water, which are strongly influenced by the local climate. These bodies are essentially transitory in nature and ultimately filled up and disappear. The birth, life and death of the lake is related to certain geological and biological processes. However, the life expectancy of the lake may vary from a short spell between two floods to millions of years. The earth land is dotted with hundreds of thousands of lakes containing over 95% of the earth's fresh liquid water (Scott, 1989). It has been estimated that there are about three million lakes on the earth and more than 70% of the world's fresh surface water in lakes occur on three continents - North America, Africa and Asia. The worldwide distribution pattern for lakes shows a bimodel pattern. The largest percentage of lakes lies between approximately 35°-55° latitude in both the Southern and the Northern hemispheres and between approximately 15° N to 20° S latitude around the Equator (Ryding et al., 1989).

The matter of a precise definition of a lake has received insufficient attention and a unique definition of lake does not exit (Kuusisto, 1985). But, a lake is easy to visualize because it has definite boundaries. Lakes generally, receive water as precipitation on their surfaces, from the surface influences, and from the ground water entering as springs. Nace (1978) called wide places in a river as lakes. But this could be true only for small lakes that are impounded by relatively minor and geologically temporary obstructions across river channels.

Zumberg and Ayers (vide Chow, 1964) define a lake as an inland basin filled or partially filled by a water body whose surface dimensions are sufficiently large to sustain waves capable of producing a barren wave swept shore. F. A. Forel (1990) regarded all bodies of standing water, irrespective of size, as lakes. Jenkins (1958) believed that 10 acres represent the arbitrary point of separation between lakes and ponds, thus water bodies with smaller surface area are ponds and those with greater surface area are lakes. However, the term pond has an universal use. Lake can be defined as large deep body of standing water in which the water is quiet and non-existing plant communities are present, as compared to ponds which are highly vegetated.

As a summary A.K. Bhar (1993), a water body should fill the following requirements to be a lake:

1. It should fill or partially fill a basin or several connected basins.
2. It should have essentially the same water level in all parts with the exception of relatively short occasions caused by wind, thick ice cover, large inflows etc.
3. It should have so small an inflow to volume ratio that considerable portion of suspended sediment is captured.
4. It should have a size exceeding a specified area e.g. 0.01 sq. km. at mean sea level.

Being the valuable natural resource, lakes have always been of great importance to mankind. From the ancient times they have been providing water for domestic purpose. Since long lake water is being used for industrial and irrigation purposes. Lake is, also, one of the means of transport and has always attracted the attention of human beings from the recreational point of view. Besides, it can also play an important role in supplying energy for driving turbines. Some saline lakes are the useful sources of some important minerals as well. In short, a lake is a sort of catalyst in the development of city. But, unfortunately, the popularity of lakes often leads to its deterioration. The increased input of industrial and domestic waste, other sediments and the human activity not only hampers the capacity of the lake but also causes an increase in the productivity of the lake. Which causes the biological and chemical changes in the lake waters leading to hazards like death of fish, obnoxious odours and unsightly conditions. Apart from the traditional uses of lakes, their role as intermediators with the global cycle of carbon dioxide is increasingly being investigated and is gaining immense importance because of the potential threat of global heating caused by "Green house effect" owing to increase in the amount of atmospheric carbon dioxide. Lakes perform this intermediatory role by:

1. Transfer of carbon dioxide between atmosphere and fresh water; that is controlled by chemical, physical and biological processes.
2. By accumulation or depletion of carbon dioxide in the lake.
3. Removal of carbon dioxide from lake-water to sediment.

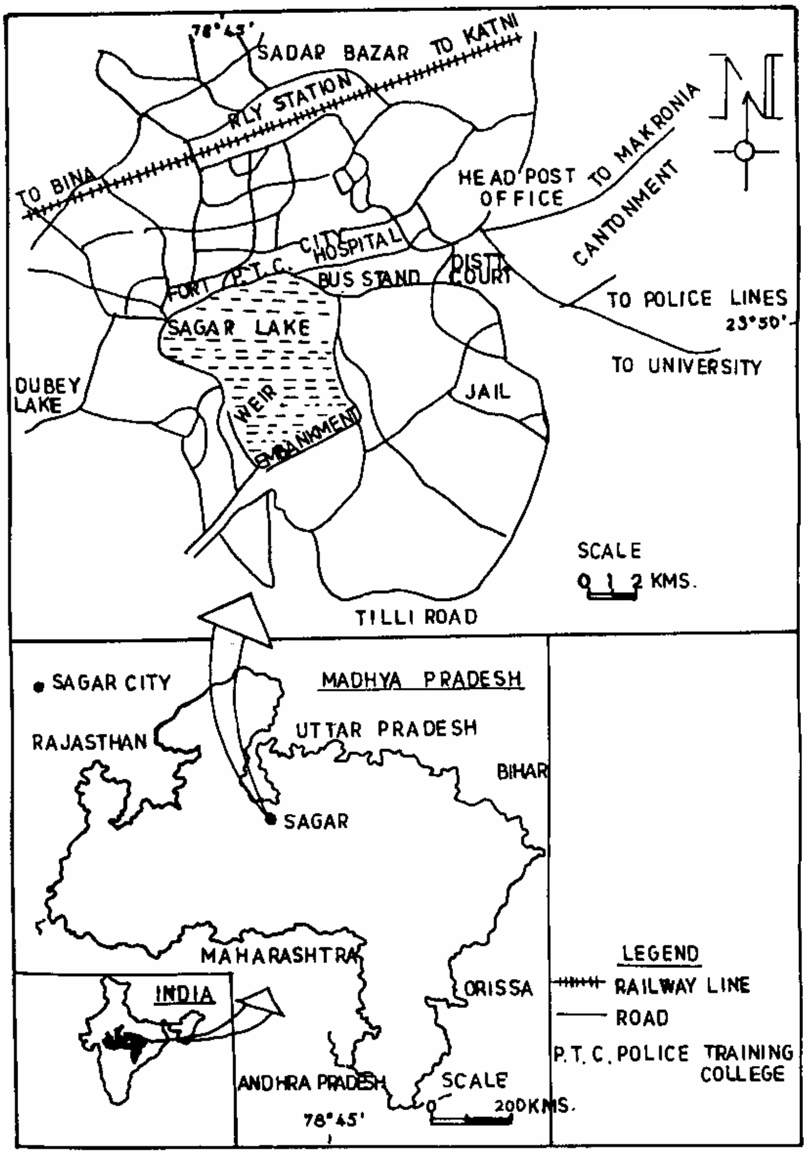
Since each lake is unique (Golterman, 1980) - unless we have the detailed records of the previous conditions and rate of change of a particular lake - it is very difficult to assess the damage caused and to adopt corrective measures.

1.2 Sagar City

Sagar is the main city of district Sagar situated only a few kilometers from North of Tropic of Cancer at an approximate height of 517 m above mean sea level. Sagar city falls between latitude 23° 50' N and longitude 78° 45' E and it can be seen on toposheets No. 55I/13 and 55I/9. Sagar city is easily accessible by highways and railways. It is situated at approximately 75 Km from Bina railway station on Bina-Katni braodgauge section of Central Railway. Bhopal, the capital city of Madhya Pradesh State, is almost 200 Km away from Sagar city.

Sagar is very much known due to Dr. Hari Singh Gour University and the Sagar lake. The university is more than fifty years old and is spreaded on Patheria hillocks in the area of over 830 hectares. This university is still very much famous at national as well as international level. However, the zenith period of this university was said to be between fifties and seventies. The university is about 2 to 3 Km away from the Sagar lake. The Sagar lake is the heart of Sagar City or it will be more appropriate to say that the city came into existence only after the formation of Sagar Lake. The index map of the Sagar lake is presented in fig. 1.1.

Geomorphology, hydrogeology, hydrometeorology, historical as well as water and sediment chemistry and biological aspects along with few other important features of Sagar lake have been discussed in detail in the following sections.



(SOURCE: AGARAWAL,1991)

FIG. 1.1 INDEX MAP OF THE SAGAR LAKE

2.0 GEOMORPHOLOGY

2.1 General

Geomorphology of a lake is associated primarily with the study of the size, shape, surrounding as well as inside features of the lake and the texture of its catchment area. Any lake, as a whole, reflects the geology, geomorphology, biology, climate and hydrology of catchment area. Thus for an expedient results of study of geomorphology of a particular lake, association of geologists, meteorologists, hydrologists and biologists would be of immense importance. Variables influencing lake geomorphology by a varying degree of inter-dependence can-be considered as below:

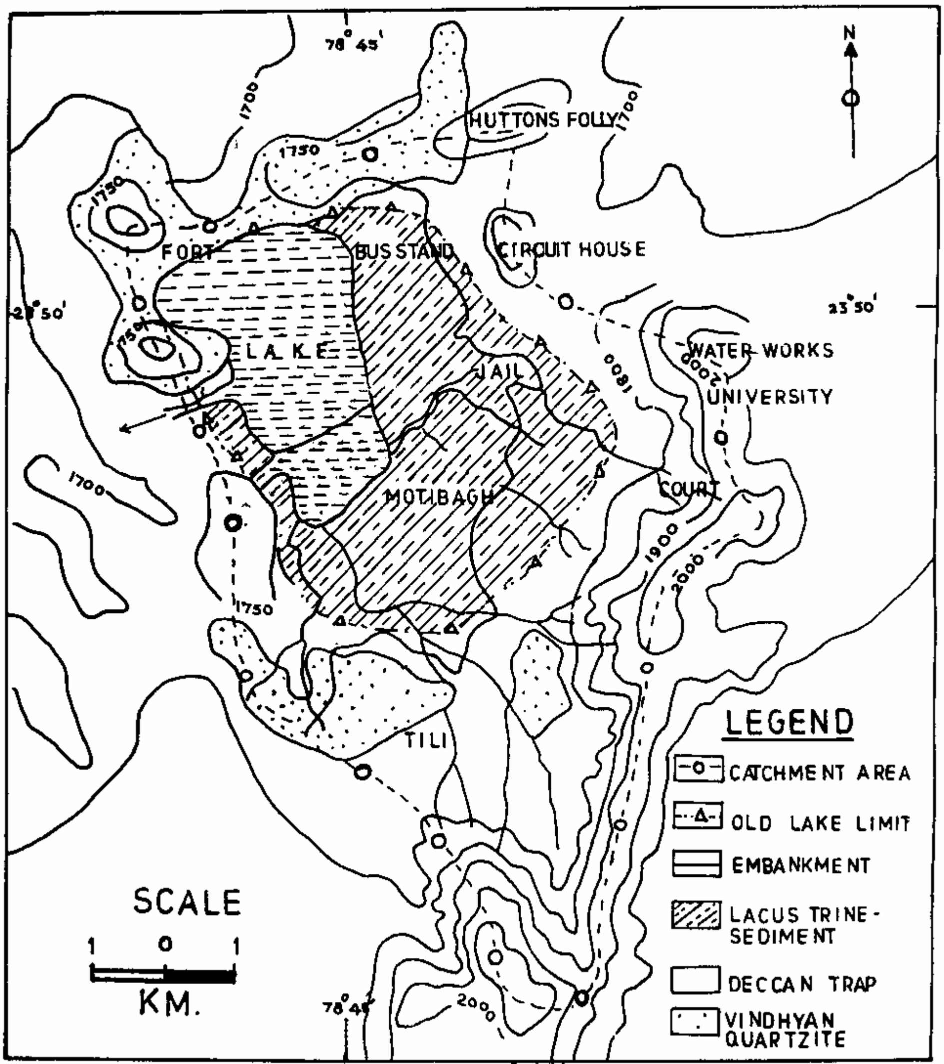
a) Time spans
b) Geology (soil type, lithology, and structure)
c) Valley dimensions (length, width, depth, and slope)
d) Climate (mean precipitation, temperature, humidity, wind speed, and evaporation)
e) Vegetation (type and density)
f) Hydrology (mean discharge of water and sediment)

2.2 Influencing Geomorphological Characteristics

2.2.1 Shape and Size

The shape and depth of lake basins affects the circulation of water within them, and therefore has a particular influence upon the distribution and deposition of fine clay and silt particles. But great size of lake does not necessary imply great depth. In broad shallow lakes, typical offshore condition never develop and wave generation is restricted by bed effects. In general, it is observed that smaller the lake the less significant are the effects of wave action in sediment transport.

The Sagar lake is physically divided into two parts. The main lake, near the bus stand, occupies an area of 68 hectares and the small lake, near Tili Hospital, occupies an area of only 14 hectares. Thus the total water spread area of the entire lake is 82 hectares only. In between the two lakes, a high earthen bund called as Sanjay Drive, is constructed. To facilitate the mixing of water between two lakes, a bridge is partly constructed in the middle of this bund. Geomorphology of the Sagar lake is presented in fig. 2.1.



(SOURCE: AGARWAL, 1991).

FIG. 2.1 GEOMORPHOLOGY OF THE SAGAR LAKE

The lake has shore area periphery of 5230 m with maximum length 1247 m and maximum breadth 1207 m. At full tank level, maximum depth of water in the centre of lake is 5.3 m. The full tank level of the lake is 526.685 m, which is also the top level of gated waste weir 'Mogha' constructed in the western bank of the lake. However, the lake has overall average length and width of 1050 m and 850 m respectively. The overall mean depth of lake is 2.48 m. The volume of water contained in the lake at its full tank level is about 277 Ha-m. The morphometry of the lake is presented in fig. 2.2. Near the periphery, the lake is very shallow which generally, dries up during summer season. In the summer season, the small lake too generally, dries up and then an economical crop called 'Trapa' is extensively cultivated on which about 300 families depend.

2.2.2 Drainage Slope

According to macro physiographic structure of deccan trap, the region lies in Central Highland, which is in north of Narmada-Sone axis. This Central Highland is spread upto Arawali series in west direction and some parts of it is spreaded up to Bihar and Uttar Pradesh in the north-east direction. The Central Highland is a part of Ganga basin. Rivers like Chambal, Betwa, Ken and Tons, tributaries of river Yamuna and rivers like Banas, Kalisindh and Parvati, tributaries of river Chambal find their way from Vindhya-Bhander-Kaimur series in the south and flow towards north direction. This makes the general slope of drainage for the whole region. The slope of Sagar lake catchment area is in north-west direction which confirms with the general northward drainage of this region. However, the lake falls under the basin of river Bewas.

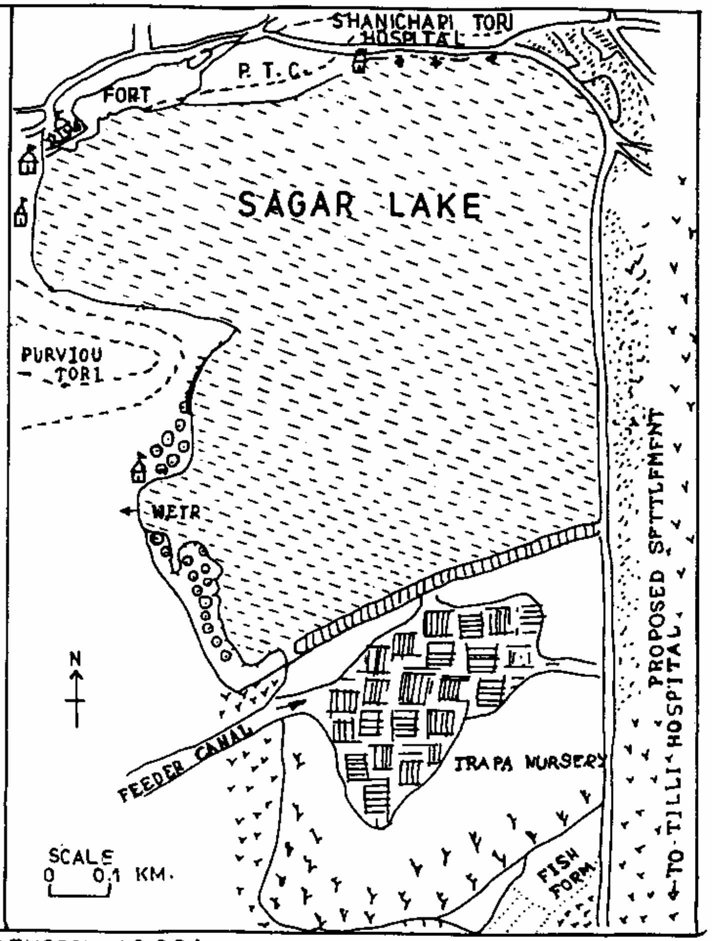
2.2.3 Watershed Tributaries and Structures

The catchment area of the lake and the feeder canal is about 1883 hectares and 831 hectares respectively. Thus the total catchment area of the lake is 2714 hectares. But due to constructions and encroachments of building etc. and pressure of increasing population, the built-up free area of the lake catchment is reduced to about 1889 hectares only. This catchment area is partly hilly and is partly covered by open forest. Catchment areas of the Sagar lake and the feeder canal are shown in fig. 2.3. The Sagar lake is perennial, though it is rain fed. However, a feeder canal 'Kanera' joins the small lake in the south-west bank. Apart from this, the lake is also fed by several local nallahs namely Baria Ghat nallah, Brindavan Bag nallah etc. draining from the surrounding nearby areas. These canal and nallahs are the main source which contribute the major part of sediment and various types of pollution to the lake. The pattern of these streams flow is of turbulent type. Besides this, the lake is well surrounded by a large number of ghats, houses and roads all along its shore except the southern, south-eastern and a part of south-western banks, which are open. However, in the north-eastern bank from the bus stand to Tilli Hospital, the lake is well surrounded by a stone facing wall.

Sl. No.	PARAMETER	VALUE	UNIT
1.	LATITUDE	23° 49' 1.8"	N
2.	LONGITUDE	78° 44' 30"	F
3.	ALTITUDE (M S L)	517	M.
4.	MAXIMUM LENGTH	1247	M.
5.	MAXIMUM BREADTH	1207	M.
6.	FULL LAKE AREA ($\times 10^3$)	1166.4	M^2
7.	MEAN WIDTH	935.2	M
8.	MEAN DEPTH	2.480	M
9.	SHORE LINE	5230	M
10.	MAXIMUM DEPTH		M
11.	FULL LAKE VOLUME ($\times 10^3$)	2895.64	M^3

LEGEND

GHATS
ROAD
TEMPLE
EMBANKMENT
FENCING WALL
INPUT/OUTPUT
ELEVATION AREA
LOW LYING AREA
BETEL PLANTATION
AGRICULTURAL FIELDS
OPEN SHORELINE



(SOURCE: YATHEESH, 1990)

FIG.2.2 MORPHOETRY OF THE SAGAR LAKE

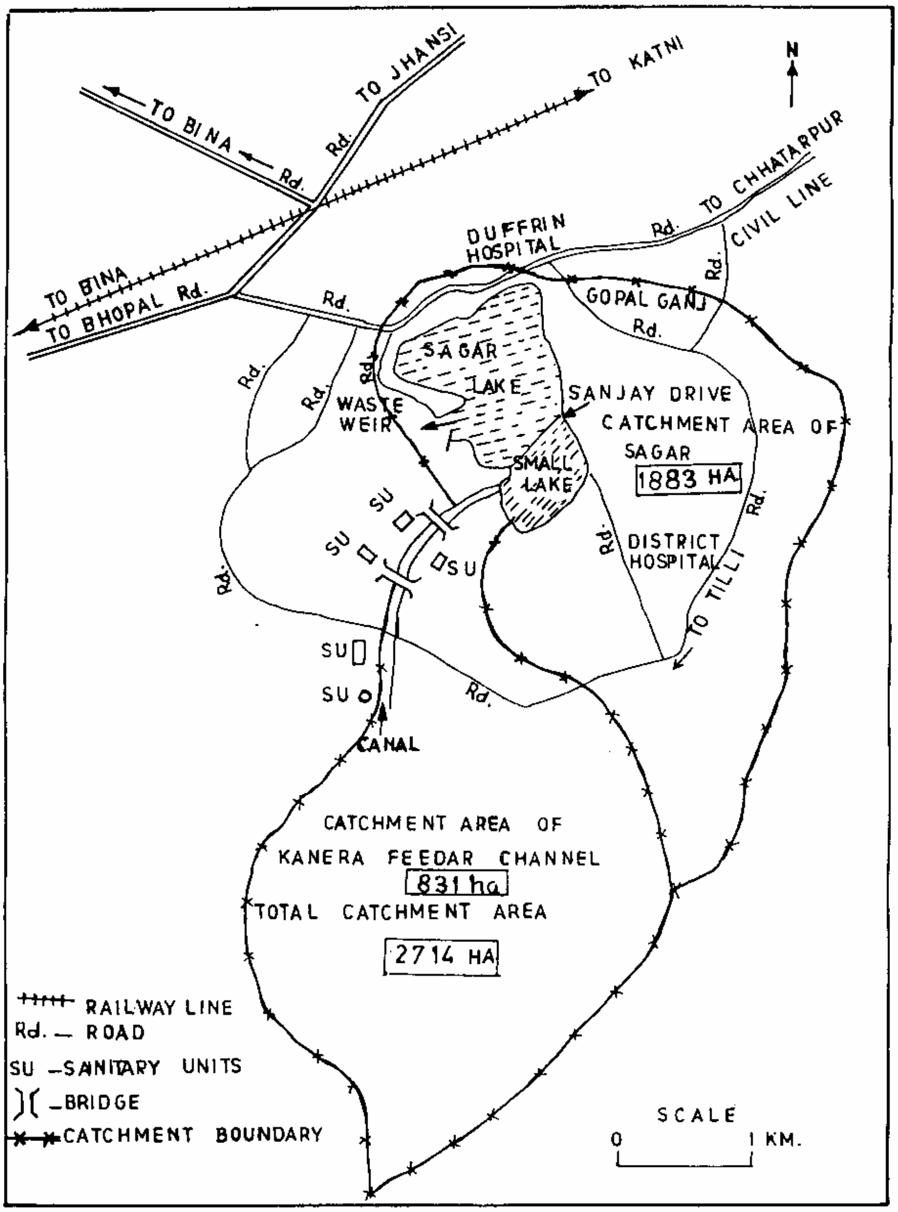


FIG.2.3 CATCHMENT AREA OF SAGAR LAKE AND THE FEEDER CANAL

3.0 HYDROGEOLOGY

3.1 Geological Features

Rocky terrain of Sagar district is characterized by formation of Vindhyan plateau system of pre-Cambrian era and deccan trap volcanic series. Vindhyan plateau system having thickness of about 4200 m is spreaded horizontally all over in the north Madhya Pradesh. It is extended from Rewa in the North-West of river Sone to Rajasthan in the west of river Chambal. At some parts in the middle, the Vindhyan rocks overlaid by deccan trap in the past, have now become visible in the surface due to the erosion. It can be divided into two parts - the lower Vindhyan and the upper Vindhyan. The lower Vindhyan is found in Vindhyanchal series, which are extended from east to west in the north of river Narmada. It is also found in the catchment area of river Sone and Bhima and some parts of Chhatisgarh district. It is reported in the studies of this rock system that limestone and sandstone are found in abundant quantity in it. The upper Vindhyan system is found in the north of river Narmada. It is divided in the series like Kaimur, Rewa and Bhander. In this system generally, building stones are found in large quantity. The Deccan Trap, comprising of a number of thick layers of basalt, is formed by the volcanic eruption over deccan plateau. Here, the meaning of trap is taken into consideration of ladder like slope. The South-West area of Madhya Pradesh, comprising of Indore, Bhopal and West Jabalpur division, is situated over Deccan Trap. The thickness of this trap is getting reduced in the north and west direction and near the boundary, the underlying Vindhyan system gets visible in the surface. The middle trap is found in the Central India and Malwa region whereas the lower trap is found in the valley of river Narmada. The each flow of trap having thickness between 3 m to 7.5 m is existing in the horizontal layer all over the regions. Along its depth, inter-trapean beds are also found, which are the main source of limestone. Sagar city is lying over the 5th flow of this trap and up to 10th flow of the trap is found in the plateaus surrounding the city. There is an inter-trapean bed in between 5th and 6th flow of the trap from where limestone is mined locally. The geological formation of the Sagar lake mainly comprises of the underlying Rewa quartzite sandstone of Vindhyan age and the Deccan Traps. Deccan Traps are very firmly grained black colour basalt formed by the consolidation of volcanic lava. The joints in this trap are mostly vertical, polygonal and columnar. These joints represent the coiling surface, which are channels for the fresh water infiltration. The Vindhyan quartzite sandstone is very hard and compact in nature, in which joints are nearly vertical. The bedding planes are thickly bedded and horizontal in the area and having low porosity. These joints and porosity behave like channels for the water infiltration.

Due to the compact Vindhyan sandstone and fine-grained basalt, many aquifer formations are not possible in this region. The ground water recharge is very poor and it is reported that only 10 to 15 % of the total rainfall is percolated into the ground water. This causes of acute scarcity of water at least every alternate year in this region.

3.2 Soils

The soils of this area is visibly of two types - the red or reddish brown lateritic type on the hill-tops and black type at the foot-hills. These soils are arrested between the undulating rocks mostly at lower elevations. Black soil is, generally, found in the deccan trap having thick basalt rocks. This type of soil is mainly formed due to weathering of the black rocks. Such type of weathering can be seen, even these days, on the top of the plateau surrounding the Sagar region. A thin layer (about 0.15 m thick) of black soil is found in the boundary areas where basalt layer is also thin and contrary to this in the river valley, the layer of black soil is very thick (about 1.0 m). The colour of soil is determined due to the excessive presence of iron and lime. During the weathering of basalt, the iron constituents of the rock gets oxidized in red colour and due to continuous chemical processes and deposition, the soil is finally converted into black colour. The texture of this kind of soil is clayey having pH value between 7.5 and 8.5. Due to its characteristics of glueness in wet condition and cracks in dry condition, the problems like air circulation as well as water logging never happens.

3.3 Vegetation

On the basis of average annual rainfall, the forests of Madhya Pradesh can be classified into two types - a) dry and wet mixed forests and b) thorny forests. The north-west areas having average annual rainfall of less than 750 mm are included in the thorny forest and the eastern areas having average annual rainfall of more than 1250 mm come under wet monsoon forest. By considering the average annual rainfall, the vegetation of Sagar region can be classified under northern tropical dry deciduous forest.

Also, in this region trees like Teak, Sirus, Eucalyptus, Bamboo etc. are found in abundant quantity. The catchment area of the lake is partly covered by this type of ordinary forest and vegetative cover is too meager to control the erosion by reducing the rate of run-off and to increase the percolation of rainy water into the soil.

4.0 HYDROMETEOROLOGY

4.1 General

Sagar city is situated near the centre of India. Hence the characteristics of climate found in this region resembles as of monsoonic. The climate can be distributed into three distinguished seasons as:

Summer -- March to June
Monsoon -- July to Oct.
Winter -- Nov. to Feb.

The summer season is found to be very hot and the winter season is very cold. Maximum rainfall occurs during monsoon season but sometimes a good amount of rainfall also occurs during winter and summer season.

However the area of this region falls into semi-arid zone.

4.2 Precipitation

4.2.1 Rainfall

Factors affecting precipitation over a lake are different from those affecting it over surrounding land areas. A lake may be affected by the topography of the adjacent land specially if there is a steep rise from the shore of the lake. Local storms accompanied by high winds are greatly influenced by the relief of the surrounding land area. Excessive heating of the land surface in warm weather leads to the formation of convective precipitation (Kuusisto, 1985).

Studies indicate that lake precipitation is lower than the precipitation over surrounding local areas. Average annual precipitation on lake Balaton (600 sq. km.) was 17% lower during 1921-58 than over the adjacent land area. For the largest lake in Finland, lake Suursaiman, the corresponding difference for annual values was 6% over period of 18 years (Kuusisto, 1985).

Precipitation on the lake surface and its catchment is measured by the rain gauges located near and around the lake. The raingauges in the catchment area are distributed according to the prevailing geomorphological conditions. The weighted average of the measured values are determined using Thesin Ploygon method etc.

I. M. D. observatory at Sagar is located about 1 to 2 km away from the lake catchment area. The I M D has analyzed the rainfall data of this observatory for the period 1901-1950 . The average annual rainfall of this observatory has been found to be 1229.4 mm. On the basis of the rainfall data of Sagar observatory for the period of 96 years (1901 to 1997 except 1951), average monthly and average annual rainfalls have been given in table 4.1 along with the monthwise and yearwise rainfalls of the selected years in which the study on Sagar lake has been carried out.

From this table, it can be seen that about 55 to 65% of the total rainfall occurs only during the month of July and August. And about 70 to 90% of the total rainfall occurs during the month of July to October which are called the monsoon months for this region. The mean annual rainfall for the period of 96 years is 1218.0 mm and the annual rainfall of the years 1970, 1978, 1983 and 1988-89 is 1042.9 mm, 1672.4 mm, 1770 mm and 853.7 mm respectively. Thus it can also be observed that in the year 1978 and 1983, the rainfall occurred in this region is more than that of the mean annual value and at the same time in the year 1970 and 1988-89 the rainfall occurred is less than that of the mean annual value of 1218.0 mm. Average annual and 96 years rainfall have been shown in fig. 4.1. Average monthly along with monthwise and average annual along with yearwise rainfalls of the selected years have been presented in fig. 4.2 and 4.3 respectively.

4.2.2 Number of Rainy Days

It is observed that number of rainy days are the maximum in the month of July and August for the region as a whole. It has also been seen that occurrence of rainy days is lowest in the months of April and December. It has been reported by I M D that the number of rainy days in the months of July and August varies between 10 to 25 days with an average of 17 and 16 rainy days respectively.

Table 4.1 : Mean monthly & mean annual alongwith monthwise & yearwise rainfalls of the selected years

Months	Rainfall in mm.				
	Mean of 96 yrs.*	Selected years			
		1970	1978	1983	1988-89
January	20.2	38.2	1.8	14.5	---
Febraury	11.9	25	110.6	0	---
March	9.7	42.8	48.4	0.5	0
April	4.3	0	23	0.8	7
May	8.9	2.5	0	7.3	4.2
June	126.7	121.4	145.9	112.1	187.3
July	359.3	147.4	298.9	538	350.3
August	401.6	501.4	774.3	458.9	219.8
September	189.9	158.8	190.2	541.8	81.3
October	33.5	5.4	0	95.9	1.2
November	20.1	0	1.1	0	0
December	9.6	0	78.2	0.2	0
January		---	—	—	2.6
Febraury		---	—	—	0
Annual Avg.	1195.7	1042.9	1672.4	1770	853.7

* : 96 years include years from 1901 to 1997, except 1951.

Table 4.3 : Normal monthly relative humidity and wind speed

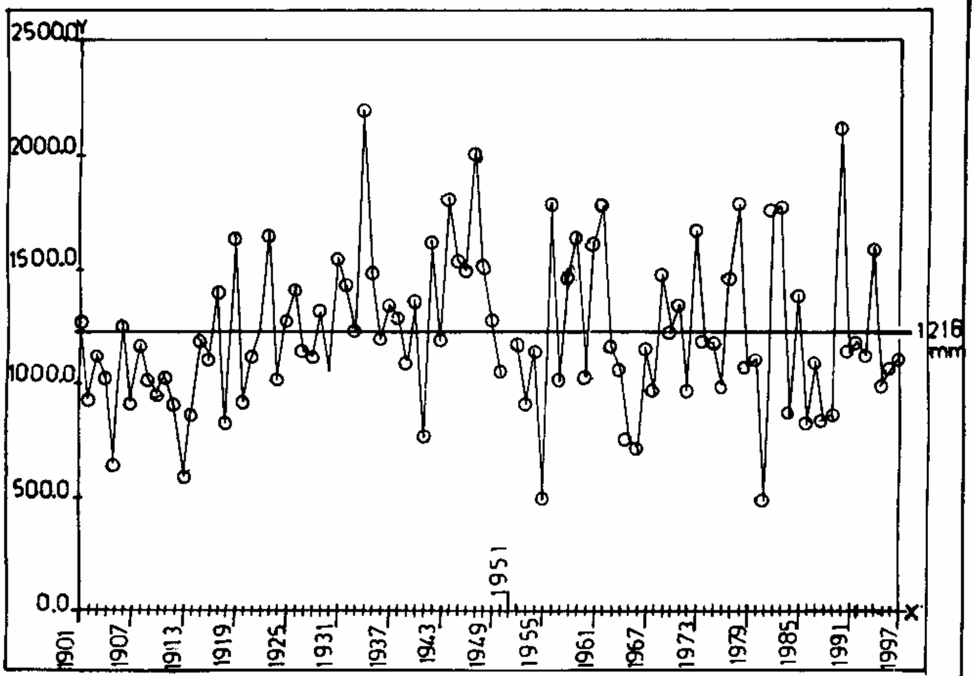
Months	Normal of 50yrs.*	
	Relative humidity	Wind speed (km/hr)
January	53	6.9
Febraury	44	7.1
March	30	8
April	24	9
May	28	10.1
June	57	11
July	84	10.5
August	86	10.3
September	80	9.6
October	54	7.1
November	46	6.7
December	51	6.5
Average	53	8.6

* : year from 1901 to 1950

Table 4.2 : Normal mnothly & normal annual alongwith monthwise & yearwise atmospheric temperatures of the selected years

Months	Atmospheric temperature in °C									
	Normal of 50yrs.*		1970		1978		1983		1988-89	
	min	max	min	max	min	max	min	max	min	max
January	11.3	24.7	12.3	24.1	9.2	26.5	10.8	23.4	—	—
Febraury	13.2	26.9	12.7	25.5	13.5	25.8	12.3	25.5	—	---
March	18.3	32.6	16.9	31.9	15.6	32.2	18.4	32	18.9	33.5
April	23.2	37.6	23.7	39.3	17.6	38.6	28.2	305	25	39.1
May	26.5	40.4	29.5	42.1	18	43.3	25.7	39.9	28	42.4
June	25.7	36.9	29.9	35.7	22.3	38.6	25.7	38.2	25.9	38.2
July	23.3	29.8	22.3	31.5	22.3	31.2	23.9	30.6	23.1	29.7
August	22.6	28.6	21.3	28.7	21.5	27.2	23.2	29.7	22.7	29.8
September	21.9	30.1	21.3	29.2	22.5	30.6	22.1	29.2	22.7	32.3
October	19.1	31.1	19.7	31.8	23.1	35.4	18	29	19.1	32.1
November	14.7	27.8	15	28.9	16.1	35.6	13.7	26.6	15.3	28.8
December	11.6	24.9	21.6	26.2	12	22.3	11.9	24	11.9	25.8
January			—	—	—	---	—	—	9.3	24.3
Febraury			---	---	—	---	---	—	12.8	28.1
Annual Av	19.3	30.9	20.5	31.2	17.8	32.3	19.5	29.9	19.5	32

* : 50 yrs. include year from 1901 to 1950



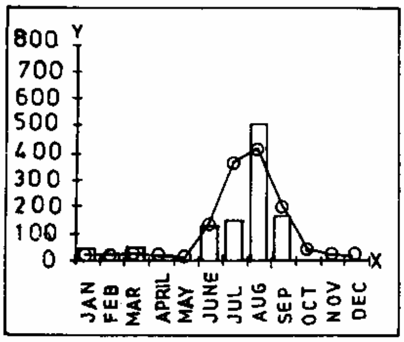
X-AXIS : YEARS

Y-AXIS : RAINFALL IN MM

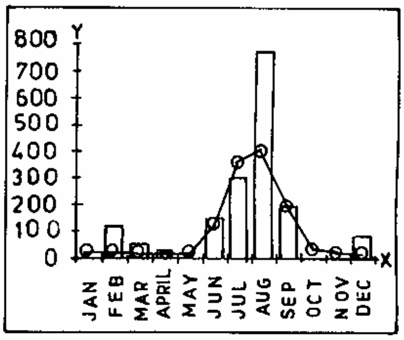
—o— : AVERAGE ANNUAL RAINFALL FOR 96 YEARS (1901-1950; 1952-1997)

—— : ANNUAL RAINFALL RECORDED AT SAGAR OBSERVATORY

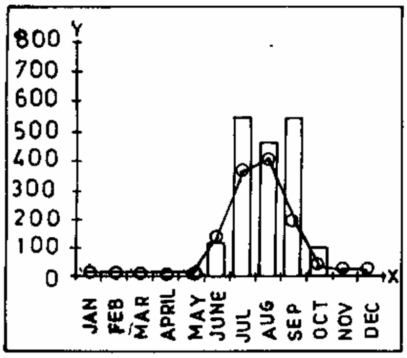
FIG.4.1 AVERAGE ANNUAL AND YEARWISE RAINFALL FOR 96 YEARS



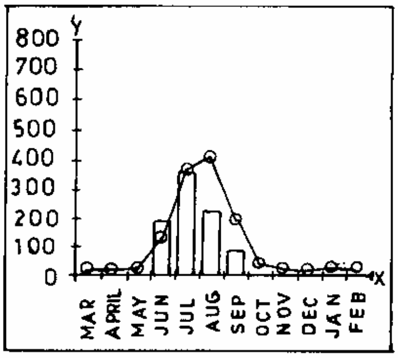
(A) YEAR 1970



(B) YEAR 1978



(C) YEAR 1983



(D) YEAR 1988-89

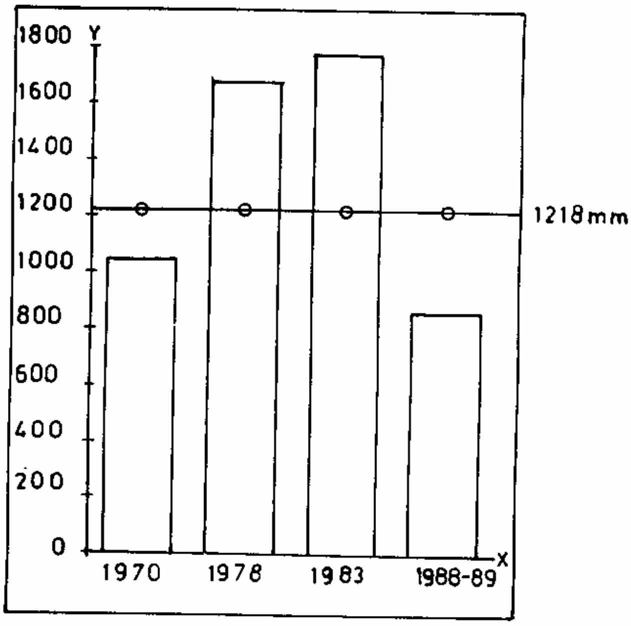
X-AXIS : MONTHS

Y-AXIS : RAINFALL IN MM

—o— : AVERAGE MONTHLY RAINFALL FOR YEARS (1901-1950; 1952-1997)

—□— : MONTHWISE RAINFALL OF THE SELECTED YEARS

FIG.4.2 AVERAGE MONTHLY AND MONTHWISE RAIN- -FALL OF THE SELECTED YEARS



X - AXIS : YEARS

Y - AXIS : RAINFALL IN MM

—o—: AVERAGE ANNUAL RAINFALL FOR 96 YEARS(1901-1950; 1952-1997)

_□_: YEARWISE RAINFALL OF THE SELECTED YEARS

FIG.4.3 AVERAGE ANNUAL AND YEARWISE RAINFALL OF THE SELECTED YEARS

4.2.3 Rainfall Pattern

The Sagar lake catchment along with surrounding region receives rainfall due to the effect of monsoon currents. The commencement of monsoon into the catchment and the surrounding region depends on the passage of the monsoon depression along suitable tracts over North-West India and Pakistan. Heavy rainfall in Sagar region occurs during the South-West monsoon period. The onset of monsoon is around the third week of June and retreats by third week of October, there by providing about four months of monsoon rainfall which is about 80% of the annual rainfall. Rainfall pattern and average monthly rainfall are similar in the months of July, August and September. During October the average rainfall decreases and the atmospheric temperature again rises simultaneously. Normally the winter season is dry in the region, with clean sky and moderate wind speed. But sometimes rainfall occurs in the month of December and January due to cyclone, which is generated from western side of the country.

4.2.4 Rain Gauge Station in Sagar Region

The World Meteorological Organization (WMO) has fixed a norm that there should be at least one rain gauge station for 1000 to 2500 sq. km. of catchment area in flat region, 300 to 1000 sq. km. of catchment area in mountainous region and 5000 to 20000 sq. km. of catchment area in arid and polar zones and according to the present practice 10% of the total number of rain gauge stations should be self-recording.

The gross geographical area of Sagar district is about 10430 sq. km. and according to I.M.D norms, the area should have at least 11 rain gauge stations against which 12 numbers are already available. The gross geographical area of Sagar block is about 984 sq. km. and has one rain gauge station maintained by I.M.D. The other rain gauge stations are maintained by State Government agencies. All these rain gauge stations are of non-recording type. Hence setting up of self-recording rain gauge stations in adequate number requires immediate attention. However, one self recording type weather station has been setup in this region by N.I.H. Roorkee but it is in the preliminary and testing stage.

4.3 Atmospheric Temperature and Evaporation

The hottest month in the region is May and the coldest one is January. There is a small variation in the monthly values of maximum and minimum temperature during the period November to February as also during July to September. The mean diurnal variation is of the order of 8 degree centigrade during July to September and 13 degree centigrade during November to February. The normal monthly and annual atmospheric temperature for 50 years along with monthly and annual atmospheric temperature of the years 1970, 1978, 1983 and 1988-89 have been given in table 4.2.

Evaporation is the process by which water is changed from the liquid or solid state into the gaseous state through the transfer of heat. Evaporation plays an important role in the water regime of a lake and yield from a lake could be seriously affected by the evaporation loss. Clearly, evaporation depends on the supply of heat energy and the vapour pressure gradient, which in turn depends on the meteorological factors such as water and air temperature, wind, atmospheric pressure, solar shape of evaporation surface etc. Because evaporation is basically an energy exchange process, solar radiation is the most important factor governing evaporation. It directly affect the temperature of the evaporating surface. As such, the temperature at the water surface is very significant for the estimation of evaporation. There are number of physical processes which transfer heat energy within the water mass. They vary in importance from climate to climate, from lake to lake and from season to season. They determine the vertical and horizontal temperature distributions in the water body and affect essentially its chemical and biological characteristics.

The effect of wind on the evaporation also depends on the size the water body. Large water bodies may require high velocity and turbulent air movement for maximum evaporation. Winds up to 25 miles/hr may be needed to increase evaporation. In the long run, a 10% change in the wind speed will change the evaporation 1 to 3% only. Wind stir up the air and remove the lowest moist layers adjacent to the lake water surface and to mix them with upper driven layer. So, wind affects the evaporation from the lake - quantity of available water. However, the relationship between wind speed and evaporation holds good only to a certain point, beyond a certain critical value, any further increase in wind speed leads to no further increase in evaporation.

Neither the observations have been taken nor the detailed study has been carried out for understanding the evaporation characteristics of the lake by any agency till date.

4.4 Relative Humidity

The relative humidity in the region is the highest during the months of July to September and lowest during March to May. The relative humidity occurs as high as about 85% and as low as 25%. The normal monthly and annual relative humidity for 50 years have been given in the table 4.3.

4.5 Surface Wind Characteristics

Wind is the most important flow generating mechanism in most of the lakes. Water motions in lakes are mostly caused by the wind. Random variability of the wind and geometrical complexity of natural lake basins combine to produce time variant changing and spatially non-uniform water motions. It is difficult to fully comprehend the complexity of these motions even in principle. Wind that blows over a lake transfer momentum to the water and causes the main flow and the velocity to fluctuate. The low frequency part of this energy input with advection eddies has a significant effect on the large-scale dispersion pattern. The duration and fetch of wind influences the generation of waves in lakes. These are responsible for the erosion and transport of coarse particulate in lake basins. The land-lake changes in surface frictional characteristics result in increased wind velocities. Influence of wind can be easily visualized in the lakes having area more than 100 Sq. km.

Surface wind data are recorded at I M D Sagar observatory. It is reported that the highest wind speed occurs in the month of June to July and the lowest occurs in the months of November to December. It is also interesting to note that the lowest is about half of the highest wind speed. The normal monthly and annual wind speed for the period of 50 yrs (i.e. 1901-1950) have been given in table 4.3.

It is reported that during July the wind direction in this region is Westerly and South-Westerly to North-Easterly and during January it is Northerly and North-Westerly to South-Westerly.

It is reported that during July the wind direction in this region is Westerly and South-Westerly to North-Easterly and during January it is Northerly and North-Westerly to South-Westerly.

5.0 HISTORICAL RECORDS

The Sagar lake, earlier known as "Sathhiya Lake", has its own historical importance. The Sagar town as well as the district is named after this lake. There is a difference of opinion regarding the origin of Sagar lake. According to historical records, it has an artificial origin whereas geological evidences favours about the natural origin and artificial maintenance of the lake. Historian believed that the lake was constructed by the chief of Banjaras, Lakha Banjara, in 16th century. It is said that the lake was constructed with the help of about 100 labourers worked for a period of about two years, in order to fulfill the all times demand of water of the inhabitants of this town. It is also said that at that time, the lake could not get water but later on it was totally filled up with water. But Professor W. D. West (1964) suggests the different theory that it came into existence when the Vindhayan outcrops, that partly surround it, became exposed as the overlying deccan trap was removed. The more resistant Vindhayn quartzite damming up the south to north drainage. And according to Mishra (1969) the lake has been formed by damming the North-Westward drainage and the construction of a bund on the Western side, due to disastrous famines at the end of the 19th century.

Geological evidences also say that originally the lake had an area of about 580 hectares. The maximum depth was about 18 m and the catchment area was spreaded over about 1420 hectares only. In the past, the quantity as well as quality of lake water was good enough and it was being used as source of water supply to the town from 1911 to 1958 without filtration. Apart from this, the water was also used by the habitants of the town during droughts. On the basis of meteorological observations for the period 1901 to 1950, the average annual rainfall was reported to be 1229.4 mm with the average annual rainydays of 58.7 days only. However, the normal rainydays for this region is about 90 days. It is reported that the overall minimum rainfall (645 mm) and the overall maximum rainfall (2057 mm) were recorded in the year 1913 and 1934 respectively. Similarly, the overall minimum and the overall maximum temperatures observed in the lake region were 6°C and 46°C respectively. It is also reported that up to seventies, there were about fifty species of fish cultivated in the lake, some of them were of high economic values.

6.0 LITERATURE REVIEW

6.1 General

A number of publications have been brought out on the Sagar lake based on the studies carried out from academic point of view. But, most of them describe the biological aspects of the lake-water. However, only a few reports describe the other features of the lake, but no work has been taken up yet in the engineering aspects such as sedimentation, water balancing etc. of the lake basin.

6.2 Siltation Rate

The response of a lake to climatological or man-made changes is recorded in its sediments, in their composition and at the rate in which they are accumulating.

The formation and behaviour of sediments in a lake is dominated by the interaction of a number of physical processes whose relative importance on the sedimentation of a lake is influenced by the form, orientation and size of the lake basin and climatic conditions.

Lake sediment consists of a heterogeneous mixture of materials and can be classified according to their origin. These components derived from outside the lake are termed allogenic, while those deposited directly from aquatic solution through biological uptake or chemical sorption and precipitation are called anthigenic. The main sources of allogenic sediments in a lake are the sediments carried into the lake by rivers, streams and overland flow. The water discharges through these sources into the lake is largely determined by climatic controls but factors such as relief, vegetation cover, agricultural activity, urbanization and the nature of the underlying rocks are also important. Sediment entering a lake may consist of a wide range of sizes, from gravel or boulders to silt and sand particles. Coarser particles are quickly deposited as water enter a lake to form deltas because of the low velocities available to transport the sediment through a lake. Sediment size larger than silt size is seldom discharged from a lake. Most of the sediments carried into lakes by streams and other agencies settle on their floors. Lakes with no outlets act as perfect settling basin, but even where there are outlets, a great many lakes are effective settling basins. With regard to sediment transport, lakes are essentially closed or nearly closed system because of high ratio of land drainage and land area and due to the relative lack of motion of lake water. A majority of lakes have a ratio of mean depth to maximum depth which exceeds 0.33, approaching the value that a conical depression would have. The ratio tends to increase as maximum depth are filled in.

The silt gauging in Sagar lake has not been done by any of the Government Departments, so far, hence the actual quantity of silt deposited in the lake is not known. However, the Water Resources Department, Sagar, Government of M.P., estimates the quantity of silt deposition in the lake by considering the annual rate of 0.062 ha-m per sq. mile of catchment area. Recently in project prepared by the Forest Department, the total annual quantity of silt deposition in the lake is estimated to 0.45 ha-m in which 55% is contributed from the built-up free catchment area of 4.08 sq. mile of the lake and the rest is contributed from the built-up free catchment area of 3.22 sq. mile of the feeder canal. It is also estimated that approximately 25 to 30% of silting in feeder canal takes place from private farms and crop fields. Apart from this, the unmeasured significant quantity of silt is also deposited in the lake by dipping or submerging a number of idols of god and goddess every year. In another project report prepared by the Public Health Engineering Department, Sagar, Government of M.P., it is said that the silt deposition in the whole area of small lake, to which the feeder canal meets, is at the rate of 3.25 cm-layer per year and if silt deposition is not controlled by adopting suitable and effective measures then this small lake will be filled up in the next thirty to forty years.

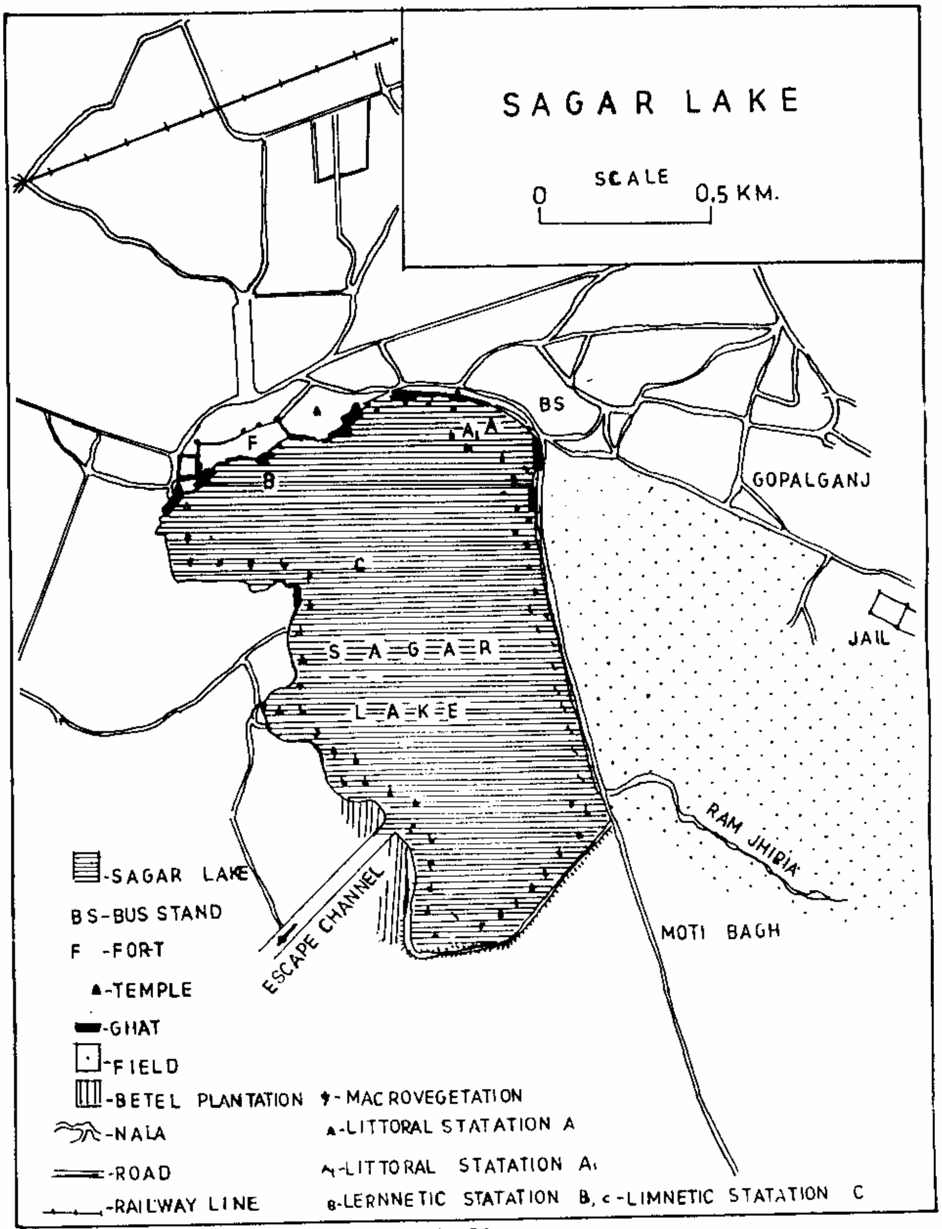
6.3 Water Quality and Pollution

There is a direct relationship between the physico-chemical properties and the biological condition of the water bodies because both of them are dependent on the quality and pollution level of the water bodies. Also, the physico-chemical conditions of the medium play a supreme role in determining the living complex of inland fresh waters, which is largely the result of their inter-dependence and interactions. Keeping this in view, most of the scientific studies carried out on Sagar lake have concentrated their works on the physico-chemical properties of the lake-water and the possible inter-relationship and interactions between these properties and biological factors like plankton, macrophytes, macrofauna etc. The first study of its kind was carried out thoroughly over the micro-biological aspects of the lake-water in the year 1969-70 and the report was published in the year 1975 (Adoni, 1975). Thereafter a number of studies were taken up in similar fashion. Out of these only four selected published works, having a considerable working year gap in between, are being referred here. This will certainly helpful in developing a broad idea towards the various characteristics of the Sagar lake-water. These studies were published in the year 1975 (Adoni, 1975), 1980 (Awatramani, 1980), 1986 (Yadav, 1986) and 1990 (Yatheesh, 1990) but the actual field work was carried out in the year 1969-71, 1978, 1983 and 1988-89 respectively. In these literature, the studies on microbiology, limnology, macrophytes, macrofauna etc. were emphasized and to work out the quali-quantitative characteristics of these factors in relation to the quality of the surrounding water and sediment, the physico-chemical properties of water and sediment of the lake were thoroughly observed and analyzed.

6.3.1 Sampling Stations

The quality and pollution level of the lake-water varies all along the length, the breadth and the depth of the lake. To represent a lake thoroughly, a number of sampling stations are selected all along its volume from where samples of water, sediment etc. are collected with utmost precautions.

In the year 1970 (Adoni, 1975) and 1978 (Awatramani, 1980), four permanent sampling stations were selected, in which two were situated in the littoral zone and the other two were situated in the limnetic zone of the lake. The littoral zone was at the shallow area of the lake near the bank while the limnetic zone was located at the deep area interior to the lake. However, they were fixed at different places in the lake. The position of the stations selected in the year 1970 and 1978 is shown in fig. 6.1 and 6.2 respectively. Besides the different positions each station was facing various depth inside the lake. In the Year 1970, the stations of the littoral zone and the limnetic zone were having the depth variation from 2 m to 2.5 m and from 4 m to 5.5 m respectively. While in the year 1978, the stations of the littoral zone and the limnetic zone were having the depth variation from 1.75 m to 2.5 m and from 3.0 m to 4.75 m respectively.



(SOURCE: ADONI, 1975)

FIG. 6.1 SAMPLING LOCATION OF THE SAGAR LAKE IN THE YEAR 1970

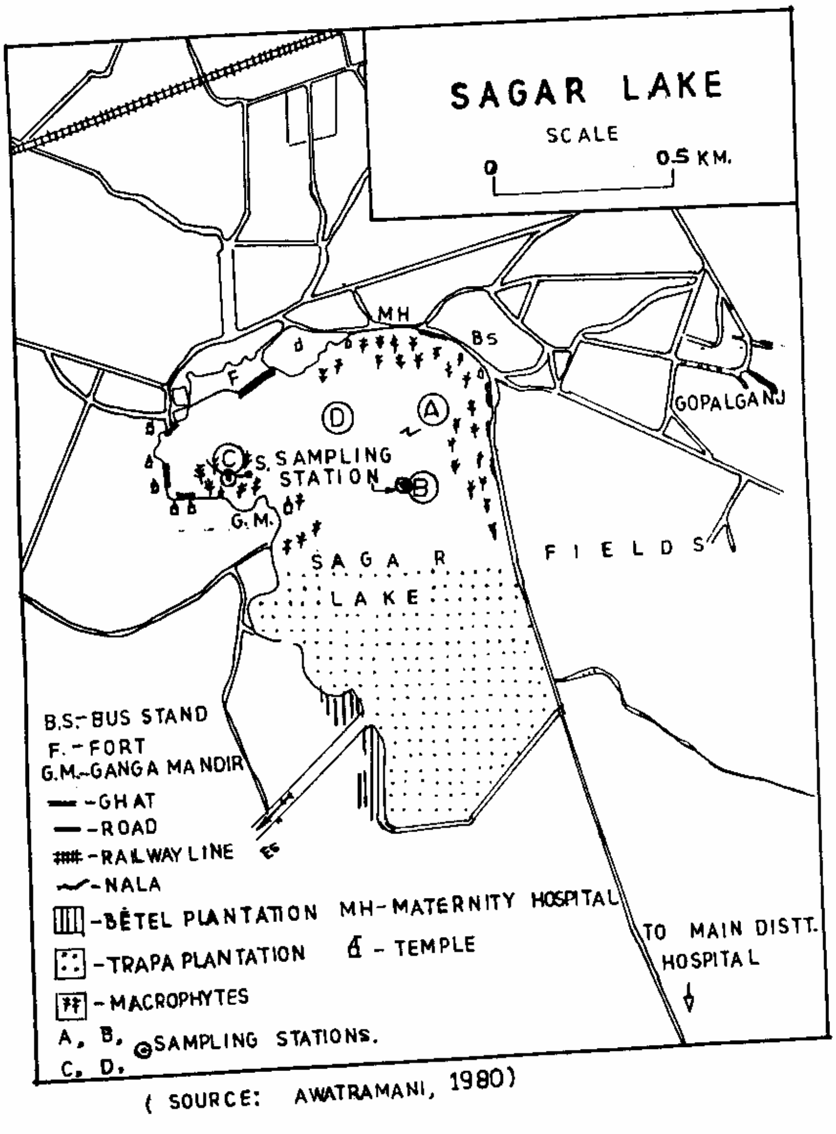


FIG.6.2 SAMPLING LOCATIONS OF THE SAGAR LAKE IN THE YEAR 1978

But, in the year 1983 (Yadav, 1986) only three sampling stations were selected in which two were located in littoral zone and the third one was in limnetic zone of the lake. The position of these stations is shown in fig. 6.3. The variation of depth experienced by these stations of littoral and limnetic zones was from 1 m to 2 m and from 3 m to 4 m respectively throughout the year of observations. In the year 1988-89 (Yatheesh, 1990), a more detailed study was carried out and total twelve sampling stations were fixed in the three selected transects all over the lake considering the feasibility and objectives of the study. The actual position of transects and stations is shown in fig. 6.4. In this study each of the three transects was divided into four stations and the zonation of lake bottom was made more narrowly such as up to 1 m from the water surface it was called littoral zone, from 1 m to 2 m, it was called sub-littoral zone, from 2 m to 3.5 m, it was named littori-littoral zone and the portion more than 3.5 m deep from the surface was called profundal zone. Water and sediment samples were collected separately from the stations lying in these zones of the lake.

Littoral zone was fallen at the lake margin and the profundal zone was the deepest region. The other two zones were falling in between the littoral and the profundal zones of the lake.

In all the above studies some precautions were taken into consideration during selection of sampling stations like,

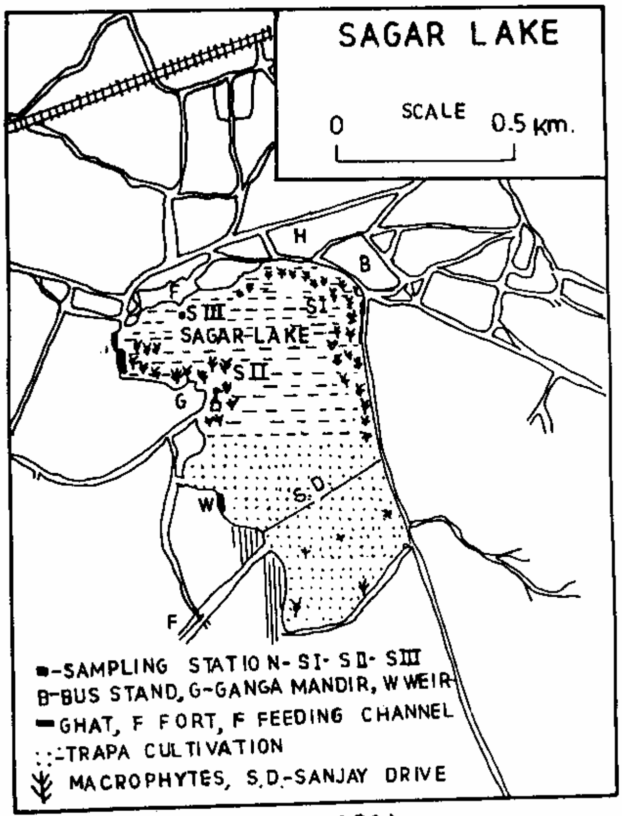
(a) absence of direct discharge of drainage.

(b) no direct disturbances from human beings and cattle.

(c) availability of water even during summer seasons.

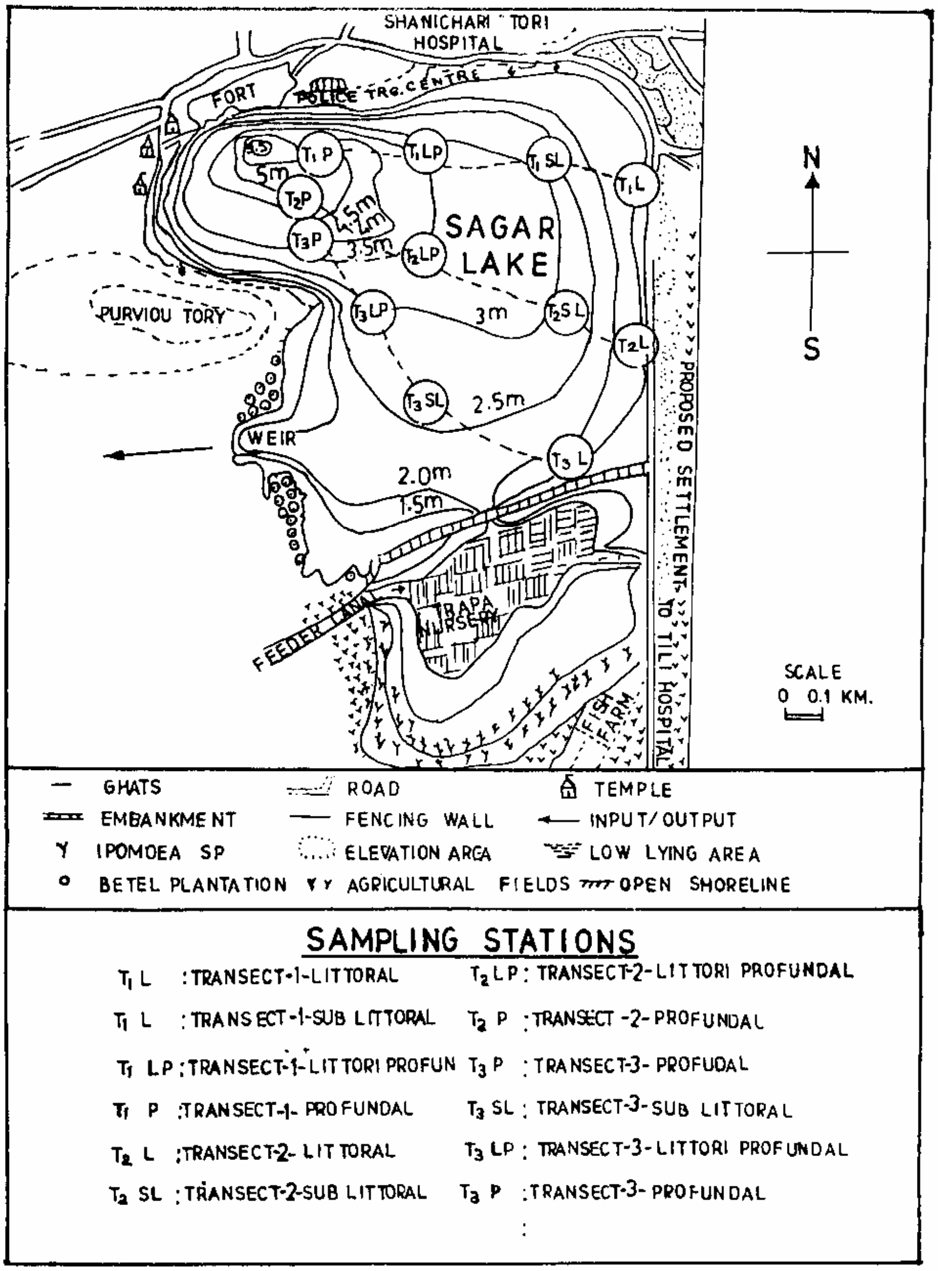
6.3.2 Materials and Methods

In all the studies, generally standard methodology was adopted in collection and in analysis of water, sediment, and plankton samples. In some of the above studies, the analysis of the monthly as well as diurnal variation of physico-chemical, planktonic, and benthic properties of the water was made. Before taking regular and uninterrupted monthly and diurnal sampling, field trials and standardization of analytical procedures were made.



(SOURCE: YADAV, 1986)

FIG. 6.3 SAMPLING LOCATIONS OF THE SAGAR LAKE IN THE YEAR 1983



(SOURCE: YATHEESH, 1990)

FIG. 6.4 SAMPLING LOCATIONS OF THE SAGAR LAKE IN THE YEAR 1988-89

The period chosen in all the studies was in such a way that it covered all the three prevailing seasons of this region. The period of taking observation in the first study (Adoni, 1975) was from August-September 1969 to June 1971 but in the first four to five months only preliminary observations were made. In the second (Awatramani, 1980) and third study (Yadav, 1986), the actual period of taking observation was from January 1978 to January 1979 and from January 1983 to December 1983 respectively while in the fourth study (Yatheesh, 1990), the actual period varied from March 1988 to February 1989. But, for convenient, in presentation of annual variation of water quality of the lake, only twelve months period i.e., from January to December in each year is being summarized here, in this report.

The high frequency of collections represents the real state of affairs. Keeping this in view, a frequent sampling practice was adopted by all the workers of the above studies. Generally monthly water sampling was done regularly in the forenoon session but the sampling interval adopted by the researchers was different. In the year 1970 (Adoni, 1975) the sampling interval was on weekly basis while in the year 1978 (Awatramani, 1980) and 1983 (Yadav, 1986), it was made in an interval of ten days and in the year 1988-89 (Yatheesh, 1990), the monthly water samples were collected in the middle of every month. Similarly, the diurnal variation studies were standardized to six hours interval after preliminary analyses. The observations presented in these reports were in the mean monthly and mean seasonal values of the respective physico-chemical factors of the lake-water and lake-sediments. The analyses of variation between stations, between seasons and between zones were done in some of these studies. The co-relationship among the physico-chemical factors of water and sediment was also presented. Besides this the inter-relationship between the quality factors of water and sediment was enumerated in the tabular form in these reports.

6.3.3 Physico-Chemical Properties of Water

The maximum-minimum and the average seasonal values of physico-chemical parameters of water of the Sagar lake have been tabulated in table 6.1 and 6.2 respectively. The statistical analysis, i.e., F-test and t-test results of these water chemistry parameters between various stations, seasons and zones of the lake are shown in table 6.3.

6.3.3.1 Physical Conditions

1. Lake level

It was observed that the lake level varied widely from season to season. The variation in the lake level was mainly due to the rainfall. However, atmospheric temperature, evaporation and outflow of water from the lake, also played their roles in deciding the lake level. Since the Sagar lake is rain fed, so during the monsoon season the lake is in its highest level. However, the weir "Mogha" built in the western side of the lake checked the flood level of the lake by overflowing the extra water over it. The lowest level of the lake was generally observed in the end of summer season. It was observed that the lake level goes up by approximately 2.5 m from summer to monsoon. It was also observed that with fall in the lake level, the rooted submerged and floating macrofytes encroaching more and more towards the centre from marginal area and with their death and decay lifted the bottom up. Almost similar variation is observed in the lake level every year.

2. Water colour

Water colour was observed to be either green or greenish brown or dirty. In rainy season reddish colour was observed due to the presence of suspended inorganic sediments which were brought with the inflowing water.

3. Ambient Air Temperature

In all the studies it was observed that the surrounding air temperature of the lake was more or less same to the temperature recorded at the Meteorological Department observatory of Sagar. The seasonal average values of ambient air temperature showed the established pattern of variation such as the maximum temperature was observed during summer followed by the monsoon season and the lowest temperature was observed during the winter season. It was also reported that the month of May is the hottest one when the mercury ranges up more than 40°C and the month of January has the lowest temperature ranging below 10°C.

4. Water Temperature

The study of thermal conditions (Adoni, 1975) of this lake has revealed that it is a homothermal lake due to the shallowness of the lake and severe wind action.

It was observed that water temperature of the lake was generally less than the surrounding air temperature. It was also observed that water temperature was more during the monsoon months than that of during the summer months and the lowest water temperature was recorded during the winter months. There was no definite pattern found in the monthly variation of the water temperature. In general, it was seen that the maximum water temperature occurred in the months of May to July while that of the minimum occurred in the months of December to February. It was interestingly observed in the diurnal variation that the water temperature was very low in the morning hours and gradually rose up the maximum in the afternoon hours. In the statistical analysis, it was found that water temperature difference observed between stations and between zones were not significant whereas between seasons, it was highly significant as shown in table 6.3.

5. Secchi Disc Visibility

The measurement of Secchi disc visibility gives the extent of transparency of water. The reading of it gives the value of penetration of light into water and the reciprocal of the value is referred to as turbidity.

During the year 1970 (Adoni, 1975), 1978 (Awatramani, 1980) and 1983 (Yadav, 1986), Secchi disc visibility varied approximately between 11 cm and 100 cm. But in the year 1988-89 (Yatheesh, 1990), the lake showed wide variation of disc visibility from 6 cm to 220 cm. The lowest disc visibility was recorded in month of June but the highest visibility was recorded in different months during the different years. In general, the highest value was observed during the late winter months. It was also observed that there was an annual cycle of low transparency in April to August, followed by a medium transparency from September to November and a high transparency from December to March. The diel variation of Secchi disc visibility in different months did not show any pattern but the seasonal average values showed that there existed a pattern in all the three seasons. Winter season favoured maximum light penetration and summer season marked the minimum light penetration. But monsoon season allowed only moderate level of light penetration as shown in table 6.1 and 6.2. The F-test and t-test results showed that the observed difference of Secchi disc visibility between stations and between zones was not significant but the variation between different seasons was highly significant as shown in table 6.3.

6.3.3.2 Chemical conditions

1. Hydrogen-ion Concentration (pH)

The pH value is a measure of hydrogen-ion concentration and is the negative exponent of the logarithm of the hydrogen-ion. A low pH solution has a high hydrogen-ion concentration and is therefore, acidic while high pH solution is low in hydrogen-ion concentration and is alkaline.

During the various years of study it was observed that pH of Sagar lake-water followed a definite diurnal and nocturnal periodicity. There was a steady increase in pH value from early morning and reached a peak in the evening. Thereafter the value decreased gradually to reach minimum unit by morning. It was also observed that in most of the months a common trend of fluctuation existed between the zones barring some irregularity at the limnetic zone during winter months. There was less then one unit difference of pH value recorded between surface and bottom water during different years. Surface water was found always more alkaline compared to bottom water. Generally, the minimum pH value of lake water was found more than 7 units but in the year 1970 (Adoni, 1975) and 1983 (Yadav, 1986), in bottom water of limnetic zone it was below 7 units and was recorded as 6.2 and 6.8 units respectively. However, monthly range of pH value was recorded in between 6.2 and 10.5 units. The maximum pH value was observed generally in the month of April and May while the minimum value occurred during January and February as shown in table 6.1. The seasonal values showed that the lake-water had always been alkaline within a range of 7.6 to 9.6 units. Summer season showed the maximum pH value while the winter season showed the minimum one as shown in table 6.2. Though there existed an apparent difference of values of pH between stations and between zones, F-test and t-test did not give significant results.

But the variation observed during different seasons gave a significant statistical evidence as shown in table 6.3.

2. Conductivity

Conductivity is the numerical expression of the ability of an aqueous solution to carry an electric current. Conductivity is directly proportional to inorganic ions and inversely proportional to molecules of organic compounds. The measure of conductivity is useful to evaluate the variation in dissolved mineral concentration of water. It can also be used to estimate total dissolved solids.

The diurnal fluctuation of conductivity of Sagar lake-water did not show a clear pattern. It was observed that in different seasons, the diurnal values of conductivity in different zones along with surface and bottom waters varied differently. The monthly and seasonal average values of conductivity showed a definite pattern of fluctuation as shown in table 6.1 and 6.2. With some exceptions, the peak values of conductivity mostly fell in late summer and the least values in late monsoon. In the year 1988-89 (Yatheesh, 1990), the conductivity of the lake water ranged between 325.87 micromhos/cm and 580.83 micromhos/cm. The lowest and the highest values were recorded in September and April respectively. It was also observed that there was a gradual increase in conductivity with depth of water. Due to the close relationship between conductivity and total dissolved solids, a strong positive correlation ($r=+0.88$) existed between them. The analysis of variation showed insignificant differences of the values between stations, between zones and between surface and bottom waters. However, a very high significant difference was found between seasonal average values of the conductivity as shown in table 6.3.

3. Total Dissolved Solids (T.D.S.)

Total dissolved solids and conductivity are closely related in the sense that the dissolved solids in natural water are generally found in ionic form. The more the conductivity the higher the concentration of dissolved solids. T D S governs the physico-chemical properties of water to a large extent.

The diurnal fluctuation of total dissolved solids showed a definite diurnal and nocturnal cycle during the year 1988-89 (Yatheesh, 1990) barring slight deviations during monsoon months. A minimum total dissolved solid was observed in the morning hours in most of the months from the surface and bottom waters of both littoral and limnetic zones whereas maximum values were recorded at noon hour. After that there was decreasing trend noticed in total dissolved solids and reaching a minimum by dawn hours. The monthly and seasonal average values of T.D.S. showed a pattern of fluctuation identical to one observed in the case of conductivity. The peak values of T.D.S. had been recorded in the summer and the least values had been found in late monsoon and early winter. It was observed that the difference in seasonal average values between monsoon and winter did not vary much. The seasonal variation was noted between 165 mg/L and 221 mg/L. The difference in values between different sampling points did not show remarkable difference. However, the monthly average values showed the variation between 142.7 mg/L and 249 mg/L. The maximum value was recorded in the month of May and the minimum value was recorded in November. Similar to other previous factors, F- test and t- test of the data showed that the difference in concentration of dissolved solids between stations and between zones was not significant where as the observed seasonal variation is highly significant as shown in table 6.3.

4. Chloride Content

The concentration of chloride can be used as an indicator of pollution due to organic wastes of animal and human origin. Sagar lake receives domestic waste flow through a large number of domestic drains. Similarly the banks of the lake are being used for defaecation by local residents and pavement dwellers. A large number of cattle are also frequently found grazing and wallowing at the southern part of the lake. So cattle dung and urine also find their way into the lake water. In spite of all these sources of organic wastes mixing with the lake water, the highest concentration of chloride in the past years, in all seasons has been observed less than 100 mg/L.

According to Sreenivasan (1965) low chloride (4-10 ppm) only indicates the purity of water and freedom from pollution whereas higher values of chloride denote to pollution of organic matter particularly that of animal origin. Also, Trivedi and Goel (1986) suggest that the concentration of chloride upto 1500 mg/L is harmless but even a concentration between 250 mg/L and 500 mg/L can produce a salty taste. However, since chlorides are highly soluble their removal is not so easy.

The diurnal variation of chloride concentration of water showed a regular pattern at the littoral zone only. At this zone, except in a few occasions, the maximum concentration of chloride was recorded in the noon and the minimum in the morning hours whereas at the limnetic zone in majority of months the maximum chloride concentration was recorded in the night hours and minimum in the early morning hours. The monthly and seasonal variation of chloride content between the different sampling points did not show remarkable difference. In the year 1970 (Adoni, 1975), the chloride content was ranged between 20.2 mg/L to 48 mg/L. And in the year 1978 (Awatramani, 1980) and 1983 (Yadav, 1986), the variation of this was between 20 mg/L and 64 mg/L. But in the year 1988-89 (Yatheesh, 1990), it was ranged between 40 mg/L and 88 mg/L. In all these years, it was observed that the fluctuation of chloride content was more at littoral zone in respect to that of at limnetic zone and at surface water in respect to that of at bottom water. Generally in most of the years the maximum concentration was recorded in the month of May or June, but the minimum value was observed in the month of September everywhere in the all the years. Similarly the highest seasonal average values for all the sampling points were noted during summer and the lowest values were noted during monsoon. The average values during winter season was recorded nearer to the values during monsoon season. This is shown in table 6.1 and 6.2. In Sagar lake, no definite relation of chloride content with other physico-chemical properties had been observed. However, F- test and t-test of chloride content showed significant result only in the case of seasonal average values as shown in table 6.3.

5. Calcium, Magnesium and Total Hardness

Temporary hardness is the one which is common to natural water bodies due to bicarbonates and carbonates of calcium and magnesium. Permanent hardness is caused mainly by sulphates and chlorides of metals. Sewage and industrial wastes are important sources of calcium. Total hardness is the sum of calcium and magnesium concentration both expressed as calcium carbonate in mg/L.

Concentration of calcium up to 1800 mg/L in water has been found not to impair any physiological reactions in man (Lehr et al., 1980). But magnesium concentration greater than 125 mg/L can cause cathartic and diuretic effects in man (APHA, 1985).

The diurnal variation of calcium content of water did not show remarkable difference in their concentration at the surface and bottom water or littoral and limnetic water due to shallowness of the lake. In all seasons, the surface water at the littoral zone recorded maximum calcium content at the evening hours and the minimum values were noted at morning hours. However, for the bottom water no such pattern was observed. The monthly variation of calcium content of the lake-water showed an increasing trend from a minimum in April and May and reached the annual peak in November and December. In the year 1978 (Awatramani, 1980) and 1988-89 (Yatheesh, 1990), calcium content ranged approximately between 12 mg/L and 55 mg/L. However, a little difference was observed in the concentration between surface and bottom water and between littoral and limnetic zones of the lake. Similar type of trend was observed for the seasonal variation also. But the minimum and the maximum concentration of calcium were recorded during the peak of summer and winter respectively and monsoon season recorded moderate levels of calcium concentration. The analysis of variance of calcium content showed highly significant results with regard to only seasonal variation.

The diurnal variation of magnesium content of lake-water showed an inversely proportional trend with calcium. Barring a few month, the maximum concentration of magnesium was recorded at forenoon hours but seasonal average values showed the maximum magnesium concentration always at morning hours. The monthly variation of magnesium content of water did not show any describable pattern of fluctuation. The peak and the least values were obtained scattered during the different periods of study. However, in the year 1978 (Awatramani, 1980), the variation of magnesium concentration was between 3 mg/L and 25 mg/L and in the year 1988-89 (Yatheesh, 1990), it was varied from 9.75 mg/L to 37.5 mg/L. But the maximum and the minimum concentration were observed in different months in both the years as shown in table 6.1. Generally, the maximum and minimum concentration was obtained in winter and summer months respectively as shown in table 6.2.

The analysis of variance showed similar results as that of calcium content, as shown in table 6.3.

Diurnal periodicity of total hardness is directly proportional with magnesium and inversely proportional with calcium. In the day hours, a noticeable difference of total hardness values was observed at the surface and bottom water. It was also observed that during winter season, water was harder compared to other two seasons but the diurnal fluctuations were least. The monthly variation of total hardness showed a pattern which was more or less same as that of calcium. The minimum and the maximum values were recorded during summer and early winter respectively. In the year 1978 (Awatramani, 1980), the range of total hardness values was between 90 mg/L to 160 mg/L but in the year 1988-89 (Yatheesh, 1990), it was ranged between 98 mg/L and 270 mg/L. F- test and t- test of total hardness values showed significant results only in the case of seasonal variation similar to that of calcium and magnesium content as shown in table 6.3.

6. Carbonate, Bicarbonate and Total Alkalinity

Alkalinity of water is its acid neutralizing capacity. Its measure is significant in determining the suitability of water for irrigation and management of waste water.

The carbonate content of water did not show any pattern of variation in the diurnal periodicity. There were more than one peak and trough values recorded at different times. Carbonates were high during daytime but in many occasion it was found nil also. The monthly variation of carbonate content in the year 1970 (Adoni, 1975) ranged between 1.5 mg/L to 25.4 mg/L. But for the other years of study it showed extreme level (0 to 100 mg/L) of fluctuation. The minimum concentration was recorded in the month of November and December. Sometimes zero (nil) value was obtained from different sampling stations during some months including November and December when free carbon dioxide was present in traces. The maximum concentration was recorded during the months of March and May. Thus there was a steady increase in carbonate alkalinity during the early part of the year and reaching maximum during March to May. This coincide with the decrease in water level and rise in temperature and pH values. On the basis of these observation it was concluded that carbonates were either brought from the lake basin itself or from the run-off into the lake. Further, plants also returned back the carbonates annually on their death and decay. Analysis of variance and t- test results did not give any significant values in either of the cases as shown in table 6.3.

The diurnal as well as annual fluctuation of bicarbonates did not show any regular pattern. However, it was observed that bicarbonates were inversely related to carbonate alkalinity but directly related to total alkalinity. Multiple peak and least values were recorded at different time intervals during the diurnal variation study. Generally, higher concentration was observed in the day hour during summer and monsoon months. It was also observed that bicarbonate alkalinity was more at the limnetic zone than that of at the littoral zone of the lake. There was a gradual increase of bicarbonate content found in the lake-water from surface to bottom. In the winter months, bicarbonate content was found maximum whereas during rest of the year it remained more or less constant. But the range of fluctuation of bicarbonate content was found very large. In the year 1970 (Adoni, 1975) and 1983 (Yadav, 1986), the range of bicarbonate alkalinity was found in between 50 mg/L and 150 mg/L whereas in the year 1978 (Awatramani, 1980), it was found in between 25 mg/L and 160 mg/L. In the year 1988-89 (Yatheesh, 1990), the variation became still wider and it ranged from 15 mg/L to 190 mg/L. F- test result showed a significant value for variation of bicarbonate content between seasons only as shown in table 6.3.

Due to its direct relationship with bicarbonates, total alkalinity showed similar trend of fluctuation. Total alkalinity was higher at littoral zone during day time and during night time it was higher in limnetic zone. In comparison to surface water, bottom water showed a regular diurnal fluctuation. Also the difference in maximum and minimum values was not significant during diurnal cycle in different months. In 1970 (Adoni, 1975), the total alkalinity was ranged between 78 mg/L and 150 mg/L but in the year 1988-89 (Yatheesh, 1990), it was to be ranged between 100 mg/L and 188 mg/L. Maximum and minimum values were found scattered from different sampling stations as shown in table 6.1. However the seasonal average values represented a clear trend. The highest and the lowest alkalinity values were recorded during winter and monsoon respectively. But the summer values also found very close to the two seasons as shown in table 6.2.

Similar to bicarbonate content, total alkalinity showed a significant value in the F-test and t- test between seasons only as shown in table 6.3.

7. Dissolved Oxygen (D.O.) and Percentage Oxygen Saturation

Oxygen is comparatively more soluble in water. Oxygen level in atmospheric air is about 21% and in water it is about 35%. Dissolved oxygen level in water bodies depends on the physical, chemical and biochemical activities. So the diurnal periodicity of dissolved oxygen represents an indirect reflection of the bio-chemical pulse of the system.

Dissolved oxygen showed a well defined diurnal fluctuation. The amplitude of fluctuation was less. It showed that despite the dumping of sewage and garbage from several sources, the lake is capable of maintaining itself by some in-built mechanism. Barring a few observations, the peak values of dissolved oxygen were recorded at the noon hours. Thereafter the concentration declined progressively and the least values were noted at morning hours. The concentration of dissolved oxygen ranged approximately between 5 mg/L and 13 mg/L during the year 1970 (Adoni, 1975) and 1978 (Awatramani, 1980). In 1983 (Yadav, 1986), oxygen concentration was ranged between 5 mg/L and 22 mg/L but in 1988-89 (Yatheesh, 1990), it varied from 1.5 mg/L to 7.5 mg/L only. The sampling stations did not show remarkable difference in the concentration of dissolved oxygen but the surface and bottom water exhibited some variation in it as shown in table 6.1. Generally maximum values of dissolved oxygen had been recorded from most of the sampling stations during winter months. The minimum concentration of dissolved oxygen was generally noticed during late summer as shown in table 6.2.

In Sagàr lake it was observed against the convention that the temperature was not a controlling factor for dissolved oxygen concentration. It was also noticed that the difference in concentration of dissolved oxygen between the surface and bottom water was remarkably different when compared with the depth of the lake. In the F- test and t- test of dissolved oxygen concentration only in the case of seasonal variation, a significant result was obtained as shown in table 6.3.

Generally it was found that the least values of percentage saturation of oxygen occurred during summer months and the highest values occurred during monsoon months. But the percentage oxygen saturation values for monsoon and winter months were found more or less similar. However, the range of variation between the least and the highest values was observed very wide. In the year 1970 (Adoni, 1975) and 1978 (Awatramani, 1980), it varied from 60% to 135% and from 18% to 185% respectively. But in the year 1983 (Yadav, 1986), the value of percentage oxygen saturation became more wider and varied between 50% and 255%, whereas in the year 1988-89 (Yatheesh, 1990), it ranged between 18% and 95% only. Generally the maximum values were observed in the month of February and the minimum values were obtained during the month of May and June as shown in table 6.1. The F- test value of percentage oxygen saturation showed statistically significant result between sampling stations as well as between seasons.

8. Ortho-Phosphate

Phosphorus occurs in natural waters and in waste water almost solely as phosphates. Among the three forms of phosphate, ortho-phosphate is determined directly. Phosphate enter the water-bodies from agricultural fertilizer run-off, water treatment and biological wastes-residues. A certain amount of phosphate is essential to organisms in natural water and is often the limiting nutrient for growth. Too much phosphate can produce eutrophication. The result is the rapid growth of aquatic vegetation in nuisance quantities and an eventual lowering of the dissolved oxygen content of the lake due to the death and decay of the aquatic vegetation.

Phosphates were mostly present in low amount in surface water of the lake. The high values were mostly seen during the monsoon and this was certainly due to addition of phosphate through drainage and sewage by the arrival of rain-wash, whereas in winter and summer seasons, values of phosphate remained very low. The exception of this was that of in the year 1988-89 (Yatheesh, 1990), when rain came late and then it fell below the average. In this year, the maximum value was reported in summer months and the minimum was obtained in monsoon. Similarly the monthly mean values of phosphate were distributed irregularly. In the year 1970 (Adoni, 1975), the concentration of phosphate was found negligibly very low and in the year 1978 (Awatramani, 1980), it was varied from 0.04 mg/L to 0.09 mg/L. But in the year 1983 (Yadav, 1986) and 1988-89 (Yatheesh, 1990), the concentration went up and it ranged from 0.005 mg/L to 0.75 mg/L and from 0.004 mg/L to 1.97 mg/L respectively. Minimum values of phosphate were observed in the month of April and June whereas the maximum values were observed during the month of June to August as shown in table 6.1 and 6.2. It was also observed, in general, that the value in limnetic zone was more than that of in littoral zone of the lake. The analysis of variance showed a significant result for variations between seasons only. The results of F-test and t-test did not give favourable evidence for other two cases such as between sampling stations and between lake zones.

9. Nitrate-Nitrogen and Ammonia-Nitrogen

In water and waste water, the forms of nitrogen are biochemically inter convertible and are components of the nitrogen cycle. Nitrate generally occurs in trace quantities in surface water. High levels of nitrate in water indicate biological wastes in the final stages of stabilization or run-off from heavily fertilized fields. Nitrate rich effluents discharged into receiving waters can degrade water quality by encouraging excessive growth of algae.

Ammonia-nitrogen is a product of the microbiological decay of plant and animal protein. It can be reused directly by plants. It is present naturally in surface and in waste waters.

Nitrate is the common form of inorganic nitrogen in lakes. The concentration and rate of supply of nitrates are intimately related to the land use practices of the surrounding watershed. Nitrate ions move easily through soil and are quite rapidly lost from the land even in natural drainage where as ammonia ions are retained by soil particle charges. Ammonia is the preferred form of source of nitrogen to aquatic antotrophs thus preventing it from reaching toxic levels. Ammonia in higher concentration is toxic to fish and other biota as well as man. Toxicity of ammonia increases with increase in pH. The most important sources of nitrate are biological oxidation of organic nitrogenous substances, the runoff from agricultural fields etc. High concentration of nitrate is useful in irrigation but in water bodies it triggers eutrophication.

Nitrate content of the lake-water showed an annual cycle starting with maximum amount during summer months. During monsoon months, the concentration of nitrate declined and then started increasing from late winter onwards. However, this trend could not be found in the year 1970 (Adoni, 1975) and 1978 (Awatramani, 1980). The monthly mean variation of nitrate showed the range very low and it lied in between zero (nil) to 1.2 mg/L. In the year 1970 (Adoni, 1975), the concentration of nitrate was found to be negligible. The lowest value was recorded in the year 1970 in May and the highest value was obtained in the year 1978 (Awatramani, 1980) in July in the surface water of limnetic zone. F-test and t-test of the value did not give significant results except in the case of seasonal variations.

The concentration of ammonia-nitrogen was studied in the year 1988-89 (Yatheesh, 1990) found upto (Nil) and 1.9 mg/L. The highest monthly average value was recorded in June and the minimum value was recorded in July and August. It was also observed that the surface and bottom waters did not show much difference in the concentration of ammonia. The highest seasonal average values and the lowest seasonal average values of ammonia were recorded during summer and monsoon respectively. Winter season showed moderate concentration of ammonia. Statistical analysis of data give significant result in the case of seasonal variation only. However, F-test and t-test did not give a significant result between stations and between zones of the lake.

10. Free and Total Carbon Dioxide

Free carbon dioxide occurs in water as the dissolved gas as carbonic acid and as the carbonates and bicarbonates of calcium and magnesium and bone tine iron. All of these substances are in chemical equilibrium with one another.

Free carbon dioxide was rarely detected in this lake. The difference in the maximum and the minimum values was not significant during the diurnal cycle in different months. But the difference in seasonal average values show a weak variation in different seasons. So, the free carbon dioxide content of the lake water did not show any comparable features. However, the range of free carbon dioxide was observed in the year 1978 (Awatramani, 1980) maximum upto to 35 mg/L but the common values were between zero (Nil) and 3 mg/L and in the year 1988-89 (Yatheesh, 1990), it ranged from zero (Nil) to 84 mg/L with the common values between 4 mg/L to 17 mg/L.

Since the values of total carbon dioxide depend on the carbonates, bicarbonates and the free carbon dioxide, the monthly and seasonal variations of total carbon dioxide had been influenced by their values. Highest values were recorded during winter months whereas lowest values were obtained during monsoon months as shown in table 6.2. It was also observed that the values of total carbon dioxide were, in general, higher in littoral zone than that of in limnetic zone of the lake-water. In 1978 (Awatramani, 1980), the range of total carbon dioxide was observed from 63.4 mg/L to 146.5 mg/L and in the year 1988-89 (Yatheesh, 1990), it was ranged between 52.8 mg/L and 198.4 mg/L. The minimum values were recorded in the month of April and May and the maximum values were recorded during the month of June to August as shown in table 6.1. Statistical analysis of free and total carbon dioxide values did not give significant results.

11. Bio-Chemical Oxygen Demand and Chemical Oxygen Demand

B.O.D. is an empirical measurement of the oxygen required for the bio-chemical degradation of organic materials and for the oxidization of inorganic materials such as sulphides and ferrous iron. So its measure can be used as an index of organic pollution.

C.O.D. is a measurement of the oxygen equivalent of the materials present in the water that are subjected to oxidation by a strong chemical oxidant.

B.O.D. and C.O.D. test for Sagar lake-water was carried out during the year 1988-89 (Yatheesh, 1990) only. The B.O.D. values did not show any remarkable monthly and seasonal variation pattern. The range of B.O.D. values was recorded between 1.12 mg/L and 20.6 mg/L and the least and the highest values were observed in the month of October and November respectively. The B.O.D. values showed difference between surface and bottom waters but it was difficult to establish a common trend. However, generally it was found that the common fluctuation of B.O.D. in this lake was from 8 mg/L to 12.4 mg/L. The F-test and t-test of B.O.D. values did not give significant results in any of the cases like between stations, between zones and between seasons.

The C.O.D. values showed some regular pattern of monthly variation. The highest value of 27.5 mg/L was measured from the surface water at limnetic zone in May and the least value of 1.3 mg/L was recorded from the bottom water at the littoral zone in September. Summer season showed the highest seasonal average values of C.O.D. whereas the lowest values were recorded in monsoon barring a few sampling stations. Analysis of variance and t-test of the C.O.D. values did not give significant results except in case of seasonal variations.

12. Sodium and Potassium

Tests for metals like sodium and Potassium were carried out in the year 1983 (Yadav, 1986) only. There was no much fluctuation found in the values of sodium in the lake-water. The range of concentration varied between 11.2 mg/L and 18.1 mg/L. The least value was obtained at bottom water of limnetic zone in monsoon months and the highest value was recorded at bottom water of limnetic zone in winter months. However, a clear cut trend between surface and bottom water as well as between littoral and limnetic zones was not found. F-test and t-test of sodium content did not support a significant result in any of the cases. In respect to sodium, the concentration of potassium was found larger. It varied between 3.3 mg/L and 9 mg/L only. The least value was observed in the surface water at limnetic zone in summer months and the highest value was obtained in the bottom water at limnetic zone in winter months. Similar to sodium, no regular pattern was obtained between surface and bottom water as well as between littoral and limnetic zones of this lake. F-test and t-test of the concentration of potassium did not give significant results in any of the cases.

6.3.3.3 Biological Conditions

1. Planktonic Property of lake water

a) Phytoplankton :- Indian fresh waters possess less species as compared to other countries (Das and Srivastava, 1959). Similar conclusions were also drawn in the investigation of five tanks at Delhi (George, 1966).

Table 6.1 : Maximum and minimum monthly values of physico-chemical properties of water at different zones of Sagar lake

Physico-chemical Properties of Water	Unit	Year	SURFACE WATER								BOTTOM WATER							
			Littoral Zone				Limnetic Zone				Littoral Zone				Limnetic Zone			
			Maximum		Minimum		Maximum		Minimum		Maximum		Minimum		Maximum		Minimum	
			Value	Month	Value	Month	Value	Month	Value	Month	Value	Month	Value	Month	Value	Month	Value	Month
1. Water Temperature	°C	1970	29.3	June	16.5	Dec									29.4	June	17.5	Jan
		1978	31.8	May	18.8	Jan	31	May	18.3	Jan	30	May	17.8	Jan	30	June	17.5	Jan
		1983	34	June	17	Feb									31	June	16	Feb
		1988	29.6	July	17.3	Dec	30.3	July	18.3	Dec	29.7	July	17.3	Dec	30.2	July	18.2	Dec
2. Secchi Disc Visibility	cm	1970	85.6	Mar	11.4	June									61.1	Mar	15.6	June
		1978	61.5	Mar	13.8	June									37.7	Jan	18.3	June
		1983	98	Jan	27	June												
		1988	132.3	Dec	8.7	June									186	Dec	12.3	June
3. Hydrogen-ion Concentration (pH)	units	1970	9.8	Mar	8.3	Nov									9.7	May	8.2	Oct
		1978	9.3	Apr	7.3	Feb	8.9	Apr	7.3	Feb	8.8	June	7.2	Feb	8.5	June	7	Jan
		1983	10.5	Apr	8.8	Feb									9.6	May	6.8	Feb
		1988	9.3	Apr	7.8	Jan	9.3	Feb	7.9	Dec	9.3	Aug	7.8	Jan	9.2	Feb	7.9	Dec
4. Dissolved Oxygen	ppm	1970	11.1	Jan	5	Apr									11.6	Feb		
		1978	13.2	Feb	4.5	June	12.6	Dec	5.7	Aug	9.1	Jan	1.2	Sept	8.9	Jan		
		1983	21	Aug	5.2	Sept									16	Aug		
		1988	7.1	Oct	3.2	June	7	Feb	4.6	Dec	6.6	Sept	3	June	6.6	May		
5. % Oxygen Saturation	%	1970	126.3	Feb	60.2	Apr									136	July	69.1	May
		1978	143.6	Feb	56	June	132	Dec	66.5	Aug	90.1	Feb	25.1	Mar	89.5	June	28.9	Oct
		1983	255.3	Aug	63	Sept									194	Aug	58	Sept
		1988	84.6	July	35.5	June	91.7	July	48.3	Dec	91.7	July	46.3	Dec	82.2	May	43.6	Mar
6. Bi-Carbonate Alkalinity	ppm	1970	134.5	June	60	Feb									146	Jan	73.7	Feb
		1978	130.7	Feb	38	Apr	123.3	Jan	50.5	Apr	140.8	Feb	66	Sept	137.3	Feb	79.5	Mar
		1983	130	Dec	42	Apr									100	June	56	Oct
		1988	146	Jan	97	Aug	133	Dec	80.3	June	144.5	Jan	77.3	Aug	156	Mar	61	July
7. Carbonate Alkalinity	ppm	1970	25.4	Mar	4.5	Dec									20.3	May	1.5	JAN
		1978	84	Mar	Nil	Aug	64.5	May	Nil	Aug	45	Mar	Nil	Aug	40.7	May	Nil	Aug
		1983	72	Apr	Nil	Nov									80	May	Nil	Nov
		1988	55.3	Mar	Nil	Nov	58.7	Feb	Nil	Nov	80	Aug	Nil	Nov	69.3	July	Nil	Nov
8. Total Alkalinity	ppm	1970	140.5	Apr	78.1	Feb									149.5	Jan	82	Feb
		1978																
		1983																
		1988	154	Mar	108	Oct	150	Mar	104	Oct	162.7	Jan	107.3	Mar	171.3	Mar	103.5	Oct
9. Chloride Contents	ppm	1970	48	May	21.5	Sept									43.3	May	20.2	Sept
		1978	56.3	June	20	Sept	59	June	26.3	Jan	53.7	June	28	Jan	51.3	June	26	Sept
		1983	55	Aug	31	Sept									60	May	31	sept
		1988	83.5	May	42.4	Sept	84.8	June	42	Sept	85.4	May	41.5	Sept	85.6	June	43.4	Sept
10. Total Hardness	ppm	1970																
		1978	150.4	June	108	Oct	140.2	June	100	Jan	147.7	June	98	Oct	150.9	June	105	Mar
		1983	172	Aug	88	May									174	Aug	90	Apr
		1988	234	Dec	122.7	May	202.7	Nov	123.3	Apr	212	Nov	134	Apr	212.7	Nov	119.3	May
11. Calcium Hardness	ppm	1970																
		1978	36.4	Jan	19	May	37.2	Sept	18	May	35.5	Jan	21.7	Apr	40.1	Aug	20.1	May
		1983																
		1988	47.3	Dec	14.4	Apr	47.6	Dec	16	Apr	46.2	Dec	14.2	May	47	Dec	16.8	May
12. Magnesium Hardness	ppm	1970																
		1978	19.5	June	8.9	Sept	18.5	Apr	7.2	Jan	19.3	June	5.5	Oct	20.5	June	6.7	July
		1983																
		1988	28.3	Dec	16.4	Aug	24.9	Oct	18.2	Dec	27.8	June	18.5	Jan	27.1	Nov	17.7	Sept
13. Ortho-Phosphate (PO4-P)	ppm	1970	0.2	Aug	Nil	May									0.2	Aug	Nil	May
		1978	0.84	june	0.048	Apr	0.085	June	0.041	Nov	0.84	July	0.047	Nov	0.093	May	0.045	Oct
		1983	0.36	July	0.006	June									0.44	Aug	0.021	Jan
		1988	0.65	june	0.024	Aug	0.39	June	0.078	Dec	0.63	June	0.078	Dec	0.46	Apr	0.047	Sept
14. Ortho-Nitrate (NO3-N)	ppm	1970	0.35	Aug	Nil	May									0.33	Aug	Nil	May
		1978	1.1	July	0.53	Mar	1.2	July	0.55	Apr	1.17	July	0.57	Apr	1.08	July	0.47	Apr
		1983	1.09	June	0.01	Oct									1.09	June	0.02	Oct
		1988	0.56	Apr	0.059	Dec	0.35	May	0.087	Aug	0.45	May	0.077	Dec	0.48	Apr	0.067	Dec

Table 6.2 : Average seasonal values of physico-chemical properties of water at different zones of Sagar lake

Physico-Chemical Properties of Water	Unit	Season/year	LITTORAL ZONE Surface Water 1970	1978	1983	1986	LITTORAL ZONE Bottom Water 1970	1978	1983	1986	LIMNETIC ZONE Surface Water 1970	1978	1983	1986	LIMNETIC ZONE Bottom Water 1970	1978	1983	1986
1. Water Temperature	°C	Sum	26.3	28.6	27.17	26.45		27.6		28.15		28.2		28.54	27.4	27.3	25.48	28.29
		Mon	27.5	29.2	28.5	27.99		28.7		27.95		29.2		27.77	27.9	28.8	27.88	27.68
		Win	18.3	26.7	19.2	19.4		25.7		18.99		21.1		19.33	19.4	20.2	19.33	19.14
2. Ambient Air Temperature	°C	Sum	31.7	28.3	31.75	31.82										22.8		32.68
		Mon	28.4	28.7	29.8	27.88										29.5		27.94
		Win	22.1	20.1	21.5	21.89										36.6		21.14
3. Secchi Disc Visibility	cm	Sum	38.3	25.4	37.03	15.29									34.3	7.9		24.08
		Mon	29.8	30.08	41.84	36.36									30.6	7.6		34.67
		Win	43.6	32.09	56.88	97.17									35.8	7.6		98.75
4. Hydrogen-ion Concent. (pH)	units	Sum	9.5	8.5	9.6	8.71		7.9		8.6		8.5		8.82	9.4		9	8.8
		Mon	8.9	8.2	8.4	8.72		7.9		8.7		8.2		8.8	8.6		8.1	8.62
		Win	8.5	7.8	7.7	8.26		7.6		8.22		7.8		8.55	8.5		7.9	8.52
5. Conductivity of Water	µmho/cm	Sum	647			461.27				486.2				495.5	593			497.68
		Mon				379.99				388.45				369.09				384.36
		Win	472			437.61				432.61				410.99	502			406.06
6. Total Dissolved Solids	ppm	Sum				219.94				219.88				221				221.6
		Mon				175.36				176.51				175.2				175.97
		Win				175.82				175.15				164.78				164.03
7. Chloride Contents	ppm	Sum	35.6	46.6	43	75.5		44.5		74.33		45.1		75.66	34.9	43.1	44.4	78.66
		Mon	30	25.8	43.3	47.47		36.2		47.22		34.9		47.97	29.6	33.6	43.4	46.39
		Win	26.9	35.6	34.6	56.31		34.5		54.73		33.1		53.06	26.7	33.2	35.8	52.73
8. Tot. Hardness of Water	ppm	Sum		128	96.2	133.67		124.5		145.17		126.7	122.7	140.33	125.6		94.8	142.5
		Mon		122.7	117.2	163		121		170.63		128.4	155.1	158.17	128.8		119.2	166.17
		Win		120.8	115.8	193.83		120.45		191.5		120	198.8	173.83	121.7		122.7	187.17
9. Calcium Contents	ppm	Sum		24.65	42.2	21.38		24.2		22.07		23.2	21.46	19.77	23.9		41.4	21.58
		Mon		30.6	70.9	31.91		30.6		34.67		30.2	34.27	31.93	32		68.7	32.06
		Win		30.3	63.3	39.34		31.9		39.29		31.6	36.71	37.91	31.5		63.4	37.67
10. Magnesium Contents	ppm	Sum		16.7	13.1	21.46		17.2		21.97		17.1	18.91	21.76	16.5		12.9	21.46
		Mon		11.1	11.3	20.43		10.8		20.26		12.2	18.19	19.13	11.8		12.3	20.55
		Win		11.2	13.1	23.19		11.2		22.71		10.4	28.86	19.5	10.9		14.4	22.5
11. Total Alkalinity	ppm	Sum	104	107.2	123.9	134.83		121.5		138.17		117.6	132	136.06	120.4		116	140.56
		Mon	108	95.4	82.7	122.5		91.4		129.67		99	122.2	122	104.3		78.6	127.5
		Win	122	116.6	105	146		119		144.17		125.5	133.8	139.17	119.4		78.8	139.67
12. Carbonate Alkalinity	ppm	Sum	17.6	35.6	57	36.5		23.7		32.67		44.6	26.5	40.17	31.3		49.5	27.17
		Mon	10.8	11.6	20.7	30.5		Nil		39.33		11.2	39.6	26.67	1		16.8	32.67
		Win	8.6	16.9	17	13.67		5.1		13.33		15	19.6	24.67	8.1		7.5	21.33
13. Bi-Carbonate Alkalinity	ppm	Sum	86.4	71.6	66.9	98		97.8		105.5		73.04	106.4	95.92	89.1		66.5	113.42
		Mon	97.2	83.6	62	90.67		91.4		90.33		87.75	82.4	101	103.3		61.6	96
		Win	113.4	101.9	86	129.83		113.9		130.83		101.51	115	119.5	113.3		69.3	116.33
14. Free Carbon Dioxide	ppm	Sum			Nil	4.9				1.2			Nil	2.7			Nil	6.7
		Mon			Nil	25.9				4.6			Nil	6.9			Nil	4.8
		Win			Nil	24				14.4			Nil	8.8			Nil	6.95
15. Dissolved Oxygen	ppm	Sum	5.98	7.8	6.45	5.27		4.8		4.42		8.5		5.99	6.8	6	5.3	5.24
		Mon	6.6	7.4	11.6	6.58		4.8		6.1		7.9		6.38	6.9	4.7	6.65	4.95
		Win	8.6	10.7	10.33	5.71		7.2		5.79		10.9		6.1	6.9	7.6	7.9	5.59
16. % Oxygen Saturation	%	Sum	79.36	92.5	99.4	60.28		58.9		51.71		102.3		69.77	91.6	71	66	61.4
		Mon	69.5	90.9	132.95	80.02		62		71.34		97.3		76.12	93.5	56.2	100.7	59.05
		Win	102	114.1	105.5	58.56		67.6		58.59		115.9		62.88	79.2	76.7	80.3	57.19
17. Ortho-Nitrate (NO3-N)	ppm	Sum	Nil	0.77	0.44	0.341		0.76		0.232		0.65		0.217	Nil	0.7	0.44	0.299
		Mon	0.35	0.92	0.05	0.095		0.92		0.097		0.9		0.103	0.33	0.61	0.04	0.092
		Win	0.22	0.76	0.09	0.1		0.77		0.066		0.79		0.106	0.2	0.63	0.08	0.121
18. Ortho-Phosphate (PO4-P)	ppm	Sum	Nil	0.069	0.039	0.577		0.072		0.367		0.07		0.297	Nil	0.072	0.046	0.327
		Mon	0.2	0.068	0.1	0.061		0.071		0.122		0.084		0.147	0.2	0.067	0.072	0.091
		Win	0.15	0.062	0.091	0.154		0.056		0.113		0.06		0.19	0.13	0.061	0.067	0.137
19. Total Carbon Dioxide	ppm	Sum		67.05	73.8	116.73		99.6		121.05		84.9		102.08		92.1	64.6	116.59
		Mon		79.6	55.3	111.24		84.1		100.99		83.75		114.28		94.8	54.5	103.97
		Win		97.1	79.4	139.35		103.6		130.33		100.9		123.86		103.6	61.4	120.77

Table 6.3 : Analysis of variance (F) & t-test of physico-chemical parameters of water of the Sagar lake

Parameters	Analysis of Varience (F)		t - test
	Between stations	Between seasons	Between zones
Secchi disc	2.73 NS	827.29 ***	0.4 NS
Water temp	2.59 NS	786.69 ***	0.24 NS
pH	0.79 NS	7.61 *	0.83 NS
Total dissolved solid	1.24 NS	375.03 ***	0.41 NS
Conductivity	0.72 NS	93.48 ***	0.43 NS
Chloride	2.44 NS	5701.5 ***	0.15 NS
Total hardness	1.7 NS	177.76 ***	0.64 NS
Calcium	2.93 NS	313.26 ***	0.71 NS
Magnesium	1.58 NS	7.77 *	0.93 NS
Total alkalinity	0.79 NS	12.82 **	0.65 NS
Carbonate alkalinity	1.04 NS	5.23 NS	0.63 NS
Bicarbonate alkalinity	1.16 NS	11 *	0.14 NS
Free carbon dioxide	0.21 NS	0.09 NS	1.36 NS
Total carbon dioxide	0.49 NS	2.19 NS	0.85 NS
Dissolved oxygen	4.4 NS	9.37 *	0.22 NS
% oxygen saturation	6.96 *	24.62 **	0.23 NS
B.O.D.	0.62 NS	0.77 NS	0.57 NS
C.O.D.	0.39 NS	10.53 *	0.75 NS
Ortho phosphate	0.78 NS	19.3 **	0.49 NS
Nitrate	3.32 NS	36.77 **	0.22 NS
Ammonia	0.59 NS	51.77 **	0.39 NS

Probability Level (p)

NS : no significant difference at 5%

* : p less than 5%

** : p less than 1%

*** : p less than 0.1%

(Source : Yatheesh, 1990)

Study on planktonic properties of Sagar lake was carried out in the years 1969-70 (Adoni, 1975) and 1978 (Awatramani, 1980). In both the studies the volume of phytoplankton was found varying from season to season in the lake. In the year 1970, the maximum and the minimum volume of phytoplankton were recorded in the months of June and February respectively where as in the year 1978, the maximum and the minimum were recorded in the months of December and March respectively. The volume of phytoplankton ranged from 5027 no./litre to 52585 no./litre in littoral zone and from 2036 no./litre to 38060 no./litre in limnetic zone of the lake.

The composition of algae in and around Sagar lake (Adoni, 1975; Awatramani, 1980) had been formed by various members mainly belonging to Cyanophyceae, Bacillariophyceae, Chlorophyceae, Englenophyceae etc. The planktonic forms were mainly contributed by these classes, out of which Cyanophyceae and Bacillariophyceae were dominating over the others. Important phytoplanktonic members present were species of Microcystis, Raphidiopsis, Merismopedia, Anabaenopsis, Spirulina etc.

Blue-green algae were found to grow in large numbers in all the months. This group in general dominated over all other phytoplankton and zooplankton populations.

b) Zooplankton :- Similar to phytoplankton, zooplankton was also found varying from season to season in the lake. In the year 1970 (Adoni, 1975), the maximum volume of zooplankton was recorded in the months of May and April at littoral and limnetic zones of the lake respectively but the minimum volume was observed in the month of August for the entire lake. However, it ranged from 80 no./litre to 734 no./litre at littoral and from 40 no./litre to 553 no./litre at limnetic zones of the lake.

Zooplankton recorded from Sagar lake mainly consisted of Rotifers, Cladocera and Copepoda. Out of these Rotifers were found dominated over other zooplanktonic fauna of the lake. Beside these Brachionus, Keratella, and Anuraeopsis were also found in abundant quantities both at littoral and limnetic zones. The relationship study, in the year 1970, showed no definite trend between phytoplankton and zooplankton whereas in the year 1978, it showed an inverse relation between the two during rainy and winter seasons.

c) **Primary Productivity** :- Production studies are primarily concerned with the evaluation of the capacity of an ecosystem to the synthesis of organic matter of high potential chemical energy from inorganic materials of low potential energy. According to Raymont (1966) productivity, in a broad sense, is the concept of organic matter synthesis potential which measures ability of an area to support a biological population and sustain a level of growth and respiration.

The trend of population values was observed in the years 1970 (Adoni, 1975) and 1978 (Awatramani, 1980). In both the years it was found that the entire lake had high gross production throughout the year. The seasonal variation (Adoni, 1975 and Awatramani, 1980) showed that the maximum and the minimum production values were attained in summer and in winter seasons respectively. In the year 1970, the maximum production value was observed in July and the minimum was recorded in February whereas in the year 1978, the maximum value was obtained in June and the minimum was in the month of January. It was also observed that the difference in the values was greater in surface water than in deeper layers. On this basis, it was concluded that the changing climatic conditions had an immediate and direct effect on surface waters (Awatramani, 1980).

2. Biotic Properties of lake water

Macrobenthic fauna :- Benthos are the biocoenoses of the solid-liquid interface. These include all the bottom dwelling organisms primarily immature insects and is probably the best single index which helps in evaluation of environmental impact on aquatic system. Benthos are an integral part of the food cycle of an aquatic environment. They serve as the primary source of food for fish and other higher aquatic life. The biotic properties of the Sagar lake was studied in the years 1983 (Yadav, 1986) and 1988-89 (Yatheesh, 1990). In both the studies it was found that the bottom biota of the lake was mainly dominated by Molluscs, Oligochaetes, Chironomids, and Insects larvae. Mean monthly variation of these organisms showed that they attained their maximum and minimum values in different months in different zones of the lake as shown in the table 6.3A.

6.4 Physico-Chemical Properties of Lake-Sediment

Water bodies exhibit great variability in their morphometry, geology and nature of the bottom. All water contain some suspended matter which settles slowly to the bottom and accumulates as sediment. Lake sediments are the product of lake life and they reflect basically the geology of the catchment area. But they will be transformed gradually and become the product and part of the ecosystem-interactive and aging. Sediment rich in organic matter generally, have higher water content. Also, in highly organic sediment, it is often difficult to find the borderline between sediment and water. Sediment deposits of lakes can function as either a source or a sink for many of the essential nutrients involved in the eutrophication process. Exchange of nutrients between sediment and overlying water depends upon chemical characteristics of water and sediment.

According to Hakanson (1984), the exploration of lake sediments is an interesting and important field of scientific endeavor, which is not very thoroughly or systematically worked out. Most of the research endeavors on fresh water ecosystem have concentrated their attention only towards the physico-chemical characterization of water and only a little data is available on the physico-chemical properties of sediments under various water bodies of India. For the Sagar lake also, only a few studies were made on this aspect. And on the basis of availability of literature, the two studies carried out on the physico-chemical properties of sediment of Sagar lake in the year 1983 (Yadav, 1986) and 1988-89 (Yatheesh, 1990) have been enumerated in this report. In both the studies, sediment samples were collected from the same sampling stations which were selected for collection of water samples. But the sampling duration was different from that of water. In the year 1983 (Yadav, 1986), sediment samples were collected from all the three stations at an interval of thirty days and the sampling hour was between 07:00 hours and 10:00 hours.
In the year 1988-89 (Yatheesh, 1990), sediment samples were collected generally, on the following day of water sample collection in the middle of every month and the sampling hour was between 07:00 hours and 16:00 hours.

Table 6.3A : Mean monthly variation in Macrobenthic fauna at Sagar Lake									
Organisms	**Year**	**Number of Organisms (no./m²)**							
		Littoral Zone				**Limnetic Zone**			
		Max	Month	Min	Month	Max	Month	Min	Month
Molluscs	1983	327	Oct	19	Feb	<———ABSENT———>			
	1988-89	733	July	11	Nov	156	March	Nil	May
Oligochaetes	1983	287	Jan	4	Oct	931	March	19	Oct
	1988-89	4022	Aug	22	Oct	2278	Aug	33	Sept
Chronomids	1983	3547	April	38	Oct	4529	Feb	66	Dec
	1988-89		-		-		-		-
Insect Larvae	1983	83	Jan	8	Feb	95	Jan		-
	1988-89	1344	Jan	11	June	1567	Sept		June

(Source : Yadav, 1986; Yatheesh, 1990)

In these studies, the observations were made for the sediments in the littoral as well as in the limnetic zones of the lake. The littoral zone was made up of the basic materials which compose the shore itself, modified by the action of water, drift material, plant growths and organic deposits of more recent origin. The limnetic zone was composed of very finely divided soft oozes, which cover the floor of the basin. The sediments of Sager lake were blackish muddy and rich in organic matter. They act as the store house of the nutrients such as nitrates, phosphates, potassium, calcium etc. The factors affecting sediment characteristics are briefed as below and their monthly variations in the year 1988-89 (Yatheesh, 1990) and 1983 (Yadav, 1986) are presented in table 6.4A and 6.4B respectively. Also, the statistical analysis i.e. F-test and t-test of sediment chemistry parameters between various stations, seasons and zones of the lake are presented in the table 6.5.

1. Temperature

The sediment temperature observed during the year 1988-89 (Yatheesh, 1990) showed variation from 18.5°C to 31.1°C at individual stations. The least and the highest values were recorded in the month of January and September respectively. The average monthly values of sediment temperature ranged between 18.3°C and 29.9°C showed that there was a narrow variation existed in it at various stations. Similarly, the seasonal average values also showed a little variation of 1°C to 2°C in various seasons. For example, the average seasonal temperature for sediment during summer, monsoon and winter ranged from 25.6°C to 26.9°C, from 27.6°C to 28.3°C and from 19.7°C to 20.4°C respectively. It was also observed that, barring at a few occasions in monsoon, generally the temperature of littoral zone was slightly more than that of limnetic zone. It was interestingly observed that there was not much difference of temperature (<1°C) between bottom water and bottom sediment but the months of attaining the maximum and minimum values were found different as shown in the table 6.4A and 6.4B. This showed that the temperature of the surface layer of sediment follows closely with that of the ambient water. Also, due to geothermal nature, the maximum and mostly the minimum temperature of sediment were recorded slightly higher than the corresponding bottom water temperature. Analysis of variance showed a significant result for the difference found between the sampling stations only.

2. Hydrogen-ion Concentration (pH)

The observations for hydrogen-ion concentration (pH) of sediment were taken in both the years 1983 (Yadav, 1986) and 1988-89 (Yatheesh, 1990). During 1988-89 (Yatheesh, 1990), it was recorded that pH of sediment was always in the alkaline side but during 1983 (Yadav, 1986), it was observed that very often pH value of sediment lying in the limnetic zone was equal to 7 units. However, in both the years, it was recorded that pH of littoral zone was more than that of limnetic zone except the months of May 1988 and February 1989 as shown in table 6.4A. In the year 1988-89 (Yatheesh, 1990), pH of sediment ranged between 7.34 to 7.89 units and it never crossed the 8 unit mark but in the year 1983 (Yadav, 1986), pH of sediment ranged between 7 and 9 units and a number of times it was recorded more than the 8 unit mark. It was also observed that pH value of sediment was always less than that of the bottom water of the lake. Analysis of variance and t-test showed a significant result for the variation between seasons only as shown in table 6.5.

3. Conductivity

The measurement of conductivity can give a clear idea of soluble salts present in the sediment. Keeping this in view, the conductivity parameter of the lake sediment was studied in the year 1988-89 (Yatheesh, 1990). It was ranged from 126.14 micromhos/cm to 391.05 micromhos/cm. The lowest and the highest values were recorded in the months of March and April respectively. It was observed that stations of limnetic zone showed a wide variation of conductivity in the months of March and April. However, the seasonal average values of conductivity ranged as follows:

Summer - 192.72 to 258.36 micromhos/cm
Monsoon - 221.86 to 286.22 micromhos/cm
Winter - 194.82 to 241.77 micromhos/cm

The highest values were observed in monsoon months and the lowest values were observed in summer months. The conductivity values during summer season found to be very close to that of winter season. t-test of conductivity values showed a significant result between littoral and limnetic zones of the lake as shown in table 6.5. For other cases it showed an insignificant result.

4. Chloride

The most important source of chloride in water bodies is domestic sewage. Chlorides are highly soluble in water. Their concentration in sediment may not be of much significance. However, the study of chloride content in the lake sediment was taken up in 1988-89 (Yatheesh, 1990). The chloride content of sediment varied from 75.08 mg/kg to 275.3 mg/kg. The maximum and the minimum values were recorded from the littoral zone of the lake in the months of July and March respectively. The seasonal average values showed that the highest values were recorded at some stations during monsoon and at other stations during summer months but the lowest values were recorded during winter months throughout the lake. t-test of chloride content showed a significant results between seasonal differences only.

5. Carbonate and Bicarbonate Alkalinity

The flux of alkalinity from sediment is an important component of acid neutralizing capacity of fresh water of lakes. There does not exist any serious problem of acidification of the Sagar lake, though the study of carbonate and bicarbonate contents of sediment was carried out in the year 1988-89.

The carbonate content of sediment varied between zero (Nil) and 240 mg/kg. The maximum and the minimum values were recorded in different months at different stations. But the seasonal average values showed that the highest and the lowest values were observed during summer and monsoon respectively. Winter average values were noted nearer to that of monsoon. Analysis of variance and t-test supported a significant result between seasonal variation only as shown in table 6.5.

The bicarbonate content of lake sediment varied more widely and the values were recorded between 976 mg/kg and 2562 mg/kg in the year 1988-89 (Yatheesh, 1990). The highest concentrations were recorded in the month of July and August and the least values were noted in May barring a few stations, where the minimum concentration was obtained in December. The seasonal average values of bicarbonate concentration showed its peak and trough during monsoon and summer respectively. Only the values between stations showed significant statistical results.

6. Calcium and Magnesium

Calcium and Magnesium are the abundant substances in natural water bodies. They have got a high affinity to absorb on the soil particles, therefore, the cation exchange equilibria and presence of other cations greatly influence their concentrations. The measurement of these metals were carried out in the years 1983 (Yadav, 1986) and 1988-89 (Yatheesh, 1990).

In both the years, there was wide range of variation observed. In the year 1983 (Yadav, 1986), it varied from 609.4 mg/kg to 1443.6 mg/kg while in the year 1988-89 (Yatheesh, 1990), the range was found between 1402 mg/kg and 2324.64 mg/kg. The highest and the least values were recorded in August and January respectively in the year 1983 but in 1988-89, these values were observed in different months at different stations. t-test of calcium content showed a significant result between littoral and limnetic zones of the lake.

The range of magnesium content of sediment was recorded from 320.8 mg/kg to 848 mg/kg in 1988-89 (Yatheesh, 1990). The monthly and seasonal variation of magnesium followed the similar trend as that of calcium during the year 1983 (Yadav, 1986) and 1988-89 (Yatheesh, 1990) both. The highest and the least seasonal average values were observed during winter and summer respectively. But none of the observed differences got significant support from analysis of variance and t-test results.

7. Phosphorus

The major sources of phosphorus to water bodies are domestic sewage, detergents, agricultural and industrial wastes. The capacity of sediments to absorb and retain phosphate is strongly influenced by their mineral composition. The variation study of phosphorus content in lake sediments was carried out in 1983 and 1988-89. In the year 1983 (Yadav, 1986) and 1988-89 (Yatheesh, 1990), the range of variation of phosphorus content of the lake sediment was recorded from 8.5 mg/kg to 39 mg/kg and from 0.4 mg/kg to 60 mg/kg respectively. The highest and the least values were observed in January and April during 1983 (Yadav, 1986) and in June and October during 1988-89 (Yatheesh, 1990) respectively. However, the seasonal average values showed the maximum and the minimum during summer and monsoon respectively. t-test showed a significant result for the case of seasonal differences only.

8. Nitrate-Nitrogen

Nitrate has similar source of occurrence as that of phosphorus. Apart from this, a good amount of nitrate is also converted from ammonia in the process of nitrification. The nitrate content of sediment was studied in the year 1988-89 (Yatheesh, 1990). This content of lake sediment ranged between 7.9 mg/kg and 22 mg/kg. The maximum value was recorded during summer months. But the minimum values was recorded in different months at different stations. Thus no regular monthly fluctuation pattern existed for nitrate content of the sediment. However, the seasonal average values of this content ranged between 13.23 mg/kg and 20.23 mg/kg during summer; 16.87 mg/kg and 17.88 mg/kg during monsoon; and 13.18 mg/kg and 17.95 mg/kg during winter. Thus the variations observed between seasons were negligibly small. t-test showed a significant result for difference noticed between littoral and limnetic zones of the lake-sediment.

9. Organic Matter

The surface sediments of eutrophic lake is chiefly composed of organic and mineral matters. The major sources of organic matter to lake-system are domestic sewage and garbage, dead remains of plants and animals, surface run-off from the catchment area etc.

The organic matter content of the Sagar lake-sediment, studied in the year 1988-89 (Yatheesh, 1990), showed its range from 15.4% to 27.72%. The different stations recorded the highest and the least values in different months. Organic matter in the sediment was observed to be more at the deeper layers compared to the shallower regions. The seasonal average values showed the maximum during winter months and the other two seasons did not show noticeable difference. Analysis of variance and t-test did not show significant result in any of the cases.

Table 6.4A : Average monthly variations in chemical properties of bottom sediments of Sagar lake during the year 1988-89

Chemical Properties	Unit	Lake Zone	<---- 1988									---->	<--- 1989	--->
			Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb
1. Temperature	°C	Littoral	23.7	26.8	28.8	27.1	27.1	29.2	29.5	25.9	21	19.6	19.2	21.5
		Limnetic	23	25.5	28.4	26.3	28.5	28.6	29.9	26	21	19.3	18.3	21.5
2. pH	Units	Littoral	7.65	7.54	7.77	7.83	7.59	7.69	7.57	7.76	7.7	7.73	7.89	7.85
		Limnetic	7.55	7.48	7.89	7.67	7.52	7.55	7.5	7.63	7.67	7.65	7.63	7.87
3. Conductivity	µmho /cm	Littoral	166.3	219.3	221.7	227.8	305.2	207.1	217.3	228.9	227.1	199.3	214.1	226.7
		Limnetic	179.2	284.4	232.2	256.9	297.6	255.2	216.5	251.8	238.9	186.5	265.6	232.1
4. Chloride	mg/ kg	Littoral	90.1	175.2	206.9	135.2	258.6	141.8	203.5	110.1	105.1	96.7	143.5	143.5
		Limnetic	113.5	192.1	220.2	148.5	193.5	166.3	203.6	101.8	105.1	93.4	110.1	145.2
5. Carbonate	mg/ kg	Littoral	220	130	140	140	Nil	Nil	Nil	120	80	70	60	Nil
		Limnetic	210	190	160	150	Nil	Nil	Nil	170	40	130	180	Nil
6. Bi-Carbonate	mg/ kg	Littoral	1413.2	1220	1179.3	1382.7	1891	1830	1494.5	1270.2	1464	1260.7	1464	1555.5
		Limnetic	1616.5	1291.2	1098	1575.7	2074	2206.2	1565.7	1362.3	1687.7	1098	1321.7	1525
7. Calcium	mg/ kg	Littoral	1857	1790.2	1870.4	1870.4	1910.5	1670	1776.8	1616.2	1776.8	1763.5	1977.3	1776.9
		Limnetic	1790.2	1817	1990.6	1736.8	1817	1670	1710	1589.8	1656.6	1763.5	1803.6	1776.9
8. Magnesium	mg/ kg	Littoral	1242.6	1242.6	1267	1258.8	1502.5	1265.3	1421.3	1185.8	1356	1300	1518.7	1494.4
		Limnetic	1234.5	1300	1478.1	1307.6	1429.4	1340.1	1461.9	1291.3	1300	1388.8	1502.5	1608.1
9. Phosphorous	mg/ kg	Littoral	12.9	17.1	32	27	21.5	7.4	7.7	12.5	27.7	31.9	8.4	28.7
		Limnetic	30.2	25.3	32.2	38.8	28.5	7.7	8.5	28.8	25.8	39.2	15.3	30.9
10. Nitrate	mg/ kg	Littoral	12.3	20.1	17.5	20.4	17.1	16.2	17.8	18.1	17.4	12.2	16.7	16.5
		Limnetic	16.9	19.5	16.7	15.5	17.5	17.8	17.9	17.1	17.7	13.2	15.1	16.1
11. Org. Matter	%	Littoral	17.8	23.9	22.2	24.8	23.1	19.7	21.8	24.6	25.5	25.4	20.9	23.5
		Limnetic	26.4	26.2	24.3	25.5	21	24.6	23.7	24.9	27	22.9	25.4	25.6

(Source : Yatheesh, 1990)

Table 6.4B : Average monthly variations in chemical properties of bottom sediments of Sagar lake during the year 1983

Chemical Properties	Unit	Lake Zone	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
			<--------					1983						------->
1. pH	units	Littoral	7.3	7.5	9	9	9		8.5	7.8	8	7.4	7.7	7.8
		Limnetic	7	7	7.5	7	8		8.5	7	7.5	7	7	7
2. Sodium	mg/gr	Littoral	0.502	0.51	0.561	0.59	0.67		0.568	0.466	0.524	0.509	0.583	0.502
		Limnetic	0.42	0.502	0.531	0.546	0.648		0.604	0.531	0.488	0.59	0.502	0.561
3. Potassium	mg/gr	Littoral	0.25	0.267	0.248	0.3	0.318		0.312	0.223	0.221	0.226	0.294	0.261
		Limnetic	0.223	0.276	0.311	0.3	0.335		0.317	0.264	0.223	0.282	0.276	0.27
4. Calcium	mg/gr	Littoral	66.56	60.15	67.76	63.36	64.96		69.27	72.18	60.15	69.37	57.74	53.73
		Limnetic	30.47	54.53	56.94	60.15	44.91		59.34	52.13	76.19	48.92	54.53	48.12
5. Magnesium	mg/gr	Littoral	39.96	34.83	38.98	32.4	36.78		35.25	42.4	31.91	38.01	31.67	32.64
		Limnetic	16.04	31.67	29.72	31.18	26.31		30.7	31.67	31.18	28.26	34.11	27.77
6. Phosphorous	mg/gr	Littoral	0.039	0.0195	0.018	0.0085	0.014		0.019	0.015	0.0155	0.0145	0.0145	0.011
		Limnetic	0.033	0.022	0.014	0.014	0.016		0.023	0.024	0.024	0.015	0.016	0.023

(Source : Yadav, 1986)

Table 6.5 : Analysis of variance (F) & t-test of chemical parameter of bottom sediment of the Sagar lake

Parameters	Analysis of variance (F)		t - test
	Between stations	Between seasons	Between zones
Temperature	10.85 *	3596.5 ***	0.13 NS
pH	4.2 NS	6.98 *	1.31 NS
Conductivity	3.8 NS	4.2 NS	1.17 NS
Chloride	3.33 NS	19.69 **	0.11 NS
Carbonate alkalinity	0.11 NS	26.78 **	0.53 NS
Bicarbonate alkalinity	3.61 NS	37.5 **	0.66 NS
Caicium	0.66 NS	2.63 NS	1.11 NS
Magnesium	0.69 NS	5.89 NS	1.03 NS
Phosphorus	4.38 NS	9.53 *	1.26 NS
Nitrate	5.01 NS	6.55 NS	1.37 NS
Organic matter	1.73 NS	1.77 NS	1.83 NS

Probability Level (p)

NS :- no significant difference at 5%

* :- p less than 5%

** :- p less than 1%

*** :- p less than 0.1%

(Source : Yatheesh, (1990)

10. Sodium and Potassium

Metal content of lake-sediment like sodium and potassium was studied in 1983 (Yadav, 1986). There was no significant variation observed throughout in the lake-sediment for these two metals. However, sodium ranged between 0.42 mg/kg to 0.67 mg/kg and potassium ranged between 0.22 mg/kg and 0.33 mg/kg. The highest concentration of sodium and potassium was observed in May but the least value of sodium was recorded in January whereas that of potassium was recorded in September.

The seasonal average values for both sodium and potassium did not show significant variations.

6.5 Statistical Correlation

Statistical correlation analysis was studied among the values observed for various physico-chemical parameters of water and sediment of the lake in different years. In 1978 (Awatramani, 1980), only the surface water parameters were correlated among themselves for different seasons whereas in 1988-89 (Yatheesh, 1990), the same type of analysis was performed for parameters of water and sediment separately and combined both. The significance of variation was studied at various levels of probability such as 5%, 1% and 0.1% level. The mutual relationship was called not significant if the statistical coefficient fallen at or more than 5% level whereas it was called highly significant for coefficients fallen less than 0.1% level. For other values lying in between the two, the relationship was called a moderately significant only. These relationship along with coefficients are presented in tabular form in the tables. Table 6.6 and 6.7 gives correlation coefficient matrix of physico-chemical parameters of water and bottom sediments of the Sagar lake respectively. And table 6.8 gives correlation coefficient matrix between physico-chemical parameters of water and bottom sediments of the lake.

6.5.1 Correlation among Water Chemistry Parameters

(a) Secchi transparency was negatively correlated with water temperature, pH, total dissolved solid, and carbonate alkalinity with coefficient of variation between 0.73 to 0.93 and positively correlated with total hardness, calcium hardness and bi-carbonate alkalinity with coefficient of variation between 0.77 unit to 0.93 unit.

For other parameters it showed a very weak and either positive or negative correlation with coefficient value less than 0.7 unit. The correlation of secchi transparency was highly significant with water temperature and total hardness whereas it showed only a moderate significant result for other parameters.

(b) Water temperature was negatively correlated with secchi transparency, total hardness, total alkalinity, bicarbonate alkalinity and total carbon dioxide and positively correlated with pH and carbonate alkalinity. Among these parameters, only bicarbonate alkalinity showed highly significant result at less than o.1.% level and the rest showed only a moderate significant result. There were a weak positive or negative correlationship existed with other parameters.

(c) Hydrogen-ion concentration (pH) was negatively correlated with secchi transparency, total hardness, total alkalinity, bicarbonate alkalinity and total carbon dioxide and positively correlated with water temperature and carbonate alkalinity only. Among these parameters, carbonate and bicarbonate alkalinity showed very high significant result with pH and the rest parameters showed only a moderate significant result.

(d) Total dissolved solids (T.D.S.) was negatively correlated with secchi transparency, total hardness, calcium hardness and dissolved oxygen and positively correlated with conductivity, chloride, C.O.D, phosphate, nitrate and ammonia-nitrogen. Among these conductivity, dissolved oxygen and C.O. D showed a significant result whereas the rest showed highly significant result. The other parameters showed very weak correlationship with total dissolved solids.

(e) Conductivity was negatively correlated with calcium and dissolved oxygen and positively correlated with total dissolved solids, chloride, C.O.D., phosphate, nitrate and ammonia-nitrogen. Among these calcium, dissolved oxygen and nitrate showed a moderate significant result with coefficient less than 0.9 unit and the rest parameters showed a highly significant result of more than 0.9 coefficient value.

(f) Among the various parameters, chloride was negatively correlated with total hardness, calcium hardness and dissolved oxygen and positively correlated with total dissolved solids, conductivity, C.O.D., phosphate, nitrate and ammonia-nitrogen. Out of these parameters total dissolved solids, conductivity, total hardness, calcium hardness, dissolved oxygen and C.O.D. showed a moderate significant result and the rest gave highly significant result.

(g) Total hardness was negatively correlated with water temperature, pH, total dissolved solids, chloride, carbonate alkalinity, phosphate, nitrate and ammonia-nitrogen with moderate significant result and positively correlated with secchi transparency and calcium with highly significant result.

(h) Calcium hardness was negatively correlated with T.D.S., conductivity, chloride, carbonate alkalinity, phosphate, nitrate and ammonia-nitrogen and positively correlated with secchi transparency and total hardness. Out of these only TDS and total hardness showed highly significant result with coefficient greater than 0.9 unit.

(i) Magnesium hardness was negatively correlated with percentage oxygen saturation and positively correlated with total alkalinity only with a moderate significant variation.

(j) Total alkalinity was negatively correlated with water temperature, pH and percentage oxygen saturation and positively correlated with magnesium hardness, bicarbonate alkalinity and total carbon dioxide. All of these parameters showed only a moderate significant variation.

(k) Carbonate alkalinity was negatively correlated with Secchi disc visibility, total hardness, calcium hardness, bicarbonate alkalinity and total carbon dioxide and positively correlated with water temperature and pH. Out of these parameters only pH showed highly significant variation and the others showed a moderately significant values.

(l) Bicarbonate alkalinity was negatively correlated with water temperature, pH, carbonate alkalinity and percentage oxygen saturation and positively correlated with secchi disc visibility, total alkalinity and free carbon dioxide. Among these parameters water temperature, pH and total carbon dioxide showed highly significant variation.

(m) Free carbon dioxide is significantly positively correlated with total carbon dioxide only.

(n) Total carbon dioxide was negatively correlated with water temperature, pH, carbonate alkalinity and percentage oxygen saturation and positively correlated with total alkalinity, bicarbonate alkalinity and free carbon dioxide. Out of these only bicarbonate alkalinity showed highly significant variation.

(o) Dissolved oxygen was negatively correlated with T.D.S., conductivity, chloride, C.O.D., phosphate, nitrate and ammonia-nitrogen and positively correlated with percentage oxygen saturation only. All of these parameters showed only moderately significant variation.

(p) Percentage saturation of oxygen was negatively correlated with magnesium hardness, total alkalinity, bicarbonate alkalinity and total carbon dioxide and positively correlated with dissolved oxygen only. All these parameters showed moderately significant variation only.

(q) BOD did not give significant correlation with any of the parameters.

® C.O.D. was negatively correlated with dissolved oxygen only and positively correlated with T.D.S., conductivity, chloride, phosphate, nitrate and ammonia-nitrogen. Among these parameters only conductivity showed highly significant variation.

(s) Ortho-phosphate was negatively correlated with total hardness, calcium hardness and dissolved oxygen and positively correlated with T.D.S., conductivity, chloride, C.O.D., nitrate and ammonia-nitrogen. Out of these parameters T.D.S., conductivity, chloride, nitrate and ammonia-nitrogen showed highly significant result.

(t) Nitrate-nitrogen was negatively correlated with total hardness, calcium hardness and dissolved oxygen and positively correlated with T.D.S., conductivity, chloride, phosphate and ammonia-nitrogen. Among these parameters conductivity, total hardness, calcium hardness and dissolved oxygen showed a moderate significant variation.

(u) Ammonia-nitrogen was negatively correlated with total hardness, calcium hardness and dissolved oxygen and positively correlated with T.D.S., conductivity, chloride, C.O.D., phosphate and nitrate-nitrogen. Out of these total hardness, calcium hardness, dissolved oxygen and C.O.D. showed moderately significant variation and the others showed highly significant variation.

(d) 6.5.2 Correlation among Sediment Chemistry Parameters

Sediment temperature was significantly positively correlated with chloride and nitrate-nitrogen and significantly negatively correlated with pH only. All these parameters were moderately correlated with coefficient less than 0.9.

pH was only negatively correlated with temperature, conductivity, chloride and bicarbonate and having a moderate coefficient of less than 0.9.

Conductivity was positively correlated with bicarbonate and negatively correlated with pH only.

Table 6.6 : Correlation coefficient matrix of water chemistry of the Sagar lake

Parameter → ↓	S.D.V	Temp	pH	T. D. Solid	Cond-uct.	Chlor-ide	Total Hard.	Calci-um	Magn-esiu.	Total Alkal	CO3 Alkal	HCO3 Alk	Free CO2	Total CO2	Diss. O2	% Sat. O2	BOD	COD	PO4-p	NO3-N	NH3-N
Secchi Disc Visibility	1	-0.93 ***	-0.81 **	-0.73 *	-0.33 NS	-0.47 NS	0.93 ***	0.86 **	0.38 NS	0.53 NS	-0.77 *	0.77 *	0.16 NS	0.61 NS	0.35 NS	-0.34 NS	-0.32 NS	-0.3 NS	-0.52 NS	-0.59 NS	-0.5 NS
Temperature		1	0.67 **	0.45 NS	-0.02 NS	-0.14 NS	-0.75 *	-0.64 NS	-0.63 NS	-0.77 *	0.79 *	-0.9 ***	-0.16 NS	-0.72 *	-0.08 NS	-0.63 NS	-0.41 NS	-0.01 NS	-0.23 NS	-0.31 NS	-0.18 NS
pH			1	0.41 NS	-0.02 NS	0.18 NS	-0.72 *	-0.64 NS	-0.57 NS	-0.67 *	0.95 ***	-0.94 ***	-0.56 NS	-0.9 **	0.09 NS	0.63 NS	0.22 NS	-0.04 NS	0.14 NS	0.28 NS	0.19 NS
Total Dissolved Solid				1	0.88 **	0.94 ***	-0.9 ***	-0.95 ***	-0.23 NS	0.13 NS	0.49 NS	-0.23 NS	-0.13 NS	-0.19 NS	-0.73 *	-0.29 NS	0.05 NS	0.8 **	0.93 ***	0.94 ***	0.94 ***
Conductivity					1	0.96 ***	-0.61 NS	-0.72 *	0.58 NS	0.53 NS	-0.11 NS	-0.19 NS	-0.03 NS	0.18 NS	-0.8 **	-0.65 NS	-0.2 NS	0.92 ***	0.93 ***	0.89 **	0.95 ***
Chloride						1	-0.74 *	-0.84 **	0.47 NS	0.41 NS	0.31 NS	0 NS	-0.17 NS	-0.01 NS	-0.78 *	-0.53 NS	-0.19 NS	0.89 **	0.93 ***	0.92 ***	0.97 ***
Total Hardness							1	0.96 ***	0.18 NS	0.22 NS	-0.73 *	0.59 NS	0.19 NS	0.47 NS	0.49 NS	-0.09 NS	-0.2 NS	-0.55 NS	-0.72 *	-0.77 *	-0.77 *
Calcium								1	0.01 NS	0.06 NS	-0.66 *	0.48 NS	0.22 NS	0.39 NS	0.6 NS	0.06 NS	-0.06 NS	-0.66 NS	-0.79 *	-0.83 **	-0.85 **
Magnesium									1	0.78 *	-0.38 NS	0.66 NS	0.06 NS	0.57 NS	-0.61 NS	-0.88 **	-0.57 NS	0.52 NS	0.45 NS	0.36 NS	0.37 NS
Total Alkalinity										1	-0.5 NS	0.64 **	0.27 NS	0.77 *	-0.5 NS	-0.85 **	-0.32 NS	0.42 NS	0.27 NS	0.18 NS	0.39 NS
Carbonate Alkalinity											1	-0.89 **	-0.57 NS	-0.84 **	0.01 NS	0.53 NS	0.19 NS	0.01 NS	0.3 NS	0.42 NS	0.31 NS
Bi-Carbonate Alkalinity												1	0.49 NS	0.93 ***	-0.3 NS	-0.78 *	-0.31 NS	0.18 NS	-0.07 NS	-0.19 NS	-0.02 NS
Free Carbon Dioxide													1	0.76 *	-0.24 NS	-0.26 NS	0.42 NS	-0.09 NS	-0.05 NS	-0.12 NS	-0.06 NS
Total Carbon Dioxide														1	-0.37 NS	-0.72 *	-0.07 NS	0.13 NS	-0.02 NS	-0.14 NS	0.02 NS
Dissolved Oxygen															1	0.76 *	0.15 NS	-0.7 *	-0.71 *	-0.69 NS	-0.74 *
% Saturated Oxygen																1	0.43 NS	-0.59 NS	-0.42 NS	-0.35 NS	-0.46 NS
B O D																	1	-0.43 NS	-0.11 NS	0 NS	-0.09 NS
C O D																		1	0.86 **	0.76 *	0.86 **
Phosphate																			1	0.98 ***	0.92 ***
Nitrate																				1	0.91 ***
Ammonia																					1

Probability Level (p): NS : no significant difference at 5%; * : p less than 5%; ** : p less than 1%; *** : p less than 0.1%

(Source : Yatheesh, 1990)

Chloride was positively correlated with temperature and negatively correlated with pH only.

Carbonate content of sediment was only negatively correlated with bicarbonates.

Bicarbonate content of sediment was positively correlated with conductivity and negatively correlated with pH, carbonate and calcium.

Exchangeable calcium content of sediment was only negatively correlated with bicarbonates.

Exchangeable magnesium content, phosphorus and organic matter of sediment were not significantly correlated with any of the parameters.

Nitrate-nitrogen was significantly positively correlated with temperature only.

6.5.3 Correlation between Water-Sediment Chemistry Parameters

Sediment temperature was positively correlated with water temperature, pH and carbonate alkalinity and negatively correlated with transparency, total hardness, total alkalinity, bicarbonate alkalinity and total carbon dioxide. Out of these parameters, only transparency and water temperature showed a highly significant correlation with coefficient more than 0.9 unit.

pH and conductivity of sediment were not significantly correlated with water temperature, pH and carbonate alkalinity and negatively correlated with transparency and bi-carbonate alkalinity. All of these parameters showed a moderately significant correlation with coefficient less than 0.9 unit.

Carbonate content of sediment was positively correlated with T.D.S., conductivity, chloride, C.O.D., phosphate, nitrate and ammonia-nitrogen and negatively correlated with total hardness, calcium hardness and dissolved oxygen. Out of these parameters total hardness, calcium hardness, dissolved oxygen and nitrate showed moderately significant correlation with coefficient less than 0.9 and the others were highly significantly correlated with coefficient more than 0.9.

Bicarbonate content of sediment was only negatively correlated with conductivity, chloride, total alkalinity, C.O.D., phosphate and ammonia-nitrogen. All of these parameters showed only a moderately significant correlation with coefficient less than 0.9.

Exchangeable calcium content of sediment was only positively correlated with phosphate and nitrate and having a moderate significant correlation coefficient of less than 0.9 unit.

Exchangeable magnesium content of sediment was positively correlated with total hardness, calcium hardness and dissolved oxygen and negatively correlated with T.D.S. only. All of these parameters showed a moderate significant correlation with coefficient less than 0.9.

Available phosphorus content of sediment was positively correlated with total alkalinity and C.O.D. and negatively correlated with percentage saturation of oxygen only. All of these parameters showed a moderate significant correlation with coefficient of less than 0.9.

Nitrate content of sediment was positively correlated with water temp, pH, carbonate alkalinity and percentage saturation of oxygen and negatively correlated with transparency, bicarbonate alkalinity and total carbon dioxide. All of these parameters also showed a moderate significant correlation with coefficient of less than 0.9.

Table 6.7 : Correlation coefficient matrix of sediment chemistry of Sagar lake

Parameters → ↓	Temp	pH	Cond -ctivit	Cl	CO3	HCO3	Ca	Mg	P	NO3	Org. Matter
Temperature	1	-0.68 *	0.4 NS	0.87 **	0.04 NS	0.49 NS	-0.18 NS	-0.58 NS	-0.49 NS	0.71 *	-0.53 NS
pH		1	-0.84 **	-0.69 *	0.11 NS	-0.69 *	0.61 NS	0.46 NS	0.3 NS	0.03 NS	0.49 NS
Conductivity			1	0.54 NS	-0.39 NS	0.8 **	-0.57 NS	0 NS	-0.4 NS	-0.19 NS	-0.2 NS
Chloride				1	0.2 NS	0.55 NS	-0.19 NS	-0.54 NS	-0.24 NS	0.47 NS	-0.4 NS
Carbonate					1	-0.77 *	0.58 NS	-0.58 NS	0.57 NS	0.14 NS	0.31 NS
Bi-Carbonate						1	-0.72 *	0.1 NS	-0.62 NS	0.05 NS	-0.53 NS
Calcium							1	0.02 NS	0.22 NS	0.24 NS	0.36 NS
Magnesium								1	-0.23 NS	-0.23 NS	0.24 NS
Phosphorous									1	-0.49 NS	0.5 NS
Nitrate										1	-0.41 NS
Organic Matter											1

Probability Level (p) : NS : not significant at 5%; * : p less than 5%; ** : p less than 1%

(Source : Yatheesh, 1990)

Table 6.8 : Correlation coefficient between physico-chemical parameters of water and bottom-sediments of the Sagar lake

Parameters Sediments → Water ↓	Tempe-rature	pH	Condu-ctivity	Chloride	Carbon-ate	Bi-carb-onate	Calcium	Magne-sium	Phosp-horus	Nitrate
Secchi disc	-0.91 ***	+0.56 NS	-0.17 NS	-0.81 **	-0.43 NS	-0.13 NS	-0.08 NS	+0.79 *	+0.17 NS	-0.68 *
Temp	+0.99 ***	-0.65 NS	+0.35 NS	+0.87 **	+0.11 NS	+0.41 NS	-0.13 NS	-0.61 NS	-0.43 NS	+0.74 *
pH	+0.84 **	-0.39 NS	+0.17 NS	+0.81 **	+0.10 NS	+0.30 NS	+0.05 NS	-0.38 NS	-0.26 NS	+0.80 **
T.D.S.	+0.38 NS	-0.08 NS	-0.30 NS	+0.34 NS	+0.91 ***	-0.54 NS	+0.54 NS	-0.78 *	+0.37 NS	+0.38 NS
Conductivity	-0.09 NS	+0.23 NS	-0.51 NS	-0.08 NS	+0.96 ***	-0.83 **	-0.65 NS	-0.57 NS	+0.63 NS	+0.03 NS
Chloride	+0.07 NS	+0.16 NS	-0.46 NS	+0.08 NS	+0.96 ***	-0.75 *	-0.66 NS	-0.62 NS	+0.59 NS	+0.17 NS
Total hardness	-0.70 *	+0.30 NS	+0.13 NS	-0.61 NS	-0.68 *	+0.22 NS	-0.31 NS	+0.83 **	-0.14 NS	-0.61 NS
Calcium	-0.58 NS	+0.22 NS	+0.18 NS	-0. 55 NS	-0.77 *	+0.34 NS	-0.40 NS	+0.81 **	-0.29 NS	-0.50 NS
Magnesium	-0.65 NS	+0.36 NS	-0.17 NS	-0.45 NS	+0.48 NS	-0.61 NS	+0.56 NS	+0.13 NS	+0.56 NS	-0.60 NS
Total alkalinity	-0.79 *	+0.64 NS	-0.55 NS	-0.66 NS	+0.36 NS	-0.72 *	+0.45 NS	+0.08 NS	+0.74 *	-0.64 NS
Carbonate alkalinity	+0.76 *	-0.21 NS	+0.06 NS	+0.73 *	+0.20 NS	+0.13 NS	+0.34 NS	-0.31 NS	-0.23 NS	+0.80 **
Bicarbonate alkalin.	-0.89 **	-0.46 NS	-0. 30 NS	-0.77 *	+0.30 NS	-0.42 NS	+0.24 NS	+0.26 NS	+0.54 NS	-0.86 **
Free carbon dioxide	-0.10 NS	-0.14 NS	+0.08 NS	-0.24 NS	-0.16 NS	+0.09 NS	-0.29 NS	-0.27 NS	-0.09 NS	-0.46 NS
Total carbon dioxide	-0.69 *	+0.28 NS	-0.18 NS	-0.64 NS	+0.09 NS	-0.30 NS	-0.04 NS	-0.05 NS	+0.40 NS	-0.84 **
Dissolved oxygen	+0.02 NS	+0.14 NS	+0.08 NS	-0.11 NS	-0.71 *	+0.43 NS	-0.35 NS	+0.66 NS	-0.57 NS	+0.28 NS
% Oxygen saturat.	+0.66 NS	-0.28 NS	+0.28 NS	+0.48 NS	-0.51 NS	+0.61 NS	-0.34 NS	+0.12 NS	-0.73 *	+0.69 *
B. O. D.	+0.44 NS	-0.03 NS	-0.19 NS	+0.20 NS	-0.31 NS	+0.28 NS	-0.08 NS	-0.28 NS	-0.58 NS	+0.48 NS
C. O. D.	-0.09 NS	+0.08 NS	-0.34 NS	-0.07 NS	+0.97 ***	-0.76 *	+0.42 NS	-0.55 NS	+0.68 *	-0.41 NS
Phosphate	+0.17 NS	+0.07 NS	-0.35 NS	-0.07 NS	+0.95 ***	-0.70 *	+0.67 NS	-0.60 NS	+0.34 NS	+0.25 NS
Nitrate	+0.25 NS	+0.05 NS	-0.35 NS	+0.14 NS	+0.89 **	-0.63 NS	+0.71 *	-0.59 NS	+0.24 NS	+0.37 NS
Ammonia	+0.12 NS	+0.13 NS	-0.49 NS	+0.04 NS	+0.93 ***	-0.74 *	+0.61 NS	-0.66 NS	+0.54 NS	+0.20 NS

Probability Level (p) : NS : not significant at 5%; * : p less than 5%; ** : p less than 1%; *** : p less than 0.1%

(Source : Yatheesh, 1990)

6.6 Fish Cultivation

Sagar lake is eutrophic in nature and hence, it is also used for cultivation of commercial fishes. It is rich in essential dissolved nutrients to bear good and healthy flora and fauna. During fishing, the water is mixed with sediment and become muddy in appearance. The greenish colour of lake-water is due to abundant growth of algae, thereby fish cultivation is also comparatively higher. Important commercial and non-commercial fishes cultured in the lake are - Notopterus, Barbus, Labeo rohita, Wallago, Mystus, Calichrous, Belone, Ophiocephalus, Rasbora, Catla, Cirrhina mrigala etc. The monthly catch of major fish groups for the years 1970 (Adoni, 1975) and 1977-78 (Awatramani, 1980) is depicted in table 6.9A and 6.9B respectively.

From the above tables, it can be observed that the catch of fish during summer and winter months seems to be appreciably higher in comparison to the rainy and post-rainy months. It is reported that for the two years 1969 and 1970, the average fish yield from this lake was approximately 26,965 Kg/Year and the average annual income from the sale of these fishes was reported to be over Rs. 35,000.00 but in the year 1977-78, the average annual income was reduced to a great extent and was over Rs. 13,566.00 only.

6.7 Trophic Status

The trophic status of a lake can be expressed in terms of inter-related measurements, viz. primary productivity, water transparency, chlorophylla content, algal volume, concentration of nutrients, and types of community of fish and bottom fauna. According to Boughey (1975) the two water soluble substances - nitrate and phosphate - are critical in the evaluation of trophic level of natural fresh water ecosystems. He also says that natural water bodies evaluation of trophic level of natural fresh water ecosystems. He also says that natural water bodies undergo a process of succession from an oligotrophic to eutrophic state, a great acceleration of the rate of this process is due to cultural eutrophication. The primary effects of cultural eutrophication are depletion of dissolved oxygen, increase in turbidity, accumulation of organic matter, algal blooms etc. and the secondary effects can manifest in the form of fish killing. According to John and

Table 6.9 A : Monthly catch of major fish groups in Sagar lake in the year 1970

Months	Carps (kg.)	Local Major (kg.)	Local Minor (kg.)	Total Catch (kg.)
January	1728.9	198.6	3.5	1931
Feburary	1568.45	215.6	2	1786.05
March	3923.1	392.9	0.9	4316.9
April	4550.2	284.1	1.1	4835.4
May	3392.7	49.6	–	3442.3
June	5198.2	141.8	6.6	5346.6
July	91.9	–	–	91.9
August	3.5	–	–	3.5
September	32.2	–	–	32.2
October	250	–	–	250
November	4333.7	53.7	–	4387.4
December	5840.5	294.2	0.8	6135.5

(Source : Adoni, 1975)

Table 6.9 B : Monthly catch of major fish groups in Sagar lake in the year 1977-78

Months	Carps (kg.)	Local Major (kg.)	Local Minor (kg.)	Total Catch (kg.)
Apr-77	509.2	67.5	26.1	602.8
May-77	414.7	50.9	131.2	596.8
Jun-77	–	–	–	–
Jul-77	29	–	–	29
Aug-77	–	–	–	–
Sep-77	417.2	61	–	478.2
Oct-77	360.2	187.4	37.9	585.5
Nov-77	185.8	128.4	51.1	365.3
Dec-77	731.2	175.1	88.6	994.9
Jan-78	867.3	210.4	206.5	1284.2
Feb-78	216.9	146.9	160.2	524
Mar-78	185.5	253	255.5	694
Apr/May-78	1262.4	251.2	438.6	1952.2
Jun-78	149.7	121.4	310.8	581.9
Jul-78	9	–	–	9

(Source : Awatramani, 1980)

Dickson (1971) the study of bottom fauna are extremely important in determining the pollution status of water bodies because:

(a) many species of benthos are extremely sensitive to pollutants and respond quickly to it.

b) since they have an attached mode of life, they serve as natural monitors of water quality.

c) unpolluted water bodies have a high species diversity as compared to polluted water bodies.

Welch (1952) classified lakes based on their nutrient status into two categories:

1. Oligotrophic lakes:- These are characterized by deep water, high oxygen concentration at all depths, poor in phosphate, nitrate and calcium content, and low fertility.

2. Eutrophic lakes:- These are characterized by shallow water, rich in nutrients, seasonal depletion and sometimes absence of dissolved oxygen at the hypolimnion, and high productivity.

On the basis of the above criteria and the results obtained in various studies on the Sagar lake, this lake is definitely within the preview of eutrophic category of lakes because:

(a) it is shallow (mean depth about 2.48 m).

(b) nutrients are in abundance even after utilization by large population of phytoplankton and macrophytes:

Diurnal Range

	Phosphate	**Nitrate**	**Calcium**
In water (mg/L)	0.004 - 1.97	0.01 - 1.06	12.83 - 52.1
In sediment (mg/kg)	0.4 - 6.0	7.9 - 22.0	1402.8 - 2324.64

(c) dissolved oxygen ranged (diurnal value) between 1.62 mg/L (summer) and 7.68 mg/L (winter) at the bottom layers of the lake-water.

(d) high fertility of the water body is evident from seasonal algal blooms, heavy macrophyte growth, and abundance of benthic macro-invertebrates.

a) 7.0 PRESENT STATUS

7.1 Recent Development

At present, the Sagar lake is divided into two parts. The main lake occupies an area of 68 hectares and the small lake occupies an area of 14 hectares only. Hence, the total water spread area for entire lake is 82 hectares. The division of lake is facilitated with the construction of a high earthen bund called Sanjay Drive, crossing the lake from South-West to North-East direction. The two lakes are well connected to each other with a partly constructed culvert situated in the middle of the bund. The small lake receives water from Kanera feeder canal and allows to flow into main lake through this culvert. During 1989-90, Kanera feeder canal was constructed for diverting the flow of Kanera nalla into the lake because a few years back, due to scanty rains, the lake was about to dry. In the same year, a 0.3 m high steel shutter was provided on the only outlet, waste weir "Mogha", for raising the water level of the lake from R.L. 526.385 m to 526.685 m. Due to this, the storage capacity of Sagar lake has increased from 2.32 M.cum. to 2.77 M.cum. However, it has been observed that still huge quantity of water flows out of the lake during monsoon season through the waste weir.

7.2 Environmental and Ecological Problems

The topography of Sagar town is undulating as there are several hillocks located around the lake and also scattered in other distant area. Several municipal wards of the town such as Purbeau-tori, Bariaghat, Chakraghat, Parkota and Sanichari-tori are located on these hills. Besides these the municipal wards like Kakaganj, Baghraj, Jawaharganj, Lajpatpura, Brindavan and Gopalganj are also located in the vicinity of this lake. Due to improper drainage system, the waste water of these wards consisting of sewage and sullage water mixed with garbage, night soil and solid waste ultimately find its way into the lake thereby causing contamination of the impounded lake water. In addition, the people use the lake for all their needs including bathing, washing cloths, vehicle and animals and even for open defecation. Also, the drainage from South-Western portion of the catchment having agricultural fields, ultimately leads to the lake through small nallas (drains) which multiplied the problem further. Thus the above factors including improper and unplanned development of Sagar city led to the pollution of Sagar lake to reach, by now, an alarming stage. However, the major problems encounter in the lake can be short listed as follows:

(a) The lake is heavily loaded with pollutants joining through open drains.

(b) The inflow of Kanera feeder canal carries a lot of silt from southern catchment along with organic chemicals, agricultural residue, fertilizers etc.

(c) Domestic waste from near by localities also carries solid waste into the lake.

(d) The activities of 'Trapa' and lotus farming in turn increases deposition of residue.

(e) Human and animals activities at different surrounding ghats deteriorate quality of lake-water.

Recently made studies on Sagar lake showed that it is heavily infested with macrophytes and highly enriched with nutrients. Due to its low mean depth, high inflow and accumulation of silt, sewage and effluent containing organic matter, the lake is full with phytoplankton, a variety of microorganism including harmful bacteria and macrophytes. A very heavy growth of the following macrophytes is evident in the lake: Nymphaea stellata, Jussiac'a repens, Trapa bispinosa, Ceratophyllum demarsum, utricularia, Hydrilla verticiliata, Eichhornia crassipes, Spirodela polyrrhiza, Potamogeton pectinatus etc.

These macrophytes together with a number of other phytoplankton support the consumers of next tropic levels. As a consequence of large biomass of primary producers, high organic matter and nutrients, oxygen depletion, toxicity due to anaerobic conditions, foul odour and other factors unhygienic conditions within and around the lake can be well anticipated.

7.3 Incidence of Diseases due to Lake-Water

It has been reported from the office of the Civil Surgeon, Sagar that the population of wards situated surrounding the Sagar lake suffer from various kinds of diseases occurring due to the precarious condition of lake-water. The incidence of diseases found in the persons out of surrounding wards total population 34,710 (Census 1991), is tabulated year wise in table 7.1.

7.4 Recent Physico-Chemical Condition of Lake-Water

In a recent study, the physico-chemical qualities of surface water of Sagar lake were analyzed by taking samples at various ghats situated in the periphery of the lake. In addition to this, the similar analyses were carried out for inflow nallas (drains) Bariaghat nalla and Brindavan Bag nalla, joining the lake at different positions. The detail of observations for these are tabulated in table 7.2 and 7.3 for selected period of one month each for pre-monsoon, post-monsoon and monsoon seasons respectively as below:

It is reported that the variation of B.O.D. for surface water of the lake showed the range between 7.2 mg/L and 22.1 mg/L during the above said periods. It is also reported that the B.O.D. variation in Bariaghat nalla and Brindavan Bag nalla was from 40 mg/L to 520 mg/L and from 32 mg/L to 480 mg/L respectively observed during these months.

However, it has been stated that the water quality of this lake is monitored by M.P. Pollution Control Board, Sagar at regular interval.

Table 7.1 : Incidence of diseases found in surrounding wards population due to the Sagar lake

Sl. No.	Diseases	Total persons suffered in the year			
		1993-94	1994-95	1995-96	1996-97
1.	Otitis externa, Media	41	30	51	38
2.	Rhinitis, Sinusits	52	35	58	49
3.	Conjunctivitis	102	86	110	119
4.	Bronchitis	88	109	128	98
5.	Eczematous dermatitis	65	79	58	45
6.	Scabies	128	152	139	118
7.	Furunculosis	92	101	89	76
8.	Malaria	29	26	30	22
9.	Viral fever	8	12	16	20
10.	Enteritis	43	54	49	35
11.	Amoebiasis	95	101	110	98
12.	Hepatitis	3	2	3	1
	Grand Total	746	787	841	719

(Source : PHED, Sagar 1997)

Table 7.2 : Physico-chemical qualities of surface water at various ghats in the Sagar lake

Sl. No.	Characteristics	Unit	Surface Water		
			May-96	Dec-96	Aug-97
1.	Temperature	°C	27.2	24.5	--
2.	Colour		Greenish	Light Green	Light Green
3.	Odour		Impleasent	Impleasent	Impleasent
4.	pH	unit	8.39	8.53	7.77
5.	Total Solids	mg/L	--	165.5	286
6.	Suspended Solids	mg/L	134	141	132
7.	Dissolved Solids	mg/L	1	175	66
8.	Nitrate	mg/L	0.065	0.13	55
9.	Phosphate	mg/L	0.138	0.23	0.23
10.	Chloride	mg/L	76	41	58
11.	Sulphate	mg/L	30.5	34	27.5
12.	Fluoride	mg/L	0.31	--	0.18
13.	Dissolved Oxygen	mg/L	6.2	7.6	5.2
14.	COD	mg/L	250	83.2	82.72
15.	Total Hardness	mg/L	170	186	144
16.	Calcium Hardness	mg/L	72	114	88
17.	Magnesium Hardness	mg/L	98	72	66
18.	Total Alkalinity	mg/L	202	182	158
19.	Specific Conductance	mg/L	0.52	0.38	0.34
20.	Coliform (MPN/100)	mg/L	--	1600	1600
21.	Sodium	ppm	78.5	--	57.5
22.	Potassium	ppm	25.5	--	14.5
23.	Nitrogen	mg/L	3.36	--	1.89

(Source : PHED, Sagar 1997)

Table 7.3 : Physico-chemical qualities of various nallas joining the Sagar lake

Sl. No.	Characteristics	Unit	Nallas joining the Sagar lake					
			Bariyaghat			Brindavan Bag		
			May-96	Dec-96	Aug-97	May-96	Dec-96	Aug-97
1.	Temperature	°C	28.2	25	2	30.6	24	28
2.	Colour		Light Black	Light Black	Black	Black	Light Black	Muddy
3.	Odour		Impleasent	Impleasent	Impleasent	Impleasent	Impleasent	Impleasent
4.	pH	unit	7.82	8.12	7.89	7.7	8.05	8.31
5.	Total Solids	mg/L	--	1066	18	--	1194	1026
6.	Suspended Solids	mg/L	592	208	584	26	118	324
7.	Dissolved Solids	mg/L	--	858	12	--	1076	702
8.	Nitrate	mg/L	0.15	0.12	--	0.08	0.18	--
9.	Phosphate	mg/L	0.69	0.51	0.6	0.72	0.44	0.9
10.	Chloride	mg/L	232	124	256	174	204	116
11.	Sulphate	mg/L	60	38	56	48	72	40
12.	Fluoride	mg/L	0.36	--	0.22	--	--	--
13.	Dissolved Oxygen	mg/L	--	--	--	--	--	--
14.	BOD	mg/L	--	--	--	--	--	--
15.	COD	mg/L	520	249.6	564	540	499.2	180.48
16.	Total Hardness	mg/L	420	284	420	392	420	300
17.	Calcium Hardness	mg/L	224	152	180	208	288	192
18.	Magnesium Hardness	mg/L	196	132	240	184	132	108
19.	Total Alkalinity	mg/L	660	440	600	432	408	334
20.	Specific Conductance	mg/L	1.7	1.6	1.5	1.55	122	0.91
21.	Coliform (MPN/100)	mg/L	--	--	--	--	--	--
22.	Sodium	ppm	156	--	132	115	--	77
23.	Potassium	ppm	87	--	68	53	--	46
24.	Nitrogen	mg/L	7.84	--	6.72	9.8	--	5.6

(Source : PHED, Sagar 1997)

8.0 PROPOSAL AND SCHEMES IMPLEMENTED ON LAKE

8.1 General

The quality of lake-water is being deteriorated gradually due to various correlated reasons. The degradation has now reached at a level which is causing ecological, hydrological and environmental disaster to the adjoining areas. Though, studies on various problematic aspects of the lake are carried out from academic point of view, recommendations are made by various Government organizations and steps are also taken for their remedies, but neither the quality of the water nor the related problems of the lake could be solved up to desired level. This may be due to lack of general awareness in people, lack of coordination among various local Government agencies and improper planning etc.

8.2 Increase of Lake Capacity

Dredging Corporation of India Limited (D.C.I.L.), Visakhapatnam, a Government of India undertaking, has recommended in 1989-90 the following measures to be adopted:

(a) On the basis of sounding chart, to desilt the whole lake up to 5 m or 6 m below full tank level (R.L. 526.385 m), the quantity to be dredged works out to 20.28 lakh Cu.m. or 31 lakh Cu.m. respectively and to desilt the lake only in the northern side up to 5 m below F.T.L., the quantity of dredging works out to 2.05 lakh Cu.m. only.

(b) The desiltation of the lake has to be done by a Portable Cutter Suction Dredger with a long pipeline of about 1500 m for disposal of the dredged material.

(c) No single disposal area can be made use of because of the larger dimensions of the lake and non-availability of adequate areas in vicinity of the lake.

(d) To desilt the whole lake, there is no alternative but to make use of small lake on the southern side for disposal of the dredged material.

(e) A small Portable Cutter Suction Dredger requires about 1000 Cu.m. of water per hours for transportation of the dredged material. This water can, however, be circulated back to the lake from the disposal grounds. Some losses of water by absorption or evaporation can not be avoided.

(f) The total amount estimated for dredging 2.05 lakh Cu.m. works out to Rs. 165 lacs approximately.

(g) The desilting of the lake will solve environmental problem of Sagar city. After removal of the silt, lake shall carry fresh water all around the year which may solve the drinking water problem of the city to some extent. But this proposal could not be adopted as it was declared very expensive by the local authorities.

Due to rejection of proposal of D.C.I.L., Visakhapatnam, the Water Resources Department, Sagar has proposed an alternative plan in the year 1990. Some steps of this plan have already been completed and the rests are reported to be in the completion stage. According to this plan, following measures are recommended for the renovation of the lake:

(a) Renovation of Kanera feeder canal by embankment stone pitching and construction of W.B.M. road over it.

(b) Construction of culverts across the canal and the Sanjay Drive.

(c) All round protection of Sagar lake by erecting protection wall etc.

(d) Construction of three units of sanitary system inside the watershed area.

(e) Raising of the floor level of various ghats around the lake.

(f) Arrangement of Boat Club and formation of parks around the lake for recreation purpose.

8.3 Sagar Lake Environmental Improvement Schemes

This scheme is approved in the year 1990 and it is being carried out under Bundelkhand Development Authority, Sagar. Under this scheme, it is proposed to divert sewage and sludge water of adjoining area reaching to lake through open drainage. According to this scheme, there are nine nallas, carrying sewage and sullage water, join the lake at different places. The total flow in these nallas is 7.0 MLD during peak hours. To facilitate the diversion properly, the area having these nallas is divided into two zones. Zone A is having main sewer line from Gaughat to Bus stand where a sump well is proposed and zone B comprises of sewer line from Chakraghat to Gola kuan near Diwalanaka. The total cost estimated for this work is about Rs. 96 lacs.

It is reported that about 50% of work is already been executed and the balance work is in progress.

8.4 Plantation and Soil Water Conservation Measure

This project is prepared in 1997 by South Sagar Forest Division, Sagar essentially to emphasize on erosion treatment by way of taking plantation and soil-water conservation activities. It is proposed to take up the following operations for treating catchment areas of the lake and the feeder canal mainly to create and increase the vegetative cover for reducing the erosion by reducing the rate of run-off and increasing percolation of rainy water into the soil. The main activities in such area will comprise of:

(a) Digging of contour trenches

(b) Planting at both ends of trenches

© Construction of check dams across nallas and water flow channels

(d) Khair and other species seed sowing on berms of trenches.

(e) Direct seed sowing of suitable species of grasses and fodder plants

(f) Singling and cut back of existing root stock of important species etc.

It is reported that the proposed treatment and effective control and protection of the area would certainly enrich the biomass production, enhance the sediment trapping or erosion, increase in bird diversity of Sagar and encourage stall feeding and people's participation. The total cost of the project has been calculated to be Rs. 1.90 crores spreaded over 8 years period.

8.5 Environment and Development Profile of the Lake

This is a prefeasibility report which was prepared by the Public Health Engineering Department, Sagar in 1997 in order to upgrade the overall environmental conditions of Sagar lake and to maintain aesthetic value as this lake has been, recently, included in the National Lake Conservation Plan (N.L.C.P.) of Government of India. In this report following proposals have been made:

(a) To divert the flow from the open drains by a peripheral sewerage system and to pump it out of the ridge beyond the catchment.

(b) To construct self arresting structures in the southern catchment on the tributaries and on the feeder canal.

(c) Removal and management of solid waste out of the catchment into the nearby dumping yard, for final disposal.

(d) The activities of Trapa and lotus farming must be shifted from main lake to the Ratona lake, which is about 8 Km. away from Sagar.

(e) Dhobighats are to be developed at down stream of the weir on Mogha nalla and arrangement of water has to be made from the lake itself by pumping.

(f) Arrangement of cattle yards is to be made on suitable place outside the city.

(g) Cleaning of macrophytes and its treatment by proper methods to control future growth.

(h) Development of buffer zone under lake front development to avoid direct approach to the lake by people.

9.0 CONCLUSIONS AND RECOMMENDATION

9.1 Conclusions

Following conclusion can be drawn from the various studies carried out on Sagar lake by different investigations:

1. The seasons influence on the biological processes going on in aquatic environment have been observed in the lake. The impact of influx of monsoon apart from bringing radical changes in surface waters also cause oxygen deficit at hypolimnetic level

2. A very weak thermal stratification occurs during summer months but there exists no chemical stratification in the lake.

3. The diurnal fluctuation of the physico-chemical features of Sagar lake do not show any extreme level of variation so as to cause any detrimental effect upon the biocoenoses.

4. The physico-chemical profile of water along the three transects did not differ significantly. The difference in quality of water between the sub-littoral zone and bottom waters does not show significant variations.

5. A critical evaluation of the morphometric, physico-chemical and biological features strongly suggest a high trophic status and high organic pollution level to Sagar lake.

6. The availability of bicarbonates (60-148 ppm) is the main cause for higher primary production of algae andacrophytes.

7. Small concentration of chlorides (20.2-48 ppm) in Sagar lake indicates low organic

effluents from outside sources.

8. During summer, the occurrence of phosphate and nitrate in traces coincide with plankton concentration

9. The peak of phytoplankton is associated with low nitrates, phosphates, water level high water temperature and pH.

10. The low volume of Desmides is suggestive of eutrophic condition and considerable productive capacity of Sagar lake.

11. Estimation of zooplanktonic fauna confirmed that Indian inland fresh waters were dominated by Rotifers and the Cyclops and large number of Rotifers abounded eutrophic waters.

12. Light, temperature, and nutrient availability regulate the productivity of macrophytes.

13. The daily net production of Hydrilla verticillata is found quite high.

14. Among mineral contents of macrophytes, the concentration of potassium has been always more than sodium

15. Photosynthesis pigments were found to be higher in submerged species than in free floating and rooted with floating leaves plants.

16. Maximum energy content has been recorded in floating leaves plants Nelumbo nucifera while minimum for submerged plant Hydrilla verticillata.

17. The Sagar lake is like a big "dust bin" for the Sagar city as every effluent is being thrown into it and thus polluting the lake and making it shallower day-by-day.

18. Abundance of carnivorous and local minor fishes spoil the fish seed of major carps

thereby reducing the fish yield per year and making the lake uneconomical for pisciculture.

9.2 Recommendation

The Sagar lake is a boon for the inhabitants of this city, though, it is infested with environmental, ecological, biological and hydrological problems. Virtually it can be said that the lake is in its dying stage. Considering various attempts, which have been made in the past to counter, these problems following recommendation are advised:

1. There have been varying opinions and proposals on the various problems of the lake such as water pollution, erosion, siltation, wastewater drainage etc. But a systematic and scientific approach has not been properly applied in the lake. To reduce the problems in the lake a scientific approach is of almost importance.

2. As hydrological studies have not been taken up yet. Therefore, a detailed hydrological study such as water balancing, sedimentation, bathymetry etc. should be taken up.

3. The years long problem of drinking water of the city and near by area may be solved partly by making water available from Sagar lake itself. But for this, purification of lake-water is essential, though it is a up-hill task. To this assignment, a step-by-step procedure should be adopted:

   (a) Nallas, joining the lake, should be diverted away from the lake. For this awareness of nearby population and some alternative arrangement for drains are required.

   (b) Though the lake have tremendous power of natural self-purification. But some artificial purification will also, be required.

   (c) Desiltation of lake should be done as it is being done in lower lake of Bhopal. Also, it can be developed in the pattern of Bhopal lakes.

   (d) Lake should be protected from all sides by developing parks around the lake for public recreation.

4. In absence of discharge measuring site in the catchment of the lake, the actual discharge and siltation rate can not be observed. However, watershed activities are required to be started I lake catchmet to reduce the soil erosion

5. Small lake should be made more deeper so that water can be stored in it even in summer season.

6 It is high time to come out with a scientifically and administratively comprehensive package plan to retrieve the lake from its present pathetic condition.

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DIRECTOR	:	Dr. S. M. SETH
HEAD	:	Dr. BHISHM KUMAR
STUDY GROUP	:	JIWESHWAR SINHA
		LAXMI NARAYAN THAKURAL