HYDROLOGICAL INVESTIGATIONS FOR CONSERVATION OF LAKES: A CASE STUDY OF LAKE PICHHOLA, RAJASTHAN

Dr. S. D. Khobragade
Scientist-E1, NIH, Roorkee

Three Days Training Course on

HYDROLOGICAL INVESTIGATIONS FOR CONSERVATION AND MANAGEMENT OF LAKES

(1-3 March, 2011)

HYDROLOGICAL INVESTIGATIONS FOR CONSERVATION OF LAKES: A CASE STUDY OF LAKE PICHHOLA, RAJASTHAN

Dr. Suhas D. Khobragade
Scientist – E1
Hydrological Investigations Division
National Institute of Hydrology, Roorkee-247 667 (Uttarakhand)
E-mail: suhas@nih.ernet.in

INTRODUCTION

Lakes are valuable sources of freshwater. In many arid and semi arid regions, they are even the only source of water. Besides serving the various domestic, commercial, agricultural and recreational needs of the society, since ancient times they are being used as natural centres of civilization. Many cities have been built up on the banks of the lakes. Udaipur City in Rajasthan state is one such city, built on the bank of Lake Pichhola. Lakes are usually centres of recreation, tourism and culture. However, because of the excessive anthropogenic pressures and interference, lakes are being overexploited. Since lakes are sensitively responsive to the changes in its catchment, this affects the lakes and their ecosystems, leading to many quantitative and qualitative problems. Although, lakes being only the transitory features of the landscape, have a definite birth and death, such 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. Many of the lakes of arid and semi-arid regions have witnessed reduced inflows and are drying out in recent times. The same is true of Lake Pichhola, Udaipur (Rajasthan) also. Rejuvenation and proper management of Lake Pichhola is necessary in view of its great socio-economic significance.

Udaipur is known as the city of lakes. There are number of water bodies in and around Udaipur. The important ones include Pichhola Lake, Fatehsagar Lake, Badi Lake, Madar Tank and Udaisagar Lake, besides a few other small tanks. Together they form the Udaipur Lake System. Of these only Pichhola, Udaipsagar and Fatehsagar are relatively bigger and rests are small water bodies. Pichhola, Rangsagar, Swaroopsagar and Fatehsagar, are interconnected water bodies, situated in the municipal limits of Udaipur city. The location map of these lakes is shown in Fig. 1

LAKE PICHHOLA AND ITS CATCHMENT

Of the various water bodies of Udaipur region, Pichhola Lake is the oldest and biggest water body. This manmade lake got its name from a small village Pichholi nearby and was created by a Banjara Chief during the time of Maharana Lakhaji (1382-1418 A. D.) by building a small earthen dam across the river Sisrama. Maharana Udai Singh established the town of Udaipur on its bank in 1559 as his capital, naming it after his own name. The water spread area of the lake varies considerably from season to season and also annually. The lake is mainly rain-fed.

River Sisarama, a tributary of river Kotra, is the chief source of water for the lake. Table 1 presents the salient features of Lake Pichhola. Fig. 2 presents a view of the lake.

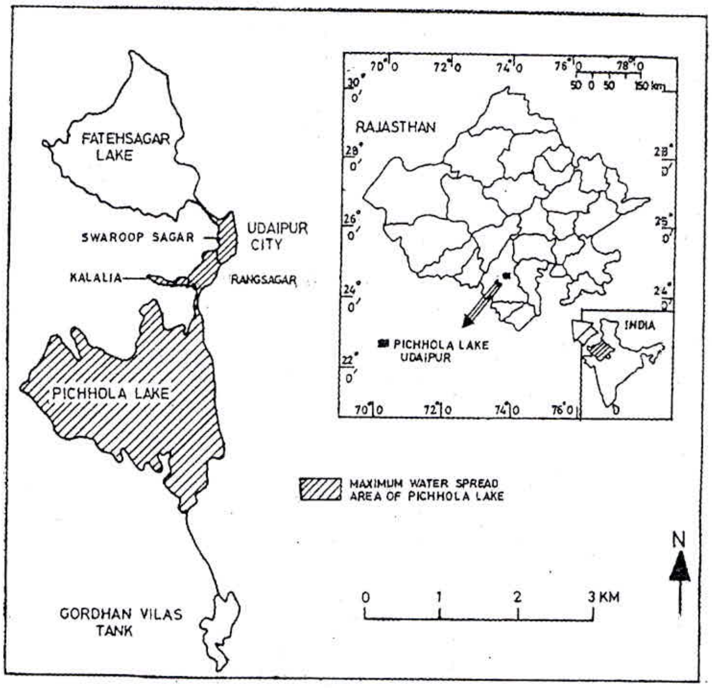

Fig. 1. Location map of the study area

Table 1 Salient features of Lake Pichhola, Udaipur

Parameter	Value
Longitude	$73^0\ 40'$
Latitude	$24^0\ 34'$
Altitude (m)	587
Storage 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

Initially the water of the lake was used for irrigation purpose. However, as the population grew, the lake became major source of drinking water supply to Udaipur. Besides drinking water supply, the lake has many other uses. A dense population residing along the northern shores of the lake uses the lake water directly for bathing, washing of clothes and socio-cultural activities. However, the most important aspect of lake Pichhola is tourism which decides the economy of the region. It is for this reason that the lake is referred to as the "Life Line of Udaipur City. The lake ecosystem once used to support a wide variety of fauna and flora most of which has disappeared now. The catchment area of Pichhola Lake lies in the Girwa plain of the Udaipur plateau. The catchment area of the lake is 142.6 sq. km. Most of the catchment is barren hard rock with high hills, the average height of which ranges from 650 m to 900 m. The mean slope of the catchment is 3.04%. The lake region forms part of the most ancient Gondwana table land of the Peninsular India. The main lithology in the catchment is slaty quartzite, phyllite, and other sedimentary structures belonging to the Aravali super group. Soils of the area are dark brown and black coloured. In the hilly tracts, soil cover is meager. Vegetation in the catchment area is very scanty. Major crops in the catchment are maize and wheat. Forest is mixed type deciduous tropical forest. Table 2 presents the land use statistics while Fig. 3 shows the land use map of the lake catchment.

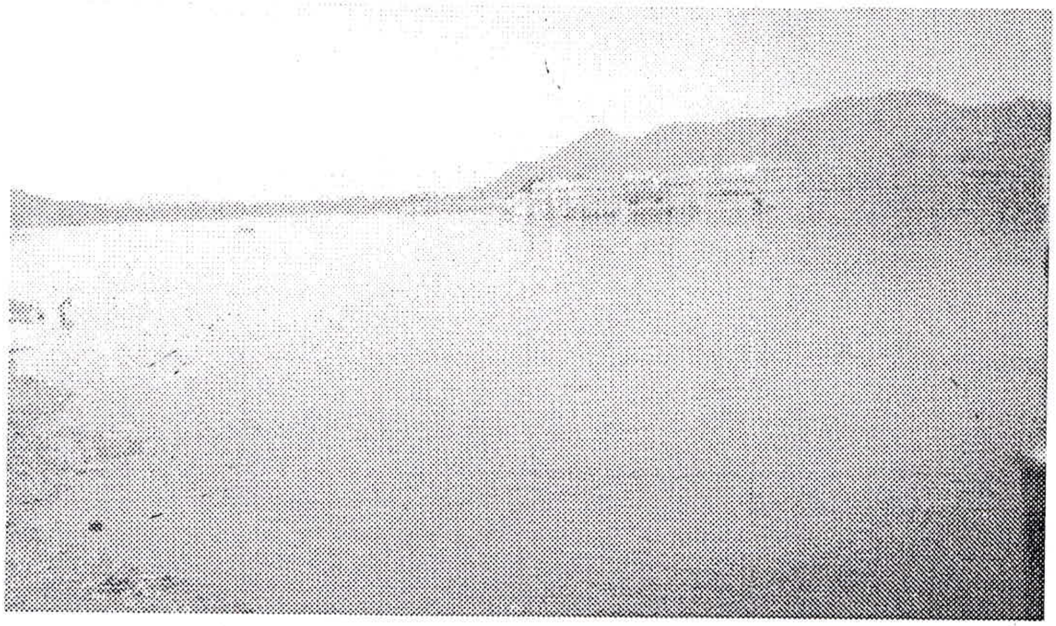

Fig. 2. A view of Lake Pichhola, Udaipur, India

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

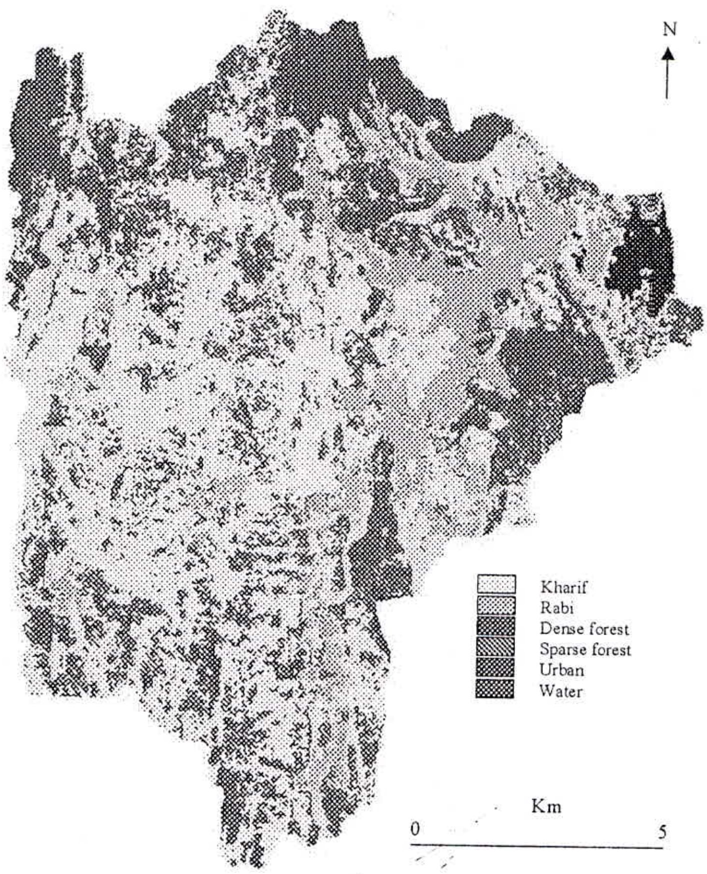

Fig. 3. Land use map of Pichhola lake catchment

CLIMATE OF THE STUDY AREA

The lake is located at 24^0 34' N latitude and 73^0 40' E longitude at an altitude of 587 m above the mean sea level to the west of Udaipur city. The study area is a semi arid climatic region. There are three distinct seasons viz. winter, summer and monsoon. The winter season from October to February is followed by a summer season which lasts till middle of June. The period from middle of June to September is the period for south-west monsoon bringing rain. Maximum temperature can be around 43^0 C in May-June while minimum is noticed during December-January. It is generally around 5-7 % but it can sometimes be as low as 1.5^0 C. The normal annual rainfall is 635 mm. Most (about 80%) of the rainfall occurs during the monsoon months of June-September. Distribution of annual rainfall is uneven and shows large spatial and temporal variations. Air is generally dry except for the south-west monsoon period when the humidity is around 70%. Summer months are the driest ones of the year when the humidity is 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

OBJECTIVES OF THE STUDY

A number of studies are reported on the lakes of Udaipur including Pichhola lake. However, most of these studies are limnological in nature dealing mostly with the biological aspects of the lake. There is no reference to any hydrological investigations. So, 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 objectives of the present investigations are:

(i) To identify the causes of quantitative deterioration of the lake
(ii) To identify the causes of the qualitative degradation of the lake
(iii) To suggest remedial measures for the rejuvenation of the lake

MAJOR PROBLEMS OF THE LAKE AND THEIR CAUSES

The health of the lake, both in terms of its quantity and quality, has deteriorated considerably over the years. From the various filed visits to the lake and its catchment, interaction with the local people, academic and field organizations and the, NGO's etc., problems of the lake have been identified. The major problems identified for the lake are:

(i) Regular drying of the lake
(ii) Water quality deterioration and eutrophication
(iii) Sedimentation.

All these problems are leading to the slow death of the lake. Efforts have been made to analyze these problems and to find out their causes.

WATER AVAILABILITY IN THE LAKE

Earlier literature reports that the lake was always filled with water. Unfortunately this scenario has drastically changed over the years. Water levels of the lake are going down considerably. It is reported that the lake dried out completely in 1973 and again in 1987. This complete drying was primarily due to the severe drought. But in recent times the lake levels are going down considerably even if the rainfall is about normal. In the years 2002 and 2005, major part of the lake nearly dried despite adequate rains. This is one of the most serious problems of the lake as the lake is a major source of civil water supply to the Udaipur city.

Analysis of rainfall and inflow

To understand the causes of this problem, analysis of rainfall and inflows was carried out. The rainfall data for the two stations (CTAE and Irrigation Observatory) in Udaipur have been collected (Fig. 4). The trend analysis has been carried out using Kendal's Rank Correlation test, Spearman-Rho Test and Linear regression test. No significant decreasing trend has been detected using these tests. The 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. Moreover the rainfall in the year 2003 is higher than about 20 out of 30 years' annual rainfall. Yet the lake did not receive adequate inflow and the water levels are going down. Thus it can be said that declining levels in the lake are not due to decreasing rainfall but may be because of other reasons.

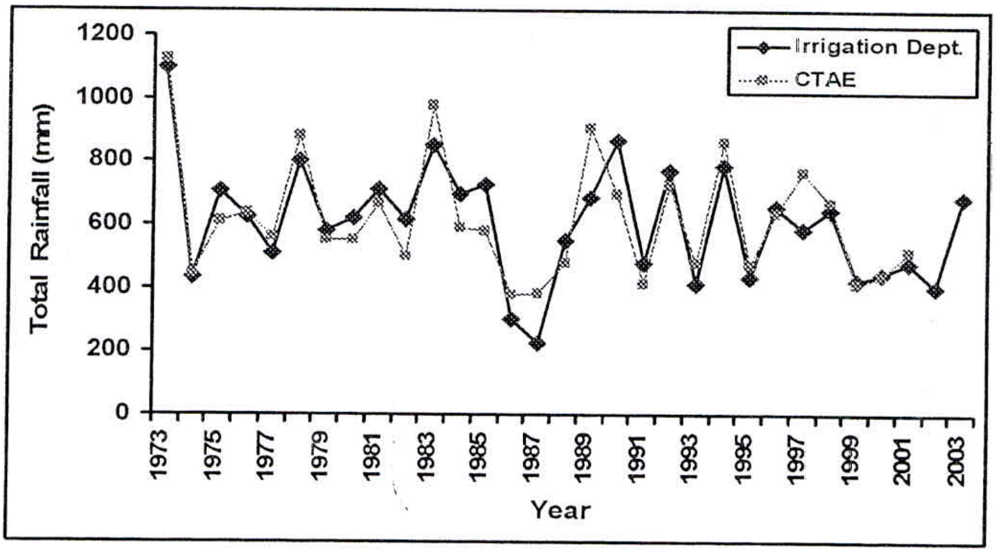

Fig. 4. Variation of annual rainfall at Udaipur

No inflow data are available for the lake as the inflow is not being monitored. So to analyze the annual inflow regime of the river, annual inflow to the lake was calculated from the annual 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 monitored. However, over the last few years there has hardly been any overflow. The major outflow is the evaporation losses and withdrawal from the lake. These have been used. 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). 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. Change in storage was calculated using the maximum and minimum water level data and from the depth area capacity curve. 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 precipitation over lake. The results are shown in Fig. 5 and Table 3. It can be observed that the inflow has reduced considerably over the last few years although the rainfall has not changed with the same magnitude. 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 after this.

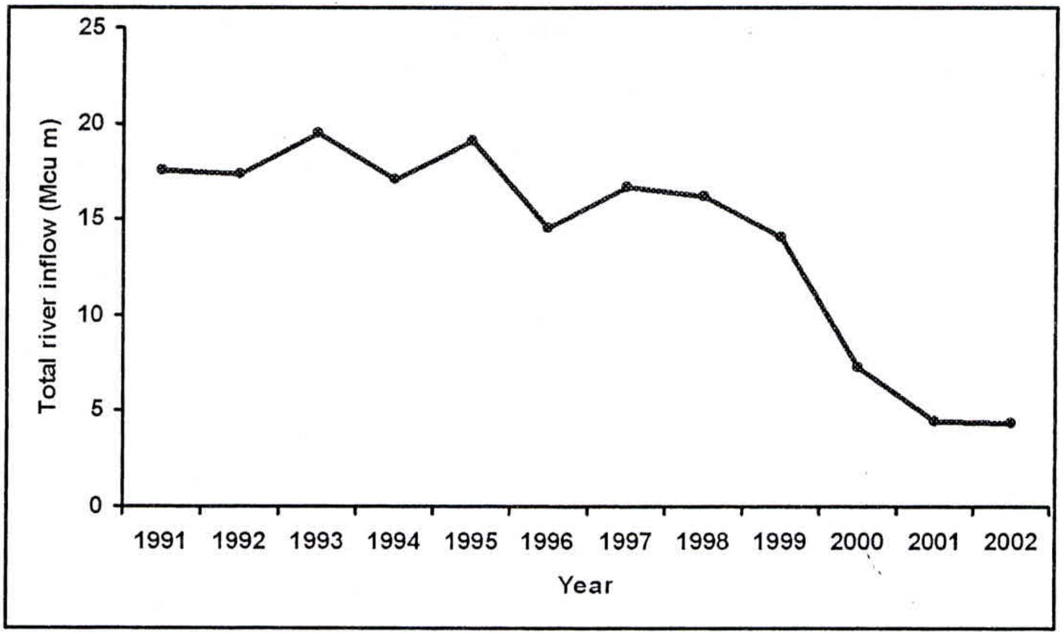

Fig. 5. Annual inflow to Lake Pichhola

However, it should be remembered that the water balance reported above is an approximation. This is because only maximum and minimum water level data have been considered. The irrigation department measures the maximum water level at the end of the monsoon season and minimum water level at the beginning of the monsoon season. These have been used in the water balance computations. However, in reality the water levels in the lake change on daily basis and as such, these daily fluctuation must be considered for estimating the change in storage over a period of a month and then over the period of an year, which could not be done in the study for the want of data. Moreover, the evaporation has been estimated from pan data by applying a coefficient of 0.7 as per the practice being followed by the state irrigation department. However, in reality the pan coefficient varies temporally and spatially.

Evaporation Losses

An analysis of the water balance (Table 3) brings out that evaporation varies from about 15-31% of the total inflow to the lake. It is further observed that the volume of water lost due to evaporation from the lake has increased in the past few years. It was 14.94% during 1994 and it has increased to 31.15% during 2002. Thus, it can be said that heavy evaporation losses have their own contribution to the problem of reduced water availability in the lake. Although evaporation is a natural process, the depth of water determines the volume of water loss. The depth of the lake is very shallow. 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. Moreover, presence of macrophytes such as water hyacinth (*Eichhornia*) is known to cause heavy transpiration losses. In case of Lake Pichhola, considerable portion of the lake is occupied by water hyacinth (Fig.6) and is removed from time to time by the local residents.

The ET rates of water hyacinth are 2 -3 times more than the open water surface evaporation. So, it can be believed that considerable water is being lost through the process of ET by water hyacinth

Table 3. Annual water balance of Pichhola lake

Year	Total Rainfall over catchment (m)	Total Rainfall over lake (Mcum)	Withdrawl from the lake (M cu m)	Evaporation from the lake (M cu m)	change in Lake storage (M cu m)	Total inflow to lake (Mcum)	River Inflow to lake (Mcum)
1991	0.48	3.32	9.57	4.54	6.79	20.89	17.57
1992	0.77	5.37	10.05	3.69	9.01	22.75	17.38
1993	0.41	2.87	10.86	4.20	7.28	22.33	19.47
1994	0.79	5.47	10.65	3.37	8.54	22.55	17.08
1995	0.43	3.02	11.86	3.61	6.67	22.14	19.12
1996	0.66	4.57	8.79	3.37	6.89	19.05	14.49
1997	0.58	4.07	9.29	3.37	8.09	20.76	16.69
1998	0.65	4.50	9.29	3.19	8.17	20.66	16.16
1999	0.43	2.96	8.13	3.39	5.45	16.97	14.02
2000	0.44	3.09	4.75	2.93	2.69	10.37	7.28
2001	0.48	3.32	2.86	2.15	2.75	7.76	4.43
2002	0.40	2.81	2.46	2.24	2.50	7.20	4.39
2003	0.68	4.76	3.29	2.11			

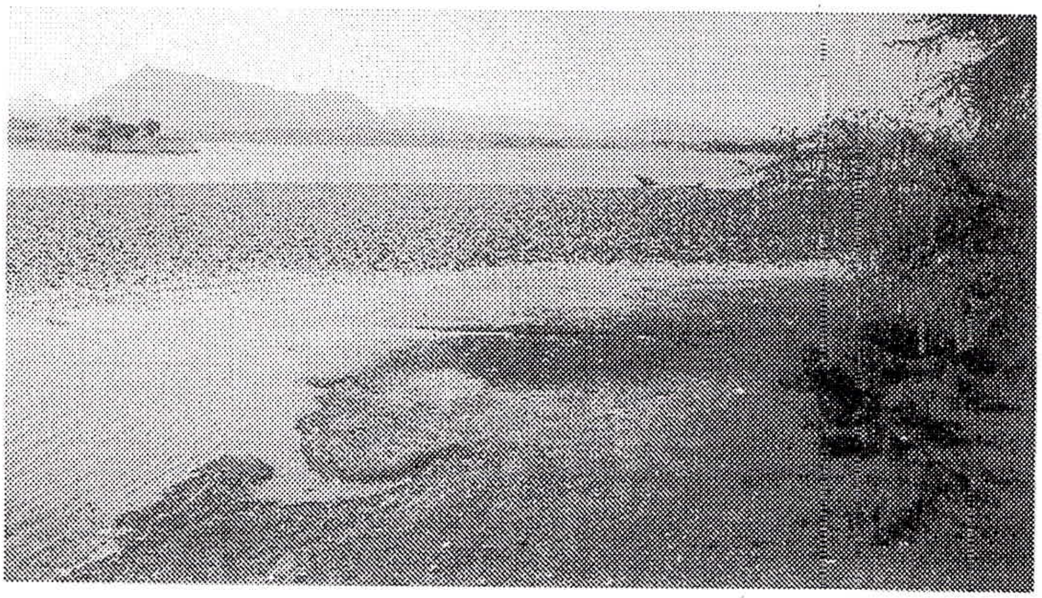

Fig. 6. A view of Pichhola Lake showing a thick mat of water hyacinth

Surface Abstraction

One of the major possible reasons for the reduced inflows may be the construction of a number of anicuts, check dams and other permanent structures in the catchment. A number of such structures have been constructed in recent times. Fig. 7 shows a view of the anicuts. The anicuts cause obstruction to the runoff and, retain water in the catchment thereby reducing the flow to the lake. Although they are means of groundwater recharge, they actually act as very shallow water bodies causing heavy evaporation losses. However, the exact impact of the anicuts on the inflow regime of the lake can be known only after detailed scientific investigations. The present data availability is not adequate to undertake such an investigation. More data need to be collected.

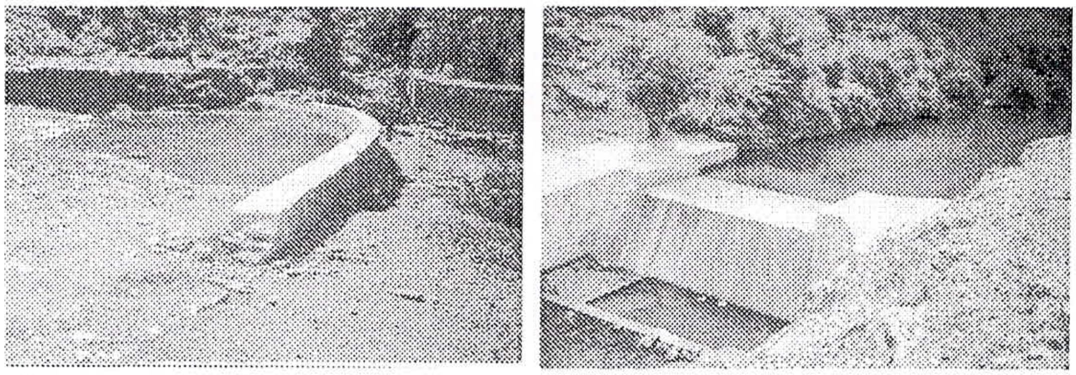

Fig. 7. Views of anicuts in the lake catchment

ET Losses from the Lake Catchment

Estimates of evapotranspiration rates from the catchments are very significant for understanding the overall water balance of the catchment as it determines the inflow to the lake. For estimating the total evapotranspiration losses from a catchment, integration method is used. In this method the total evapotranspiration from a given area is determined as the summation of evapotranspiration losses from the individual crops, natural vegetation, bare land, water surfaces etc existing in that area. The method requires the knowledge of evapotranspiration rates from the split up areas which may be obtained through different methods.

Data of pan evaporation, maximum and minimum temperatures, maximum and minimum humidity, bright sunshine hours and wind velocity were used in the study. Monthly data of 12 years (1990-2001) were used. Point rates of evapotranspiration losses from different land uses for different months have been estimated and based on these estimates, overall monthly and annual evapotranspiration losses from the catchment have been estimated considering the area under each land use. Relative contributions of evapotranspiration losses from different land uses to the total losses from the catchment have been studied. Since area under other crops in both the kharif as well as rabi are relatively very small compared to area under maize and wheat, a single crop (maize or wheat) was considered for the whole agricultural area in both the seasons (Table 4).

Table 4. Major crops and the distribution of their maturity period

Maize		Wheat	
Month	Period	Month	Period
July	Last 6 days	November	Last 10 days
August	All 31 days	December	All 31 days
September	All 30 days	January	All 31 days
October	All 31 days	February	All 28/ 29 days
November	First 7 days	March	First 10 days
Total	105days	Total	110 days

For the study purpose, the land uses have been assumed to be constant throughout the study period. Waste land is a total hard rock area without any soil cover. So, ET losses are considered negligible from the waste land. Urban area is less than even 1% of the total catchment area (0.79%). So, ET losses from the urban area have also been neglected. The forest is categorized into two types viz. dense forest and sparse forest. For the purpose of the study the forest has been considered as a single category by considering 20% of the sparse forest as dense forest and clubbing it with the dense forest. The remaining 80% of the sparse forest has been considered as uncultivable fallow land and considered under the fallow land category. Area under kharif and rabi have been estimated for different years and an average value has been considered for the study area. During the non-agriculture season (period between harvesting of the previous crop and sowing of the new crop) when there is no crop, the area is fallow. So, this area has been added to the category of fallow land. The fallow land category, thus, contains uncultivable fallow (80% of the area under sparse forest) and the cultivable fallow land (i. e. total cultivable land minus area under agriculture either kharif or rabi). The crop evapo-transpiration has been estimated using FAO- 56 Method. Methodology used for determination of ET_{fallow} is same as that for the crop evapotranspiration except for the coefficients. Evapotranspiration rates from the forest (ET_{forest}) were calculated as per Shuttleworth (1993).

As per the present investigation (Table 5), ET losses from the lake catchment are 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 improve the water balance of the catchment.

Table 5. 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

Groundwater - Lake Interaction

Investigations have been carried to trace the subsurface/inflow components of the lake and its movement using stable isotope of oxygen. Samples were collected in pre-monsoon of the year 2005 from 14 different locations from the lake catchment and from around the lake. The distribution of the sampling locations is shown in Fig. 8.

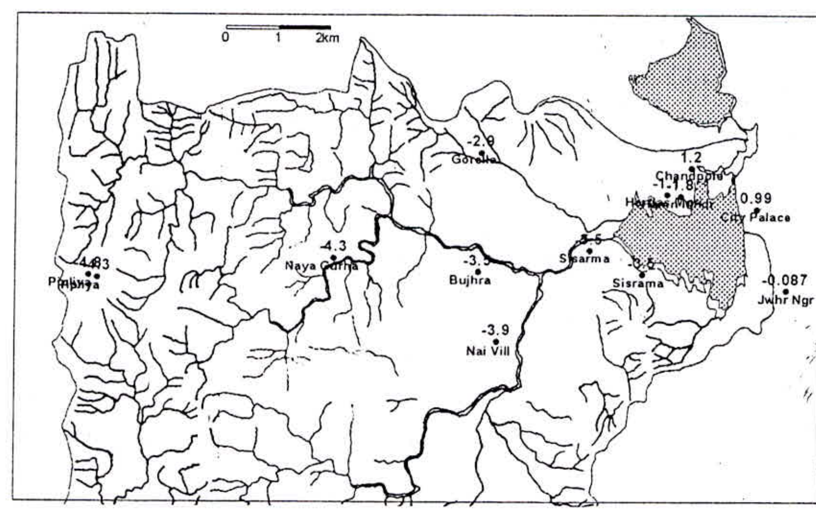

Fig. 10. Sampling locations and the observed $\delta^{18}O$ in groundwater at these sites

Samples were collected from different altitudes (sampling altitude range- 650 – 1000m above msl) to analyze the altitude effect. Assumption has been made that the shallow groundwater in the recharge area represents seasonal average precipitation water. All the samples were analyzed for oxygen-18 isotope ($\delta^{18}O$).On the basis of $\delta^{18}O$ data and their distribution, the groundwater can be segregated in four groups as:

(a) Groundwater at high altitude region represented by $\delta^{18}O < -4.0$
(b) Groundwater in the foot-hill region represented by $\delta^{18}O$ in the range -3 to-4
(c) Groundwater in the region close to lake in the north-northwest side represented by $\delta^{18}O$ in the range -1 to -2 and
(d) Groundwater distributed in the north-east and east side of the lake with $\delta^{18}O > -1$.

Change in $\delta^{18}O$ with altitude is a straight line (Fig. 11). with the mean gradient is 0.36‰ depletion in $\delta^{18}O$ per 100m rise in the altitude. (Observed range at global scale 0.1‰ to 0.4‰ per 100m rise in altitude). Extrapolating back this line to the altitude of Pichhola Lake which is at 600m indicates isotope value -3.3‰ for the precipitation on the lake.

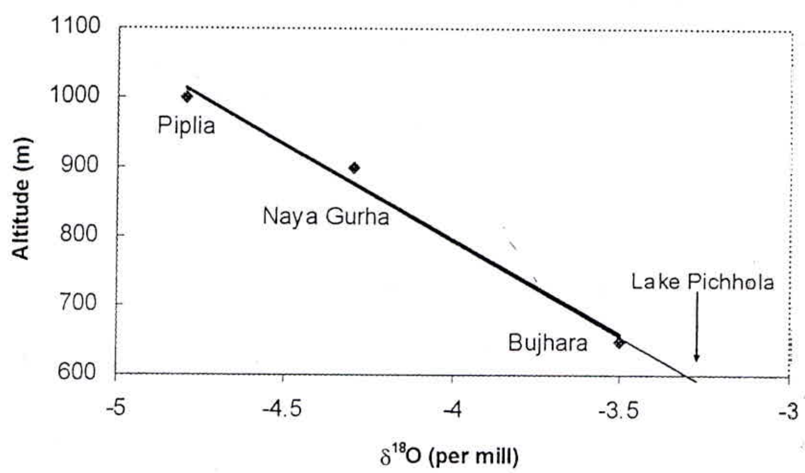

Fig. 9. Altitude effect in the groundwater

The observation of altitude effect in the groundwater indicates that groundwater is recharged locally in the surroundings of Bujhara with a minimum mixing with high altitude water. Similar $\delta^{18}O$ in groundwater at Bujhara and its down stream location at Sisarma located close to the lake indicate flow of recharged water near Bujhara moving along the direction of Sisarma towards the lake (Fig. 10). Enriched $\delta^{18}O$ in the range -0.1to +1.2 ‰ is observed in the groundwater in the periphery of the lake (City Palace, Chand Pole, Jawahar Nagar etc.) indicate evaporation effect in the recharging water. The data indicate losses from lake water due to evaporation and the sub-surface outflow due to its interaction with groundwater. Therefore, using isotopes it is possible to map areas where groundwater is not principally recharged through lake. The isotopic data shows principle component of groundwater flow in the west to east direction along Bujhara-Pichhola Lake-Jawahar Nagar direction along which the lake is gaining due to inflow from up stream and losing in the down stream as its base flow discharge.

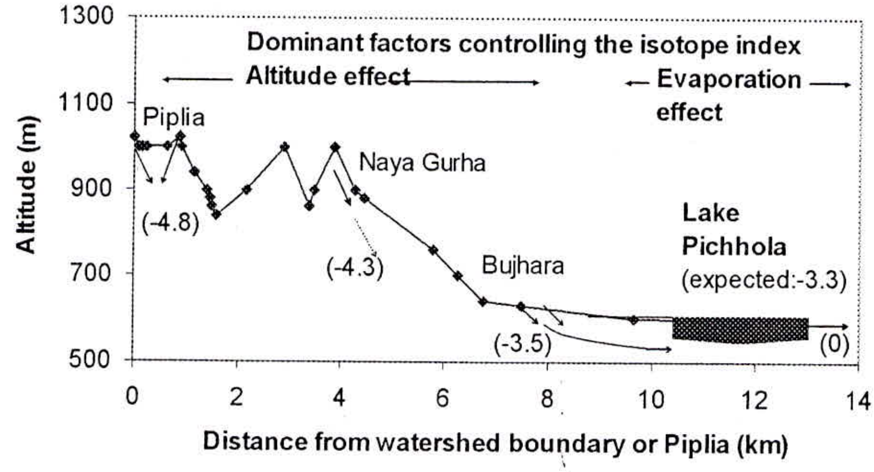

Fig 10. Direction of groundwater flow between Piplia and Lake Pichhola

Thus, isotopic characterization of groundwater in the catchment area of the lake indicates that; the major component of the groundwater flow is in the west to east direction along Bujhara-Pichhola Lake. The lake receives its base flow from the groundwater recharged in the area near Bujhra. The lake is losing major fraction of its water due to evaporation and sub-surface losses, in addition to the regulated surface out flows. One of the causes for drying of the lake is its sub-surface outflow due to lake water- groundwater interaction It can be controlled by shifting the tub-wells in areas where groundwater is not interacting with the lake water to the lake.

SEDIMENTATION IN THE LAKE

Lake Sediments contain radioisotopes from both natural and artificial sources. Natural radioisotopes are generated by cosmic ray interactions of the earth's atmosphere while the artificial radioisotopes have been introduced into the environment as a result of the testing of atomic weapons and accidents involving nuclear power installations. Out of all the radioisotopes, Cs-137 and Pb-210 have been found very useful for the dating of the sediments that deposit in the lakes and reservoirs. 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 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 228 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, 110 samples from 6 cores obtained from the exposed bed of the lake, as well as the 51 samples obtained from 3 cores from the lake catchment, representing different land uses viz. agriculture, wasteland and forest. Of these, 177 samples belonging to the lake have been analyzed for radioactivity to determine the sedimentation rate in the lake. Fig. 11 shows the pattern of sedimentation in the lake. The estimated sedimentation rate of the lake was 0.48 cm/year. With this rate the useful life of the lake comes out to be 162 yrs. However, it should be noted that with the decline in runoff from the catchment these the sedimentation may not be the same and the life of the lake be more than the predicted life. 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.

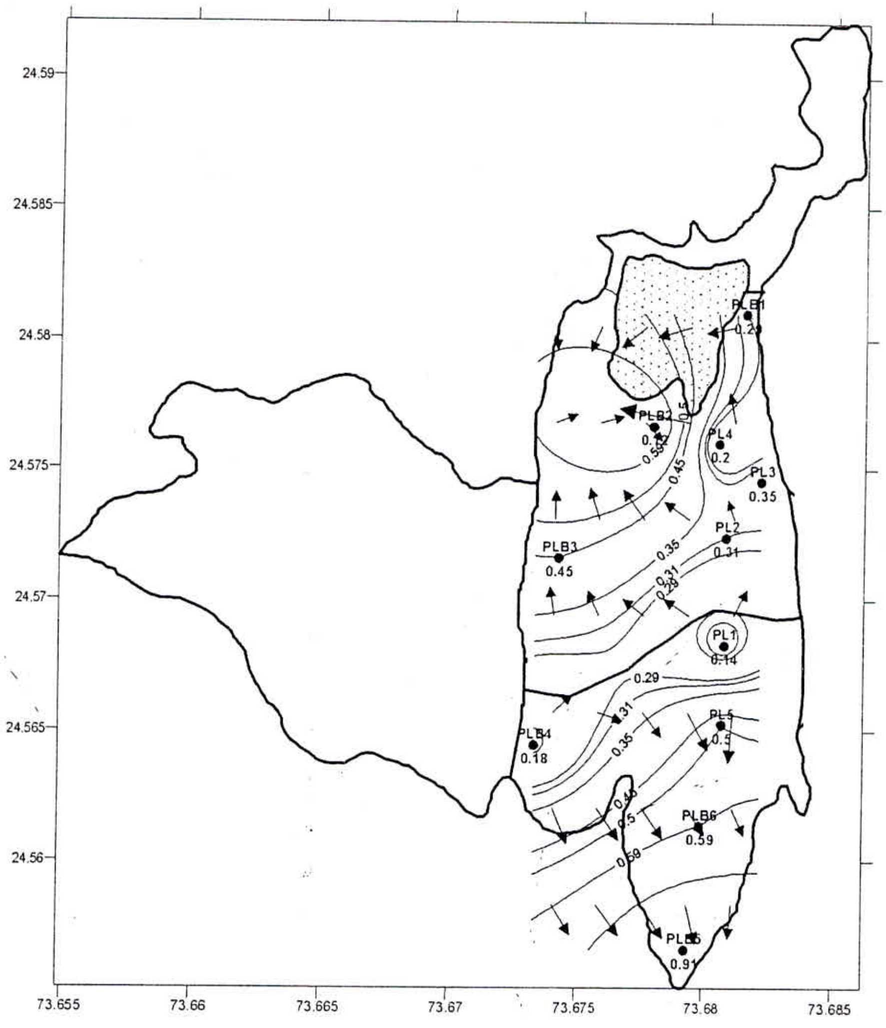

Fig. 11. Pattern of sedimentation in Pichhola lake

EUTROPHICATION IN THE LAKE

In this study, an attempt has been made to assess the trophic status of the lake and to assess its suitability for different uses based on the trophic status. Published data from various sources have been used for the study. In the absence of the hydrological data, nutrient loading data and other supplementary data such as hypolimnetic oxygen, chlorophyll-a, primary productivity etc., it is not possible to carry out any modelling studies or mass balance of nutrients required for eutrophication problem. A simple indices based approach has been used. Available water quality data have been used. However, total phosphorous data, as required for the indices is not reported by many, rather data on orthophosphates are reported. These have been used instead. Annual loading of phosphorus has not been reported by any investigator. As per the data requirement of the various indices used in the study, only the data of summer has to be used. This has put further restriction on the data availability. Thus, the quality and availability of data restricted the objectives of the present study to only preliminary assessment of the trophic status of the lake. The trophic status has been evaluated based on various trophic status indices. Four univariate and one multivariate (bivariate) index have been applied. The univariate indices used are Chapra-Dobson, Vollenweider, OECD and EPA-NES while the only multivariate index used is the Carlson Index. Univariate Carlson Index has also been used to substantiate the results of the various other univariate indices. The trophic status has been evaluated based on the phosphorous and the secchi depth data. Since the data of chlorophyll was not available, it has not been used in either the univariate indices or in the Carlson Index. Thus, only phosphorous and secchi depth data could be used for Carlson Index, making it a bivariate index.

The results of trophic state assessment indices indicate the present hypertrophic status of the lake. From the analysis of the phosphorus based index, 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 (Fig. 12). Analysis of the secchi depth based indices indicates the similar status, although no secchi depth data are available to confirm the trophic status prior to 70's (Fig. 13). 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 All the indices indicate that at present the lake is in an advanced hypertrophic state.

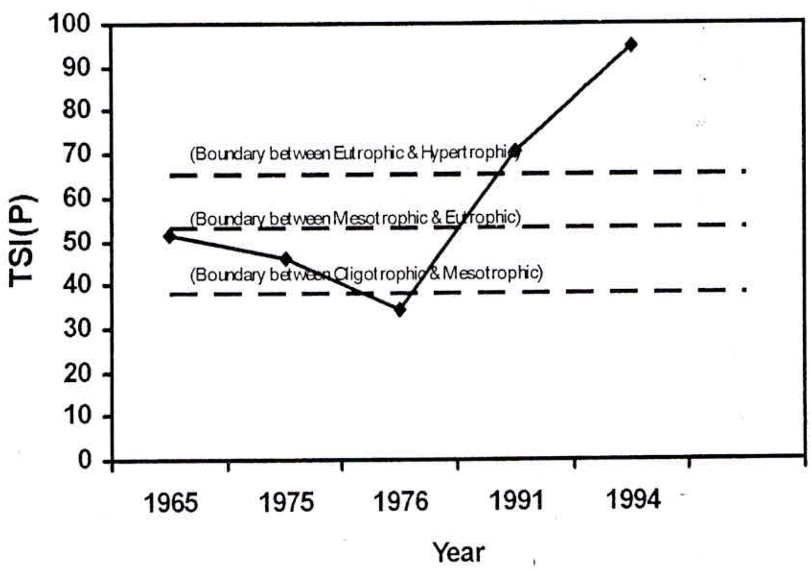

Fig. 12. TSI value of Pichhola lake based on Carlson (phosphorus) Index

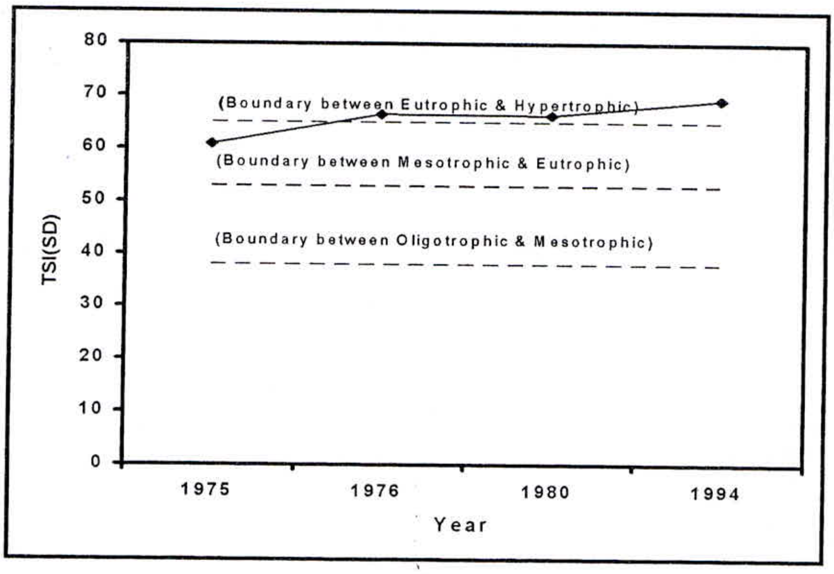

Fig. 13. TSI value of Pichhola lake based on Carlson (Secchi depth) Index

Due to the present hypertrophic condition of the lake, the lake water (without treatment) is found to be unsuitable for most uses except irrigation (Table 6).

Table 6. Suitability of Pichhola lake water for various uses based on trophic status

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

WATER QUALITY

The water of Pichhola lake is used for variety of purposes such as drinking, washing, bathing, industrial supply and socio-cultural activities. Standards have been set for suitability of water for various uses. To analyze the existing quality of the lake water, water quality samples were collected during April 2004 and analyzed at the water quality laboratory at NIH. The sampling locations are shown in Fig. 14 while the data are presented in Table 7. Although many of the water quality parameters are within the permissible limits as far as BIS standards are concerned, the DO and BOD are important parameters to know the quality of lake water. It can be observed from Table 7, that while DO values are very low for the lake, the BOD values are very high indicating degraded status of the lake. In particular the DO is very low in the Rangsagar portion. Similarly the BOD values are high all over the lake. As has been mentioned earlier the degraded water quality of the lake has rendered the lake eutrophic showing presence of algal mats, macrophytes, foul odours etc.

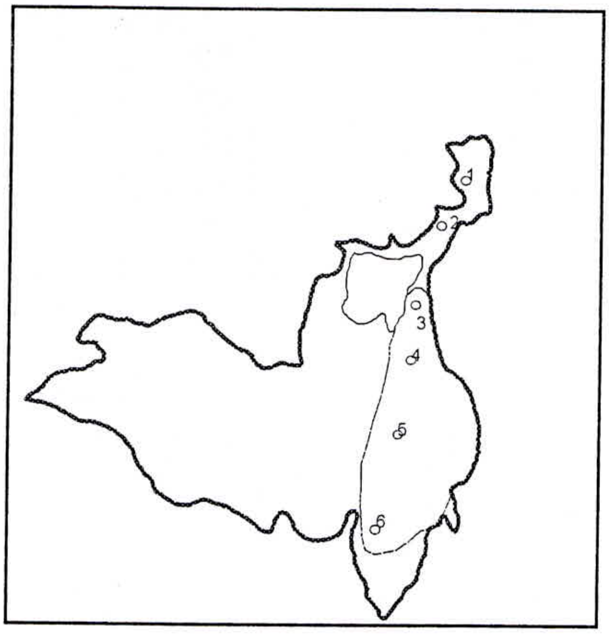

Fig. 14 Sampling locations for water quality

Variety of factors are contributing to the deterioration of the water quality of Pichhola lake. Major among these are the number of hotels which are located on the lake banks. They directly drain the polluted water into the lake. Garbage and debris of the surrounding areas, dead animals etc. are thrown on the lake banks. The ghats located on the lake shores are used for bathing, washing clothes and domestic animals, and for carrying out various socio-cultural and religious activities (Fig. 15). These add detergents and other pollutants to the lake. Boating activity add oil and other hydrocarbons. Municipal sewerage lines drain into the lake adding bacterial and organic load. Thus, the lake acts as a sink for all kinds of pollutants and contaminants Since the lake water is stagnant in the absence of any outflow and, since the water levels of the lakes are going down considerably, and since there is lack of dilution due to reduced inflows, the self purifying capacity of the lake has decreased drastically which further enhances the process of quality degradation.

Table 7. Surface water quality of Pichhola lake (April, 2004)

Parameter	Sampling Location						
	1	2	3	4	5	6	7
pH	8.10	8.12	8.06	8.08	8.00	8.02	8.04
EC (□S/cm)	500	557	1095	1265	496	1113	503
TDS (mg/L)	320	356	701	810	317	712	322
DO(mg/L)	3.2	0.5	3.4	1.4	3.2	3.6	5.0
BOD (mg/L)	18.0	16.0	16.0	16.0	16.0	16.0	16.0
Alk (mg/L)	168	202	260	306	184	322	163
TH (mg/L)	135	176	228	256	148	243	140
HCO3 (mg/L)	205	246	317	373	224	393	199
Cl (mg/L)	62	30	180	190	70	140	82
SO4(mg/L)	17	17	50	54	17	60	17
NO3 (mg/L)	3.96	2.64	8.80	4.40	5.28	7.04	4.40
PO4 (mg/L)	0.17	0.10	0.93	0.56	0.09	0.09	0.10
F (mg/L)	0.06	0.06	1.01	0.74	0.32	0.58	0.40
Na (mg/L)	51	45	142	157	51	152	45
K (mg/L)	5.0	5.0	22	24	5.4	10	5.1
Ca (mg/L)	40	49	47	58	38	52	36
Mg (mg/L)	9.7	13	2.7	25	13	13	8.7

(Note: Location 7 refers to the water being pumped into lake from Jaisamand Lake)

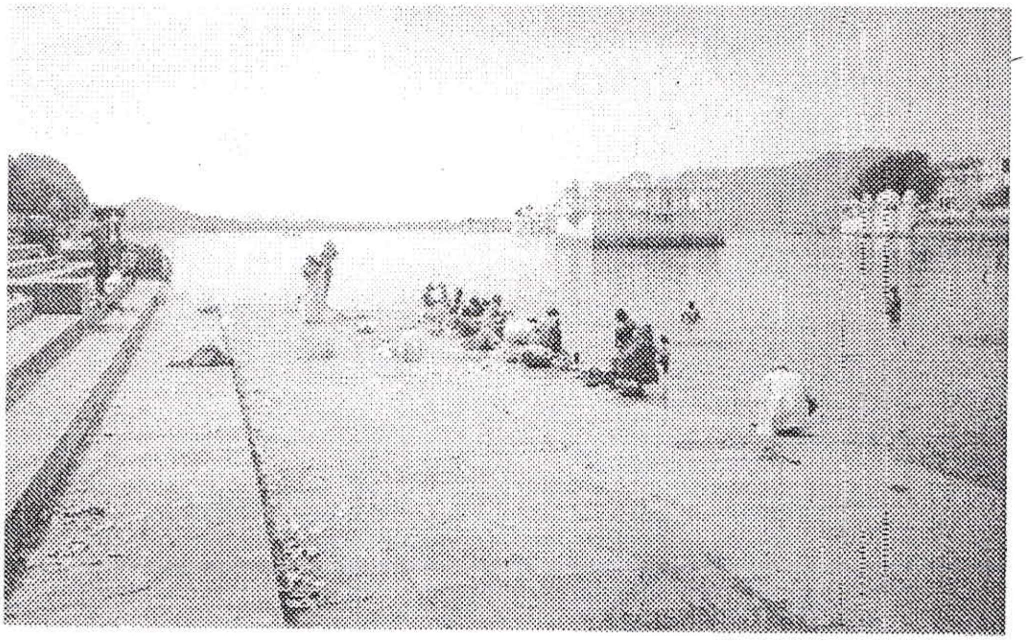

Fig. 15. Bathing and washing activities in Pichhola Lake

CONCLUDING OBSERVATIONS AND RECOMMENDATIONS

Based on the studies conducted so far and analysis of the data collected, various problems of the lakes have been identified along with their causes. On the basis of these findings following observations and recommendations to rejuvenate, conserve and manage the lake are made:

1. Trend analysis does not indicate any falling trend in rainfall for the region. Thus, the possible causes of drying of the lake appear to be: (i) reduced inflows due to surface abstraction because of construction of anicuts and checkdams etc, (ii) heavy evaporation losses, (iii) seepage losses from the lake to the downstream of the dam and (iv) higher withdrawls than availability of water in the lake. More scientific investigations on impact of anicuts on the inflow regime of the inflowing stream to the lake need to be carried out. Since water is also required by the villages in the catchment, an optimum volume may be decided for retention by the anicuts. Moreover, since there are heavy evaporation losses from the anicuts due to the shallow nature of the anicuts, other structures with lower exposed surface area may be planned instead of the anicuts.

2. The bathymetry survey of the lake is about a quarter century old. Due to sedimentation over the years there is a possibility that the volume of water available in the lake at any specific water level may not be equal to the storage volume as was at the time of the carrying out bathymetry survey. This may lead to wrong assessment of availability of water which may subsequently lead to over exploitation or mismanagement of water. So fresh bathymetry survey should be carried out to derive the depth–area-capacity relationships for the lake for better management of the lake water.

3. From the preliminary studies on the groundwater–lake interaction, it is observed that the water is being lost through the downstream end of the lake through seepage (particularly in the Jawahar nagar side). Exploitation of groundwater in this area through the tube well may be regulated to ensure that the overexploitation does not cause considerable reduction of the lake water.

4. From the comparative study of the catchment water balance and the inflow regime of the Sisarama river, it is apparent that a significant amount of water that falls in the catchment does not reach the lake. It is either retained as surface retention or is lost through to the ground. A major portion is also lost through the ET in the catchment. The water that goes to the ground does not enter the lake till the Bujhra village. Further detailed investigations on these aspects are needed.

5. Detailed scientific field investigations may be carried out on the ET losses from various land uses/crops/ forests in the catchment and, efforts be made to minimize these losses and maximize the runoff to the lake.

6. A considerable amount of water is being lost through evaporation from lakes. 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. Presence of thick mats of water hyacinth causes additional evaporation losses, so these need to be removed from time to time.

7. The lake is already in an advanced stage of hypertrophic condition. A comprehensive action plan for control, reversal and management of the eutrophication problem needs to be undertaken. For this purpose, various point and non-point sources of nutrients (phosphorous) need to be controlled and treated before they reach the lake. In-lake nutrient control techniques such as bio-manipulation (using fish and faunal introductions etc) may be employed. Scrapping of the upper layer of sediment containing nutrients as cleansing of the lake to control eutrophication may be taken up whenever the lake bed is exposed due to drying or reduced inflows. A wetland may be developed at the mouth of the lake where the river water enters the lake. This will settle the nutrients and other pollutants in the wetland and prevent their progression to the lake.

8. Considerable deforestation in the lake catchment has been reported. Extensive 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. The reported sedimentation rate of the lake is 0.48 cm/year and with this rate, the expected life of the lake is about 160 yrs.

9. Improvement in present sanitary conditions is required to prevent people from directly using the lake banks for open defecation. Similarly activities like washing, bathing, socio-cultural rituals which add detergents and other organic pollution should be strictly controlled.

10 Creation of a Lake Development Authority to undertake all the works related to the conservation and management of lakes along with a high power supervising committee to review the work and to suggest measures as and when needed. It should also have a research wing to undertake research and generate data on various aspects as needed from time to time.

11. There is a need to create an eco-friendly buffer zone along the periphery of the lake in the catchment wherein activities which damage the lake ecosystem through generation of pollutants etc, need to be banned. The distance from the lake to Bujhra village may be taken as an approximate radius for this buffer zone.

12. 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 is highly recommended.

13. 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. 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.

SELECTED REFERENCES

Allen, R. G., Pareira, L. S, Raes, D, and M. Smith. (1998). "Crop evapo-transpiration : guidelines for computing crop water requirements". Irrigation and Drainage Paper No. 56, F.A.O., Rome, Italy.

Benton, A. R., James, W. P. and Rouse, J. W. (1978). "Evapotranspiration from water hyacinth". Water Res. Bulletin, 14(4): 919-930.

Carlson, R. E. (1977). "A trophic state index for lakes". Limnology and Oceanography, 22(2): 361- 369.

Dingman, S.L. (1994). "Evapotranspiration". In: Physical Hydrology, McMillan Pub. Co., New York, pp. 256-265, 516.

Harper, D.,(1992). "Eutrophication of fresh waters: principles, problems and restoration". Chapman and Hall, London.

Jheel Sanrakshan Samitee, Udaipur. (1996). "Pre feasibility report on environmental improvement of Udaipur lake system- Vol. I: Past and Present Status". Sub. to Divisional Commissioner, Udaipur.

Khobragade, S. D. (1992). "Classification of lakes and inventory of lakes of India".TN-98. NIH, Roorkee.

Khobragade, S. D. (1996). "Major and important lakes of Rajasthan: status of hydrological research". SR-45. NIH.

Khobragade, S. D. (2003). "Status Report on Pichhola Lake". Unpublished Report, NIH, Roorkee, 2002-2003.

Khobragade, S. D. and Bhishm Kumar (2003). "Sedimentation Studies of Pichhola Lake Catchment using Isotope Methods". Unpublished Report, NIH, Roorkee, 2002-2003.

Khobragade, S. D. and D. S. Rathore (2003). "Evapo-transpiration Studies for Pichhola Lake Catchment". Unpublished Report, NIH, Roorkee, 2002-2003.

Khobragade, S. D. (2004). "An Introduction to Lakes and Their Hydrology". Lecture notes for Training Workshop on Hydrological Investigations and Catchment Management for Lakes. 28-29 Sep., 2004. NIH. Roorkee.

Khobragade, S. D. and K. K. S. Bhatia. (2004). "Preliminary assessment of trophic status of Lake Pichhola, Udaipur (Rajasthan)". Proc. 11th National Symposium on Hydrology with focal theme on Water Quality held at NIH, Roorkee, 22-23 November, 2004. Org. by NIH & CPCB.

Khobragade, S. D. and K. K. S. Bhatia. (2005). "Eutrophication: A serious water quality problem in lakes". Proc. National Seminar on Sustainable Water Management'. Ed. By Arvind Kumar, org. by Dr. S. P. M. Govt. Degree College, Allahabad during 26-28 October, 2005.

Kumar, S. and L. L. Sharma. (1991). "Comparative physico-chemical limnology of lakes of Pichhola and Fatehsagar, Udaipur, Rajasthan". Pollution Research., 10(3): 173-178.

Purohit, R. C., Acharya, M. S. & M.S. Babel. (1991). "Sedimentation studies of Pichhola and Fatehsagar lakes, Udaipur: Final Report." Proj. .No. J 22012/6188-W. Dept. of SWCE, CTAE, Udaipur. Spons. by Dept. Envn & Forest, GOI.

Rajasthan Pollution Prevention and Control Board, Jaipur. (1986). Environmental status of lakes in Rajasthan, environmental status document series on surface waters, ESDS/SW/1/86-87.

Vyas, L. N. (1968). "Studies in phytoplankton ecology of Pichhola Lake, Udaipur". Proc.

sympo. recent advances in tropical ecology, 335-347.

Vyas, L.N. Snkhla, S. K. and P.P. Paliwal. (1989). "Hydrobiological studies of Udaipur lakes". 'Perspectives in Ecology', ed. by j. S. Singh & B. Gopal. Jagmander Book Agency, N. Delhi. pp. 389-410.

Weert, R. D. and Kamerling, G. E. (1974). "ET from water hyacinth". J. of Hydrol. 22:201-212.