HYDROLOGICAL INVESTIGATIONS ON LAKE PICHHOLA, UDAIPUR (RAJASTHAN) FOR ITS CONSERVATION AND MANAGEMENT

S. D. Khobragade, K. K. S. Bhatia, C. S. P. Ojha*, D. S. Rathore, Bhishm Kumar and K. D. Sharma
National Institute of Hydrology
Roorkee (Uttaranchal)- 247 667
suhas@nih.ernet.in, kksb@nih.ernet.in, **dsr@nih.ernet.in**, bk@nih.ernet.in; kdsharma@nih.ernet.in

Dept. of Civil Engg*.
Indian Institute of Technology
Roorkee (Uttaranchal)- 247 667
cojhafce@iitr.ernet.in

ABSTRACT

Lake Pichhola in Udaipur (Rajasthan) is a very significant and valuable manmade lake of the region. For the last few centuries, it has acted as a catalyst in the development of the region by serving variety of domestic and developmental purposes such as civil water supply, irrigation, fish-culture, recreation, industrial and other commercial activities. As a matter of fact, it has become the lifeline of Udaipur by being the backbone of the economy of the region due to tourism. However, due to excessive interference in the lake catchment and unscientific use of the lake water over the years, the lake is engulfed with various problems. The condition of the lake is precarious and calls for an urgent remedial action. So, hydrological investigations are being undertaken with the objective of identifying the various problems of the lake, their causes and possible remedial measures to rejuvenate the lake. This paper presents the results of the investigations carried out so far based on the available data. Based on this, certain preliminary suggestions to for proper conservation and management of the lake have been suggested.

INTRODUCTION

Lakes are significant and valuable natural resources, and quite often the only source of drinking water during the lean season, particularly in the water scarce arid and semi arid regions. Lakes act as catalysts in the development of a region by serving variety of domestic and developmental purposes such as civil water supply, irrigation, fish-culture, recreation, tourism, industrial and other commercial activities etc. Many cities have been built up on the banks of the lakes. Udaipur City in Rajasthan is one such city, built on the bank of Lake Pichhola. However, because of the increasing human interference in the catchment for developmental and domestic reasons, lakes are quite often overexploited leading to their quantitative and qualitative degradation. Hydrologically, because of relative lack of motions of their waters, lake basins act as sediment traps. Sediments bring nutrients with them and this causes growth of the aquatic plants, a process called eutrophication. Although, lakes being only the transitory features of the landscape, have a definite birth and death, interference with the lakes and their catchments, in many or most cases, actually hastens their death. The trend has increased especially after the process of urbanization.

Lake Pichhola is the major source of drinking water for the city of Udaipur. Moreover, it is the lifeline of lake Udaipur as it is the backbone of the economy of the region due to tourism. However, due to excessive interference in the lake catchment and unscientific use of the lake water, the lake is engulfed with various problems. People residing by the banks of the lake are reported to be suffering from many water borne diseases (Jheel Sanrakshan Samittee Report, 1996). This has caused increased health costs and water treatment costs. The declining water availability in the lake has necessitated the arrangement of an alternate water supply causing increased costs of water supply. Moreover, the quantitative and qualitative degradation, supplemented by foul odours, have reduced the aesthetic value of the lake causing threats to tourism, which is the major economy of the region. In general the condition of the lake is precarious and calls for an urgent remedial action. Since behaviour of a lake ecosystem depends to a large extent on its hydrological regime understanding of the hydrological aspects of a lake is a prerequisite for a successful planning and implementation of any lake conservation and management programme. Since Lake Pichola has been in limelight in recent years for the various environmental problems, hydrological investigations on the lake have been undertaken by the National Institute of Hydrology, Roorkee since April, 2004 to scientifically investigate into the various hydrological aspects of the lake so as to suggest proper measures for its conservation and management. The present paper presents the results obtained so far based on the preliminary analysis of the available data. More detailed investigations are being undertake.

WHY STUDY HYDROLOGICAL ASPECTS ?

Lakes form an important component of the Hydrologic cycle. The precipitation falling over the land ultimately reaches the oceans and is evaporated back to the atmosphere not before it visits lakes through the rivers and streams. Since the lake water has a residence time, it provides a natural storage and is a viable means to accelerate or enhance recharge of ground water. However, growing urbanization and industrialization, land use changes etc. are leading to qualitative and quantitative degradation of the lakes, posing serious threats to their very existence and many a lakes in India have been reported to have even undergone untimely extinction.

Problems of the individual lake vary. Each lake will have its own set of problems depending upon its morphology, climate of the region, land use in the catchment, degree of human interference in the catchment and use of the lake water along with other environmental factors. Thus, some lakes particularly in arid and semiarid regions may face the problem of heavy evaporation and reduced inflows and may even dry out completely in summer as in the case of some lakes in Rajasthan. Since the demand for fresh water is increasing day by day due to exponential growth of population, proper conservation and management of all the fresh water resources including lakes has gained great significance in recent times. Moreovr, the management has to be efficient, economic and environmentally friendly. This is not possible without a proper understanding of the various hydrological aspects of the lake. For example lake waters are used for variety of purposes including the developmental activities. To properly plan the supply of water to meet the various demands, knowledge of the availability of water in lakes at different points of time, based on the water budgeting of the lake is essential. To arrive at a more realistic and precise water balance, understanding of the various hydrological processes such as rainfall-runoff relationships for the lake catchment, surface abstractions, ground water-lake interaction, evapo-transpiration in the lake catchments and lake evaporation etc is required. Understanding of these processes is also important for lakes which are suffering from the problem of reduced inflows or drying. It is for these reasons that hydrological investigations of lakes are significant.

REVIEW OF EARLIER WORKS ON LAKE PICHHOLA

The first reported study on Lake Pichhola is probably that of Vyas (1968). A number of studies have been reported since then. Billore (1981) studied the ecological aspects of Lake Pichhola including the productivity of macrophytes. Madhu Sudan et al., (1984) studied the eutrophication problem of the lake. They have also studied the contribution of surrounding habitation in this process and the consequences of eutrophication for the people residing in the surrounding area. The Rajasthan Pollution Prevention and Control Board (1986) reported the chemical analysis of the lake water. Vyas et al (1986) conducted hydro-biological studies and studied the energy status of the species of different zones of the lakes. Rao et. al. (1988) conducted morphometric studies on lakes of Udaipur including Pichhola-Swaroop Sagar Complex. Vyas et al. (1989) have carried out a comprehensive review of the various hydro-biological studies conducted on Udaipur lakes over the period of 25 years (1964-1989). The review includes various hydrobiological aspects such as physico-chemical characteristics of water and sediments, variations in species composition, phytoplankton and zooplankton, macrophytes, community structure, biomass etc. Sharma and Durve (1990) have studied the relationship between water clarity of 26 water bodies of Rajasthan including Lake Pichhola. Majoo (1991) conducted studies on impact of habitation on hydrobiology of Lake Pichhola. Kumar and Sharma (1991) studied the physico-chemical limnology of Pichhola lake and compared it with that of the nearby Fatehsagar lake. In one of the only reported engineering studies on Lake Pichhola, Purohit et. al. (1991) conducted studies on sedimentation of the lake and determined the life of the lake. The life of the lake has been estimated to be less than a century. Das and Singh (1995) studied the water chemistry of Lake Pichhola. The Jheel Sanrakshn Samitee (1996) have carried out comprehensive assessment of the environmental status of lake Pichhola and suggested measures for its short term and long term management

The review of the earlier work carried out on Lake Pichhola so far indicates that there is a distinct bias towards the limnological aspects in the various reported studies. This is understandably so because most of these studies have been carried by the limnologists and biologists. These studies are quite significant to analyses the qualitative aspects as they reveal the biological and chemical characteristics of the lake at different points of time. However, the studies are inadequate for overall understanding of the hydrological .behaviour of the lake ecosystem as they do not consider the various hydrological aspects.

OBJECTIVES OF THE STUDY

Keeping in view the significance of the lake, the present environmental status and problems of the lake, and the present gaps in the research, the present investigations have been taken up with the following objectives:

(i) To identify the major problems of the lake
(ii) To understand the hydrological behaviour of the lake
(iii) To identify the causes of quantitative and qualitative deterioration of the lake
(iv) To suggest remedial measures for proper management and conservation of the lake

STUDY AREA

General

Udaipur is called the city of lakes. There are a number of lakes in and around Udaipur. Lake Pichhola, which is the oldest and biggest of all of them is in particular very significant. It is located at 24^0 34' N latitude and 73^0 40' E longitude, at an altitude of 587m above mean sea level. It was constructed by a Banjara chief in 14^{th} century. It is at the bank of this lake that the city of Udaipur was established by Rana Udai Singh in 1560 A. D.. The lake is the major source of drinking water for the city of Udaipur. Till recently, of the total water supply to Udaipur city, about 85% used to be met from Lake Pichhola alone. Of late, however, the water availability in the lake is unable to meet the demand and water is being brought to Udaipur from Lake Jaisamand, which is located at about 40 kms from Udaipur. The lake ecosystem once used to support a wide variety of fauna. According to the Rajasthan Pollution Prevention and Control Board Report (1986), 240 different species of birds were seen on the island of the lake, whereas thirty five different kinds of fresh water fish were identified in the lake before the disastrous drought of 1972-73. Some of the fishes have now disappeared (Jheel Sanrakshan Samitee Report, 1996).

The lake is fed mainly by rain water. River Sisarama is the major inflowing stream to the lake. A dense population resides along the northern shores of the lake. These people use the lake water directly for bathing, washing of clothes and socio-cultural activities. Figure 1 shows the location map of study area. Fig. 2 presents the view of Lake Pichhola. Table 1 presents the salient features of the lake.

Table 1. Salient features of Lake Pichhola, Udaipur
(Kumar and Sharma, 1991)

Parameter	Value
Longitude	$73^0 40'$
Latitude	$24^0 34'$
Altitude (m)	587
Normal rainfall (mm)	635
Storge capacity (MCF)	483
Water Spread Area (Sq. Km)	6.96
Maximum depth (m)	8.25
Mean depth (m)	3.3
Maximum length (km)	3.6
Maximum width (km)	2.61
Mean width (km)	1.93
Length of shoreline (km)	12.9

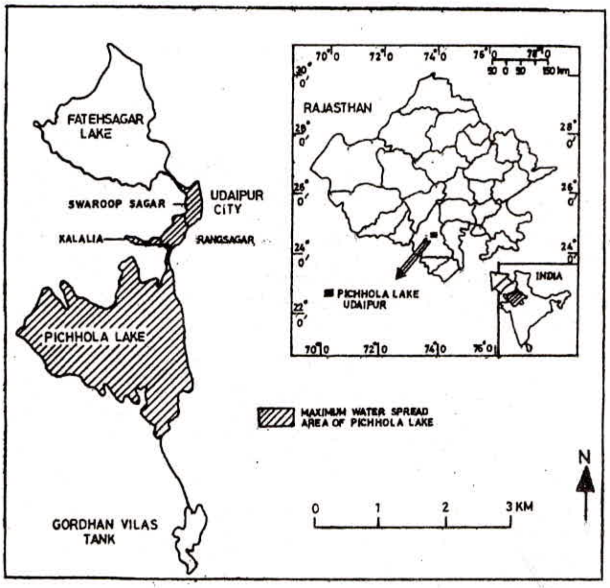


Fig. 1. Location map of Lake Pichhola, Udaipur (Rajasthan)

Fig. 2 View of Lake Pichhola
(coloured photograph is given at the end of the book)

Catchment

The catchment area of the lake is about 142.6 sq. km. Most of the catchment is barren hard rock with high hills, the average height of the which ranges from 650 m to 900 m. The mean slope of the catchment is 3.04% (Purohit et a., 1991). The main lithology in the catchment is slaty quartzite, phyllite, current bedding and other sedimentary structures, and dolomite limestones at the west of the lake, belonging to the Aravali super group (Das and Singh, 1995). The catchment area is a semi-arid climatic region. There are three distinct seasons viz. winter (October to mid February), summer (mid February to mid June) and monsoon (mid June to September). Maximum temperature is around 43^0 C in May-June while minimum can be as low as 3^0 C. The normal annual rainfall is 635 mm. About 80% of the total rainfall occurs during the monsoon months of June-September. Distribution of annual rainfall is uneven and shows large temporal and spatial variations. Air is generally dry except for the monsoon period when the humidity is around 70%. Summer months are the driest of the year when the humidity goes to about 20-25%. Winds are generally light with some strengthening in the latter half of summer and the monsoon. Dust-storms and thunderstorms occur sometimes in the hot months of summer. No specific information on the soils of the catchment is available. Major crops in the catchment are maize and wheat. Forest type is mixed type deciduous tropical forest.

Fig. 3 presents the land use map of the lake catchment and Table 2 presents the land use statistics for the study area obtained from the remote sensing data. It can be seen that the land use in the catchment is predominantly wasteland and forests with each occupying nearly 39% of the catchment area, aggregating to 78%. Agriculture area is only 19%, not all of which is cultivated every year. The dense forest is only 20.82 % of which most of the forest is Acacia/ Prosopis Juliflora. Forests are mostly distributed in the east and north part of the basin. The other deciduous forests area e.g. Bamboo etc are located in the north-west part of the area, either on the hills or in plain areas around the lake.

Table 2. Land use classification of Pichhola lake catchment

Major Land Use	Area (sq. km)	Area (% of total)
Cultivable land	27.43	19.24
Urban	1.13	0.79
Dense forest	29.69	20.82
Sparse forest	27.56	19.33
Wasteland	56.79	39.82
Total	142.6	100

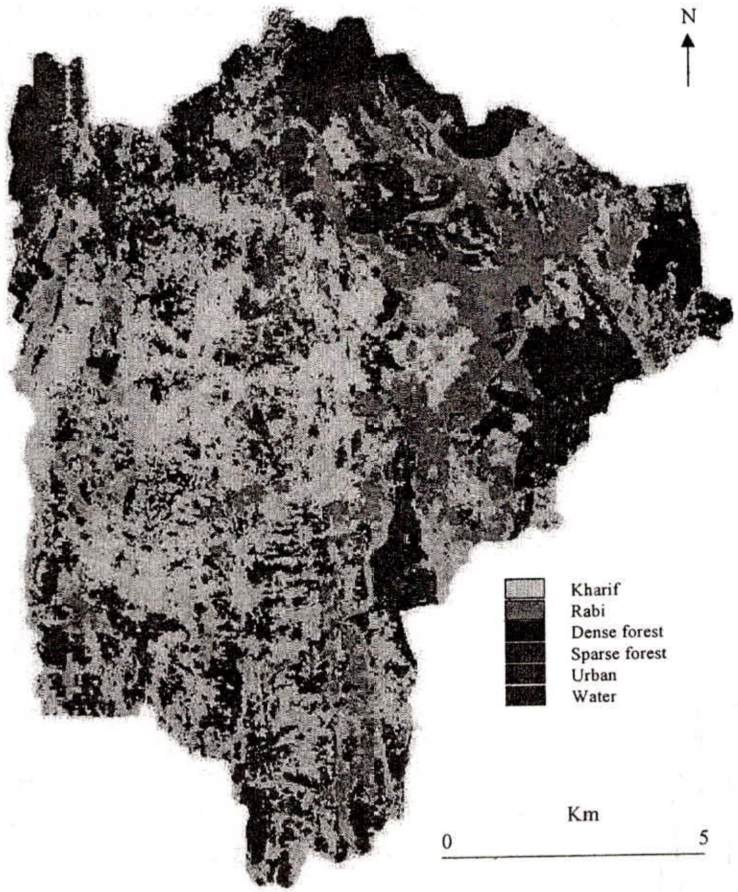


Fig. 3 Land use map of Pichhola lake catchment

MAJOR PROBLEMS IN THE LAKE AND THEIR CAUSES

Based on the review of the literature, interaction with local people and the local field organizations, and through various actual field visits to the lake and its catchment, three major problems have been identified for the lake. These are : (i) regular drying of the lake due to reduced inflows, (ii) eutrophication and water quality deterioration and (iii) sedimentation. All these problems are leading to quantitative and qualitative degradatio of the lake. Supplemented by problems like foul odours, they are reducing the aesthet he lake causing threats to tourism, which is the major economy of the region. The lems are discussed here in brief.

DRYING OF THE LAKE DUE TO REDUCED INFLOWS

Vyas in 1968 observed that the "record of last six years (1960-65) indicates that the lowest water level never went below the sluice level even during the driest part of the year". Even during his investigation period from June, 1965-May, 1966 he observed the pre-monsoon water level to be about 0.8 m above the sluice level and during the post-monsoon period the level to be about 4 m above the sluice level. Unfortunately this scenario has drastically changed over the years. The lake dried out completely during 1987. However, this drying was due to the severe drought. But, despite the adequate rains, the lake water level has gone down considerably over the last few years and most part of the lake is getting dry as the lake is not getting adequate inflows. To understand the nature and causes of this problem, analysis of inflow regime and rainfall was carried out.

Analysis of Inflow Regime

No inflow data are available for the lake as the inflow is not being monitored. So to analyze the inflow regime of the river, inflow to the lake was calculated from the lake water balance as follows :

Change in storage = Inflow – Outflow

Therefore,

Inflow = change in storage + outflow.

There is no controlled outflow in the lake. The overflow, if any is not being measured. However, over the last few years there has hardly been any overflow. The major outflow are the evaporation losses, withdrawal from the lake and possible sub-surface outflows (seepage losses). Since data for seepage analysis is not available, for the preliminary assessment on an annual basis, the term net ground water flow (ground water inflow- ground water outflow) was assumed as negligible. There are two pumping stations for Lake Pichhola. The data of only Dudh Talai station was available with the authors. This was used. A reasonable assumption for the other station was made after discussion with the authorities of the PHE Dept. Monthly average data of withdrawal was collected from PHED for the period 1990-2003 and using these values annual losses due to withdrawal were calculated. Data on pan evaporation has been obtained from the CTAE, Udaipur. Lake evaporation has been estimated from the pan data by applying a coefficient of 0.7 which is a reasonable assumption only for annual basis. Maximum and minimum water level data were obtained from the Irrigation Department, Udaipur along with the depth area capacity curve. Using these data, change in annual storage was estimated. For estimating volume of water lost through evaporation, the water spread area of the lake was calculated as average of the water spread area at maximum and minimum water levels. The inflow from the catchment is calculated as total inflow minus direct precipitation over the lake. The results are shown in Table 3 and Fig. 4. It can be observed that the inflow has reduced considerably over the last few. The inflow to the lake was about 17.5 m cum in 1991 and about 19.5 in the year 1993. It has come down to about 16 m cu m in the year 1997 and 1998 and further reduced to about 4.4 m cu m in the year 2001 to 2002. It is known to have gone down further in the years 2003 and 2004.

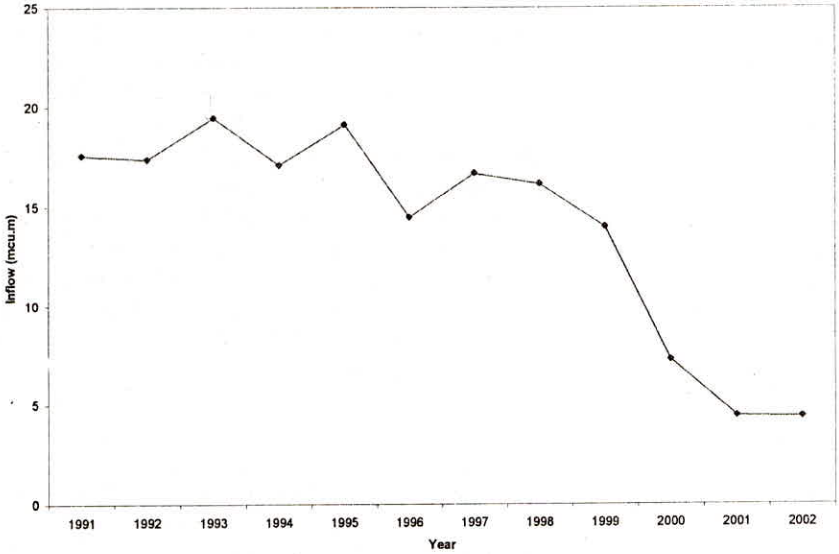


Fig. 4. Annual inflow to Lake Pichhola

Table 3. Preliminary annual water balance of Pichhola Lake

Year	Rainfall	Rainfall over lake	Withdrawal	Evaporation	change in storage	Total inflow	River inflow
	m	cu. m	cu m	cu m	cu m	cu m	cu m
1991	0.477	3317136	9566041.7	4536330.8	6785613.1	20887986	17570850
1992	0.771	5366160	10052708	3690823.3	9005947.3	22749479	17383319
1993	0.412	2867520	10858750	4196437.1	7278391.4	22333579	19466059
1994	0.786	5470560	10645833	3368375.7	8538657.6	22552867	17082307
1995	0.434	3020640	11862500	3611018.9	6669498.7	22143018	19122378
1996	0.656	4565760	8793181.8	3373156.5	6887567.3	19053906	14488146
1997	0.585	4069512	9290909.1	3372002.6	8094024.4	20756936	16687424
1998	0.646	4496160	9290909.1	3192977	8173322	20657208	16161048
1999	0.425	2958000	8129545.5	3392295.9	5451713.4	16973555	14015555
2000	0.444	3090240	4750700.8	2930614.8	2690456	10371772	7281531.6
2001	0.477	3322704	2858069.7	2149081.2	2748853	7756003.9	4433299.9
2002	0.404	2811840	2458069.7	2242900	2498470.7	7199440.4	4387600.4
2003	0.684	4760640	3288946.7	2105800			

The water balance so obtained is crude because it is based on the maximum and minimum water level data which may not give true values of the change in storage because it does not take into account the daily variation in the water levels. The depth area capacity curve available is almost a quarter of century old and with considerable sedimentation over the years, it may not be valid for today. The seepage losses from the lake have been assumed to be negligible which appears to be grossly erroneous as indicated by the isotope based investigations being carried out by the Institute. Similarly, in the absence of local pan coefficients or energy balance of the lake, lake evaporation has been obtained using the pan data by applying the coefficient of 0.7 which may give very crude and not precise values of evaporation. However, despite all these limitations, it is apparent that the inflow to the lake has been significantly reducing over the years. Some of the possible reasons for these could be decreasing rainfall trends, increased evapo-transpiration losses form lake catchment, increasing surface abstractions in the catchment etc. Some of these are discussed here.

Analysis of Rainfall

The rainfall data for the two stations (CTAE and Irrigation Observatory) in Udaipur have been collected (Fig. 5). The trend analysis has been carried out using statistical tests such as Kendal's Rank Correlation test, Spearman-Rho Test and Linear regression test. No significant decreasing trend has been detected using these tests, although a decline in the trend does appear in the plot, due to the exceptionally high rainfall of 1973. However, if the data is broken in three decades (1973-1982), (1983-1992) and (1993-2002) then the average values of the three decades show a declining trend (Table 4). Interestingly rainfall in the year 2003 (and even in the year 2004) was more than the normal rainfall or the average rainfall over the three last three decades, yet a decline in the inflow to the lake has been observed. Although, apparently it looks that the declining levels in the lake are not due to decreasing rainfall, however, since the rainfall data does not belong to the catchment and the variation in rainfall is not known, it would be erroneous to conclude definitely regarding the relationships between the rainfall and the lake water levels. This is also because the water levels in the lake are also affected by evaporation rates, sub-surface outflows from the lake and the with drawl of water from the lake through pumping etc. A detailed analysis on the long term data (of a century or so, which is known to be available for Udaipur) needs to be carried out along with the characteristics of precipitation such as intensity, duration, number of storms etc. At present these data are not available with the authors for detailed analysis. From the discussion with the local people etc it appears that precipitation regime of the area has changed over the years. Unlike the past, less intense rains of shorter duration are being received which are unable to produce the required runoff.

Table 4. Variation of rainfall at Udaipur

Period	Average rainfall (mm)
1973-1982	670.15
1983-1992	615.73
1993-2002	526.91
2003	684

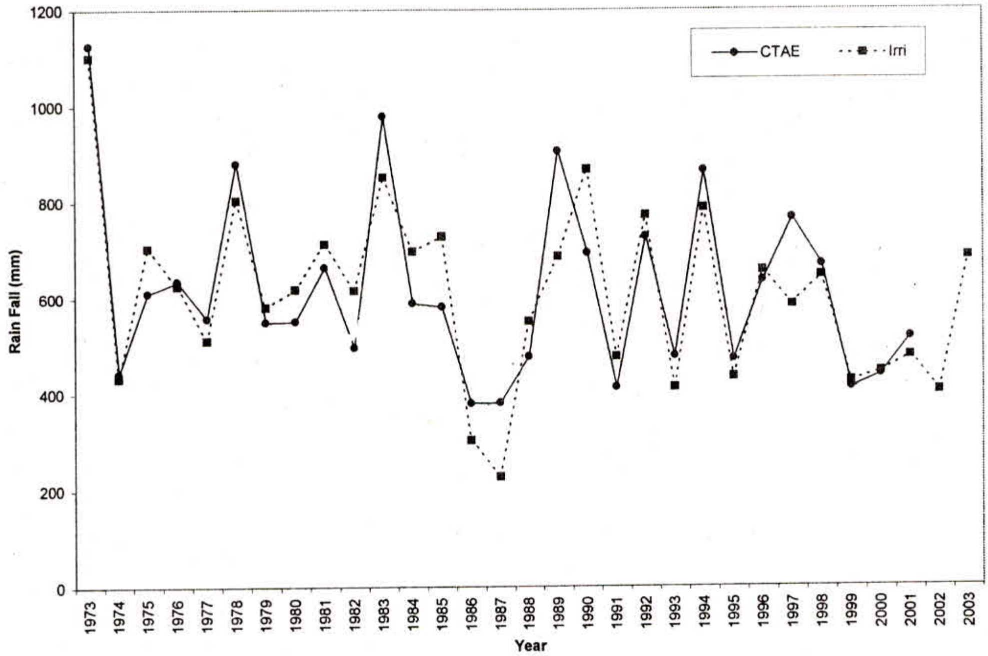


Fig. 5.Variation of annual rainfall at Udaipur

Seepage Losses From the Lake

Preliminary studies carried on the lake-groundwater interaction using isotope techniques by the Institute indicates considerable seepage losses from the lake. This could be one of the important factors for the declining water levels.

Surface Abstraction

One of the possible reasons for the reduced inflows could be the construction of a number of anicuts, checkdams and other permanent structures in the catchment. A number of such structures is known to have been constructed in recent times in the catchment of the lake. Table 5 lists the existing structures in the lake catchment as provided by the Irrigation Department, Udaipur. Since detailed hydrological data of these structures is not available, it is not exactly known as to how these structure are affecting the inflow regime of the lake, although seemingly they appear to be a major cause of reduced inflows to the lake. Moreover, they play a significant role in recharging the groundwater. They, however, act as very shallow water bodies causing heavy evaporation losses. Besides the anicuts , there are some other abstractions also. For example, big pitholes have been created in the lake bed just at the mouth of the inflowing river itself by local people who collect soil for the preparation of bricks. It has been observed that the water of inflowing river first gets accumulated in these pitholes. In case of very low flows it fully gets accumulated here and does not advance further. A channel has now been constructed in November, 2004 to divert this water to the down stream of the lake.

Table 5. Different anicuts in Pichhola lake catchment

S. No.	Name of Village	Name of Anicuts	Maximum water spread area (ha)	Storage capacity (feet)
1	Pipalwas	Near Charch	1	4
2	Kumaria Khera	Humaria Khera Ta!ab	2	12
3	Alsigarh	Alsigarh Anicut	1	6
	Alsigarh	Alsigarh Talab	2	34
	Aar	Aar Anicut	2	12
6	Popalti	Popalti Anicut	1	5
	Bari Uandri	Hakariyawala Anicuts	1	6
8	Bari Uandri	Kudikhadra Anicut	1	4
9	Bari Uandri	Nalawala Talab	1	8
10	Kaliwas	Mungu hariya Anicut	1	6
11	Kaliwas	Dadmiya Anicut	2	4
12	Nnohra	Mamadev Anicut	.2	4
13	Chokadia	Nandeshwar Anicut	5	8
14	Kodiat	Gariya Anicut	.5	8
15	Bujra	Bhanvar Nal Anicut	1	10
16	Nayaguda	NehreeKhadra Anicut	2	12

Evapo-Transpiration Losses From the Lake Catchment

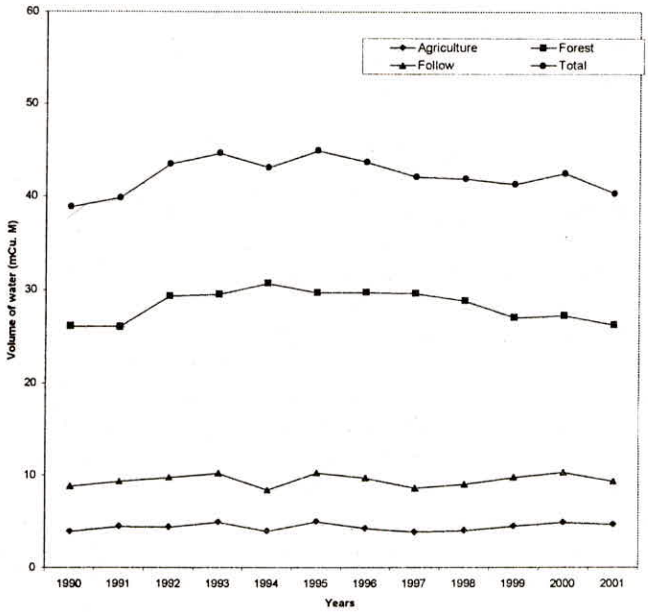
Catchment water balance determines the amount of water coming to the lake. Evapo-transpiration is one of the significant components affecting the catchment water balance, particularly in arid and semi-arid regions. In the present study an attempt has been made to investigate the ET losses from the catchment based on the meteorological data of Udaipur and the land use data of the lake catchment. Land use statistics obtained from the remote sensing data have been used. Point rates of evapo-transpiration losses from different land uses for different months have been estimated and based on these estimates, overall monthly and annual evapo-transpiration losses from the catchment have been estimated. Relative contributions of evapo-transpiration losses from different land uses to the total losses from the catchment have been studied. Major crops in the area have been identified and using the FAO-56 methodology (Allen et al., 1996) , crop coefficients and the evapo-transpiration have been estimated using the single crop coefficient approach. Similar methodology has been used for fallow land except for the coefficients. Evapo-transpiration rate from forest (ET_{forest}) has been calculated as per Shuttleworth (1993).

Resutls obtained indicate that ET rate of fallow land is found to be very less. Evapo-transpiration from forests is observed to be high compared to agricultural ET and fallow land ET. It is also observed that the ET rate of crops is higher than the forest ET rates barring the rainy season. This means that the transpiration losses from forests is less than the ET rates of crops

The average monthly volume of water lost through ET from different land uses under consideration (averaged over the 12 year study period 1990-2001) have been studied. As is obvious, it depends on the ET rates of the different land uses as well as on the areas under them. In case of forest it also depends on the precipitation in the month as it affects the interception loss. The average monthly volume of water lost from the total catchment is 3.53 mcum while for the different land uses it is different. It is 0.37, 2.38 and 0.78 mcum for agriculture, forest and fallow land respectively. However, the monthly values show a great variation from the average values.

The annual volume of water lost through ET from the catchment are shown in Figure 6. The volume varies from year to year for the period 1990-2001. Most of contribution (about 66%) comes from the forests. Volume of water lost from agriculture and fallow land are relatively very less. It has been observed that of the 84.21 mcum of water which is received by the catchment on an average per year, about 52% (42.46 mcum) is lost through the process of ET (Table 6)

Fig. 6 Annual volume of water lost through ET



There are a number of limitation to the present investigations on ET losses and the study needs further refinement for more precise inferences. For example, only three major land uses have been considered. They are also assumed to be constant throughout the study period. However, in practice and from the land use data obtained for different years, it is known that even the agriculture land changes from year to year and from region to region in the catchment depending upon the rainfall pattern. The altitudinal variations and the shading effect have not been considered and radiation has been considered to be constant throughout the catchment. A single crop has been considered for both kharif and rabi seasons. However, despite the limitations of the study, it can be safely inferred that the ET losses from the study area are still found to be very high causing a negative impact on the catchment water balance. Hence, comprehensive ET management strategies, based on detailed field investigations, need to be implemented to reduce the ET losses and to subsequently improve the water inflows to the lake.

Table 6: ET losses in relation to water received by the catchment

Year	Annual rainfall (mm)	Water received by catchment (mcu m)	Total volume of water lost through ET from catchment (mcu m)	Volume of water lost as % of water received (%)
1990	693.8	98.94	25.68	25.96
1991	413.1	58.91	32.13	54.54
1992	727.7	103.77	38.24	36.85
1993	477.9	68.15	47.16	69.20
1994	864.1	123.22	52.09	42.27
1995	472	67.31	51.44	76.43
1996	636.3	90.74	56.62	62.40
1997	765.3	109.13	51.16	46.88
1998	669	95.40	56.07	58.77
1999	412.1	58.77	49.67	84.53
2000	439.3	62.64	26.09	41.65
2001	515.9	73.57	23.11	31.41
Mean	**590.54**	**84.21**	**42.46**	**52.58**

There are a number of limitation to the present investigations on ET losses and the study needs further refinement for more precise inferences. For example, only three major land uses have been considered. They are also assumed to be constant throughout the study period. However, in practice and from the land use data obtained for different years, it is known that even the agriculture land changes from year to year and from region to region in the catchment depending upon the rainfall pattern. The altitudinal variations and the shading effect have not been considered and radiation has been considered to be constant throughout the catchment. A single crop has been considered for both kharif and rabi seasons. However, despite the limitations of the study, it can be safely inferred that the ET losses from the study area are still found to be very high causing a negative impact on the catchment water balance. Hence, comprehensive ET management strategies, based on detailed field investigations, need to be implemented to reduce the ET losses and to subsequently improve the water inflows to the lake.

LAKE EVAPORATION

Evaporation rates are generally high for lakes in arid and semi arid regions. Same seems to be true of lake Pichhola also. Evaporation losses obtained form the preliminary water balance given earlier indicate that evaporation losses from the lake have increased over the years. (Table 7). As per these estimates the overall losses are almost 50% of the river inflow to the lake and it is about 30 percent of the total inflow to the lake (river inflow + direct precipitation over the lake). Although evaporation is a natural process, the presence of macrophytes such as water hyacinth are known to cause heavy transpiration losses. In the case of lake Pichhola considerable portion of the lake is occupied by water hyacinth (Fig. 7). The ET rates of water

Table 7. Evaporation losses from the lake

Year	Total inflov	River inflow	%of total inflow lost through evap	% river inflow lost through evap.
	cu m	cu m		
1991	20887986	17570850	21.71741616	25.8173672
1992	22749479	17383319	16.22377085	21.23198304
1993	22333579	19466059	18.78981075	21.55771356
1994	22552867	17082307	14.93546594	19.71850633
1995	22143018	19122378	16.30770902	18.88373378
1996	19053906	14488146	17.7032288	23.28218254
1997	20756936	16687424	16.24518472	20.20684914
1998	20657208	16161048	15.45696274	19.7572394
1999	16973555	14015555	19.98577169	24.20379329
2000	10371772	7281532	28.25568224	40.2472307
2001	7756004	4433300	27.70861423	48.47588137
2002	7199440	4387600	31.15381035	51.11905848

Fig. 7 Presense of thick mat of water hycinth in Lake Pichhola
(coloured photograph is given at the end of the book)

hyacinth are 2 -3 times more than the open water surface evaporation. It is believed that considerable water is being lost through the process of ET by water hyacinth. Another important factor is the shallow depth of the lake. Since evaporation is caused by a surface energy transfer, the more the exposed area, more is the loss of water by way of lake evaporation. That is, for the same volume of water stored in the lake if the surface area is reduced by increasing the depth of the lake, the evaporation losses can be reduced.

SEDIMENTATION

Sedimentation is known to be one of the important problems of the lake, causing reduction in the storage capacity as well as expected life of the lake. Earlier studies conducted by Purohit et al. (1991) predicted a life of less than a century for the lake. In the present study sedimentation rate of the lake has been studied by isotope technique using Pb –210. The analysis has been carried out at the Nuclear Hydrology Laboratory of NIH using alpha spectrometer and useful life of the lake has been estimated. Sediment samples have been collected from 14 cores from different locations in the lake as well as the catchment. A total number of 177 sediment samples have been obtained from the 14 cores by cutting slices of 2 cm thickness. These include, 67 samples from the 5 cores of the water spread area of the lake and 110 samples from 6 cores obtained from the exposed dry bed of the lake.
The pattern of sedimentation in the lake is shown in the Fig. 8.

During the period of investigation the mean depth of the lake was only 0.782 m. The estimated sedimentation rate of the lake was 0.48 cm/year. However, it should be noted that these are past rates of sedent deposition and with decline in runoff from the catchment, the sedimentation rate may not be the same and the life of the lake be more than the expected life with this rate of sedimentation. The major cause of the sedimentation is the considerable reduction in the forest cover. The present forest cover of about 20% dense forest is not adequate for the hilly catchment.

EUTROPHICATION

Eutrophication, which denotes nutrient and productivity status of lakes, is one of the serious problems of most lakes. Cultural eutrophication is caused due to human interference in the lake catchments. It has significant negative biological, health, social and economic impacts on man's use of lake water. Control and management of eutrophication needs proper understanding of the problem. However, where information available does not permit scientific investigations of the problem, trophic status indices prove a useful management aid to assess the extent of eutrophication. A number of univariate and multivariate indices have been developed for the purpose. Lake Pichhola is suffering from eutrophication as evident from the symptoms such as foul odours, mats of algae and macofhytes, aalgal blooms etc. investigation has been undertaken to assess the trophic status and suitability of the lake for various purposes. Availability of the data permits only the preliminary assessment of the trophic status based on various existing indices. Published data from various sources have been used for assessment of the trophic status of the lake. The quality and availability of data permit only the preliminary assessment of the trophic status of the lake (Table 8) and no modeling studies are possible.. The trophic status has been evaluated based on various trophic status indices. Four univariate indices (OECD, EPA-NES, Vollenweider & Chapra-Dobson) and one multivariate (bivariate) index i.e. Carlson's Index is used. Suitability of water for different uses has been evaluated.

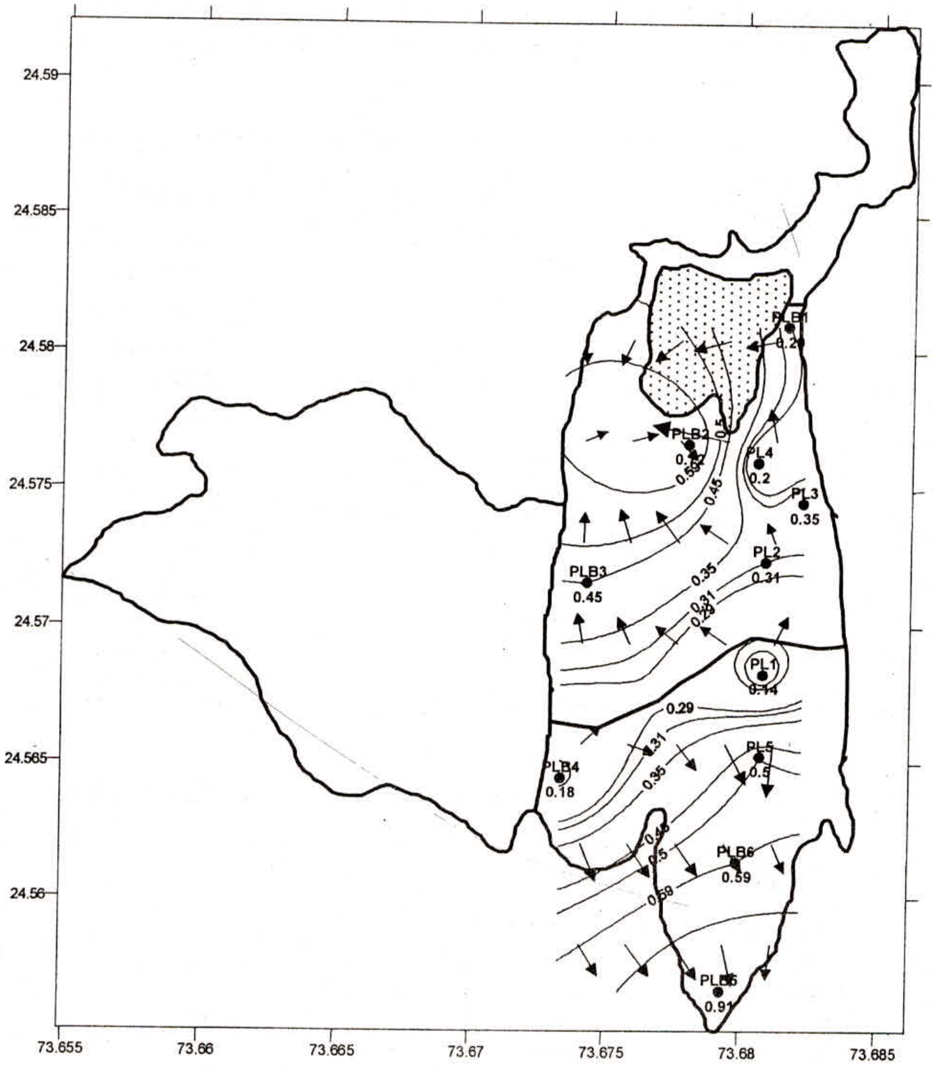


Fig. 8. Sedimentation rate of Lake Pichhola

The results of trophic state assessment by various indices indicate that both phosphorous as well as secchi depth based indices indicate the present hypertrophic status of the lake. The results of Carloson indices are presented in Table 9 and and Fig. 9 and 10. . It is observed that the lake was in oligotrophic to mesotrophic condition till the 80's (1965-76) and has advanced into the eutrophic to hypertrophic status thereafter. Analysis of the secchi depth based indices indicate the similar status, although no secchi depth data are available to confirm the trophic status prior to 80's. Analysis of the Carlson Bivariate Index indicate that the lake was in a strongly mesotrophic to eutrophic status during 1975-76 while it is in a hypertrophic state as on today. Thus, all the indices indicate that at present the lake is in an advanced hypertrophic state. The present trophic index values of 94.87 based on phosphorus data, 69.33 based on the secchi depth data and 84.10 based on the overall average illustrate the advanced hypertrophic status of the lake.

Table 8. Data availability scenario for eutrophication study of Pichhola lake

Reference	In Lake Phospho.	In Lake Nitrogen	Chloro-a	Secchi Depth	Primary Productivity	Nature of data
Kumar & Sharma, 1991	√	√	X	√	X	Data of June and August, 1987 Min., Max and Avg. values reported.
Majoo, 1991	√	√	X	X	X	Data for four months (Sep-Dec) reported. Year not mentioned
Madhu Sudhan et. al., 1984	√	X	X	√	√	Monthly data for two years (1974-76)
RPPCB, 1986	√	√	X	X	X	Single value. Year and period not mentioned.
Sharma & Durvey, 1990	X	X	X	√	√	Two observations Feb-Mar and Nov-Dec., Year of observation not mentioned
Das & Singh,1995	√	X	X	X	X	Surface and subsurface data for May/June, 1991
JSSR, 1996	√	√	X	√	X	Max., Min. and Avg. values for the period Feb-June, 1994.

(RPPCB- Rajasthan Pollution Prevention and Control Board; JSSR- Jheel Sanrakhan Samitee Report)

Table 9. Trophic status of Lake Pichhola based on Carlson Bivariate Index

Reference	Period	TSI Value	Trophic Status
Madhusudan et al., 1984	Summer, 1975	60.28	Eutrophic
Madhusudan et al., 1984	Summer, 1976	50.33	Strongly Mesotriophic
JSSR, 1996	Summer, 1994	84.10	Hypertrophic

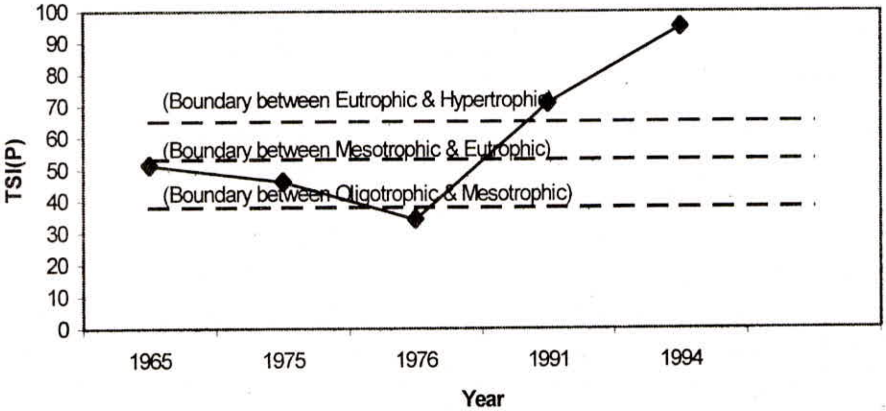


Fig. 9. . TSI value of Pichhola lake based on Carlson (phosphorus) Index

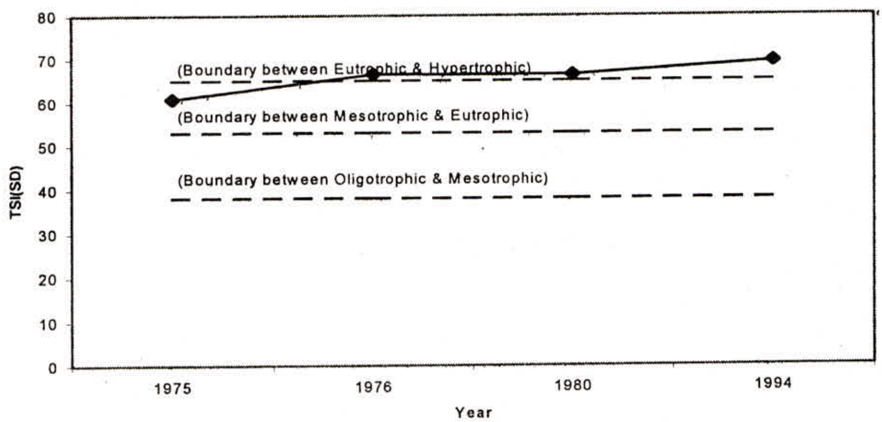


Fig. 10 . TSI value of Pichhola lake based on Carlson (Secchi depth) Index

Suitability of the lake water for various purposes has been evaluated by relating the trophic status of the lake to the intended use based on suggested criteria. . The suitability is indicated in Table 13. It can be observed that for direct use (without treatment) the lake water is unsuitable for most uses except irrigation, based on the trophic status.

Table 11. Suitability of Pichhola lake water for various uses

Desired use of lake water	Suitability of water (without treatment)
Direct consumption by humans and animals	Unsuitable
Bathing	Unsuitable
Fish culture	Unsuitable
Industrial supply	Unsuitable
Water sports	Unsuitable
Irrigation	Can be used

Variety of factors are contributing to the deterioration of the water quality of Pichhola lake. According to the various earlier investigations, these include the number of hotels located on the lake banks, garbage and debris of the surrounding areas, washing, bathing and socio-cultural activities at the ghats detergents and other organic pollutants to the lake, municipal sewerlines etc. Thus, the lake acts as a sink for all kinds of pollutants and contaminants and is subjected to heavy pollution and organic contamination. Since the lake water is stagnant in the absence of any outflow and since the water levels of the lakes are going down considerably the self purifying capacity of the lake has decreased drastically which further enhances the process of quality degradation.

CONSERVATION AND MANAGEMENT OF LAKE PICHHOLA

Based on the studies conducted so far and preliminary analysis of the data collected, various problems of the lakes have been identified along with their causes. Although more detailed analysis of the various problems are required, yet based on these findings, following general observations (preliminary recommendations) are made to rejuvenate, conserve, manage and rejuvenate the lake:

1. The surface abstraction of water in the catchment needs to be minimized to the extent possible so as to allow the flow of water to the lake.
2. Presence of thick mats of water hyacinth may cause heavy evaporation losses, which are already generally high for lakes in arid and semi arid regions. So these need to be removed from time to time
3. Comprehensive strategies may be taken up to reduce the ET losses from the catchment through detailed field investigations and experimentation.
4. Efforts be made to minimize the seepage losses from the lake through identification of the seepage zones and then lining them.
5. The present depth of water is very shallow. So the lake is vulnerable to heavy evaporation losses. Dredging of the lake may be carried out especially at the dam end to increase the depth so that surface area of the lake gets reduced. This will reduce the evaporation losses. The soil may be deposited in the pits created upstream of lake bed.
6. A comprehensive action plan for control, reversal and management of the eutrophication problem needs to be undertaken. For this purpose, first the limiting nutrient (whether phosphorous or nitrogen)) needs to be identified and then various point and non-point sources of this nutrients need to be identified, controlled and

treated before they reach the lake. As far as possible direct entry of point sources of nutrients and pollutants to the lake may be stopped. In-lake nutrient control techniques particularly bio-manipulation may be employed. To control the non point sources of pollution and the siltation, the pitholes created at the mouth of the lake need to be developed into wetlands.

7. Considerable deforestation in the lake catchment has been reported. Aforestation may be undertaken to curb the sedimentation in the lake. The present cover of about 20% dense forest is not adequate for the hilly catchment.
8. Creation of a Lake Development Authority to undertake all the works related to the conservation and management to review the environmental as well as management status from time to time and suggest corrective measures. It should have a research wing as well as specific legal powers.
9. A number of Central and State government organizations, N.G.O., Academic Institutions are at present involved in research and management of different aspects of the lake. At present most of these agencies are working in isolation and there is no coordination between the various organizations. A close interaction between these organizations, particularly between the limnologists and hydrologists and the field engineers is highly recommended.
10. Excessive human interference in the lake catchment and increasing socio-cultural and religious activities in the lake area are causing threat to the lake's health and life. Efforts be made to control these activities. An effective mass awareness campaign should be undertaken to sensitize the people about their role in conserving the lake. Without the people participation, no lake conservation programme would yield the desired results.

ACKNOWLEDGEMENT

The first author is particularly thankful to the Director, NIH for not only allowing and supporting the investigations on Pichhola lake but also for his useful suggestions, constants encouragement and appreciation which has been a source of inspiration for the work.

The authors are grateful to Head, SWE, College of Engineering & Technology, College of Maharana Pratap University of Agriculture & Technology, Udaipur; Irrigation Department, Udaipur; , Public Health Engg. Dept., Udaipur and The Maharana of Mewar Charitable Trust, City Palace, Udaipur for providing the various information/data and other logistic support and help during the course of the study.

The authors are also grateful to Dr. L. L. Sharma, Head, College of Fisheries and Dr. Tej Razdan and Er. Anil Kumar Mehta for the providing information as well as feedback regarding the various issues related to Lake Pichhola.

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