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MAJOR AND IMPORTANT LAKES OF RAJASTHAN : STATUS OF HYDROLOGICAL RESEARCH

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NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN
ROORKEE - 247 667 (U.P.)
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Preface

The presence of numerous freshwater bodies in the water scarce State of Rajasthan is a fine example of man playing his role where nature has created void. However, with the advance of the industrial age this marvelous achievement of man is getting destroyed and many of the lakes are being threatened by problems like excess pollution, sedimentation, eutrophication etc making it inevitable to take proper control measures to conserve these valuable natural resources. However, for proper management a knowledge of the various hydrological processes affecting the lakes is needed. To conduct such studies it was decided to first review the present status of the lakes and find out the problems faced by the various lakes alongwith the present research status. Based on the findings a subsequent research programme will be taken up by the Institute.

The report gives useful information about many major and minor water bodies of Rajasthan. It also gives useful physical and water quality data about these lakes and is perhaps the first compilation of its kind. This information will be useful not only for the Institute's future programmes but it will also be useful for various workers working in this field. The report entitled "Major and Important Lakes of Rajasthan : Status of Hydrological Research" is part of the work programme of the Lake Hydrology Division of this Institute during 1995-96. It is prepared by S.D. Khobragade, scientist - B, of the Division.

S. M. Seth
Director

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Abstract

Notwithstanding its climatic regime, the State of Rajasthan has many minor and major water bodies especially in the eastern and southern part. However, most of these are manmade and there are almost no natural lakes in the State. There are a number of saline lakes also in the desert region.

Many studies have been reported on the lentic freshwater bodies of the State but mostly on the bio-limnological aspects. The lakes of Udaipur are relatively better studied than other lakes of the State. Lot of confusion has been observed in the nomenclature used for different water bodies. There has been a lot of variation in the various physical and bio-chemical data of the lakes reported. A standardization of estimation procedures and units is needed. Most of the lakes are facing threats from pollution, sedimentation, high evaporation and eutrophication. There are numerous studies on pollution aspect but studies on hydrological aspects are almost negligible. However, since, for proper management and conservation of lakes and its ecology, a complete knowledge of all the processes in lakes is needed, it is suggested that the hydrological aspects be given due attention without much delay.

The status report gives information about many minor and major freshwater bodies of Rajasthan along with their present problems and status of present research. An attempt has also been made to prepare a comprehensive inventory of freshwater bodies of Rajasthan.

1.0 Introduction

Rajasthan, area wise the second largest state of India, lies between 22°3' to 30°12' N latitude and 69°3' to 78°2'E longitudes. In the north and north-east it is bounded by Punjab and Uttar Pradesh, in the east and south-east by Madhya Pradesh and in the southwest by Gujrat. As far as the terrain is concerned Rajasthan is known for its desert, rocks, jungles and waterbodies. The Aravali range which extends south-westerly to north-easterly, divides the state into two unequal parts. The western three fifth part, lying to the north-west of the range forms the major portion of the Indian desert or the Thar desert as it is known, whereas the remaining two fifth part which lies to the south-east of the range is comparatively fertile.

The major geological feature of the Indian desert are concealed under the aeolian sand deposits. Such deposits according to some geologists are due to long and continuous aridity. Sand deposition is also aided by drifting, caused by the south-west monsoon which blows the material derived from atmospheric weathering or rock outcrops with considerable force (Saxena, 1982).

The elevation of the land surface ranges between 214 m to 1375 m at few places in the Aravallis, while the larger part part of the state is less than 370 m in altitude (Misra, 1967). The latitudinal location determines to a great extent the amount of insolation and the direction of the prevailing winds as is the case for Tropics. The Aravallis are the most conspicuous physiographic feature in the state demarcating the variations in climate. In general, the climate of Rajasthan west of Aravallis, like other desert and semi-desert regions, is characterized by great extremes of temperatures and long periods of severe drought accompanied by high wind velocity and low relative humidity to semi arid conditions.

The Thar Desert in the west is one of the hottest regions in India. The maximum temperature in summer (April-June) are above 40°C almost all over the state. In many places like Bikaner, Phalodi, Jaisalmer and Barmer etc. it is above 45°C. There is a constant increase in temperature north and west of the Aravallis. Areas near the desert see hot to very hot desert winds of 20-35 km/hr speed (Ghulati,1992) and dust storms at places which have recorded temperatures as high as 50°C. In contrast, the winter months of October to March are cool with temperature falling below 15°C and even approaching zero degree at a few places. The nights even in summers are cool and occasionally frost occurs in winter. The difference between day and night temperature is so much that the mean values convey a very inadequate picture of the true climatic condition. The hot summer aided by the high speed winds are responsible for high rates of evapo-transpiration particularly in the western part.

The rainfall all over the state is low and erratic. The variability of rainfall is extremely high for e.g. Jaisalmer recorded no rainfall for 8 years prior to 1970 while many parts of the state experienced unusual floods during the monsoon of 1990 (Ghulati, 1992). The rainfall mostly occurs during June to September and decreases most markedly from east to west in the State. Mt. Abu in the south receives about 149.3 cm of rainfall, the highest in Rajasthan. East of the Aravallis, nowhere rainfall increases more than 76.2 centimeters (Misra, 1967). The arid west has a mean rainfall of less than 25.4 centimetres (Misra, 1967). The rainfall is associated with the rare depressions from the plains in the north and also with easterly winds. Part of it occurs due to local thunderstorms. Jhalawar and Jaipur have 40 to 45 days of thunderstorms in a year while Ajmer and Kota have 30 to 35 days, Jodhpur about 20 days and Bikaner and Barmer about 10 days. Ganganagar has very rare thunderstorms (Misra,1967). These storms generally occur during May to September, particularly in June and July.

The relative humidity is minimum in the hot weather months of March, April and May and maximum during the monsoon months of July, August and September, being lowest in April and highest in August. The moisture content of the air is lowest during the cold season. During the hot season,. humidity ranges between 35 per cent to 60 per cent in the morning hours and 10 per cent to 30 per cent in the afternoon hours. In the cold season, mainly December to February, humidity ranges between 50 per cent to 60 percent in the morning and 25 per cent to 35 per cent in the afternoon hours. The humidity is lowest at Jodhpur (Misra, 1967). The increase in relative humidity during monsoon is less marked in the west and the northwest of the Aravallis as compared to the areas lying to the east and southeast where rainfall is much higher.

Rajasthan has the distinction of being the world's most densely populated arid region. This has been possible because of the availability of water. Notwithstanding its natural arid climate, there are numerous lentic water bodies, both major and minor, spread all over the state although proportionately low in the western part, thanks to the work of Maharajas of the then Rajputana state who constructed many artificial waterbodies to cater the civilian needs. The lentic water bodies of the state include the lakes, reservoirs, tanks and ponds etc. Most of these are manmade and a very few are natural. A list of some of these waterbodies with some physical parameters has been appended in Annexure - I. However, it is to be noted here that the surface area data for the lakes have been computed from the topographic maps which are a few decades old (mostly late sixties and early seventies). The surface area (water spread area) indicates the area in that particular year and the season of that year. But the rainfall pattern of the state is very erratic and variations in rainfall in different years give different figures of water spread area depending upon the yield from the catchment and precipitation in the waterbody. Consequently, the computation of surface area is also affected by the season. Often there is a drastic quantitative reduction of available water in smaller waterbodies in summer due to high evaporation rates and many, particularly in the western desert region, dry out completely during summer. Reduction in capacity due to sedimentation and waste disposal also leads to a subsequent reduction in the surface area. For these reasons the surface area of the waterbodies fluctuate. So, the surface area data in Annexure-I should not be considered to give a permanent or even present position of the water spread in the waterbody.

2.0 Classification of lentic waterbodies of Rajasthan

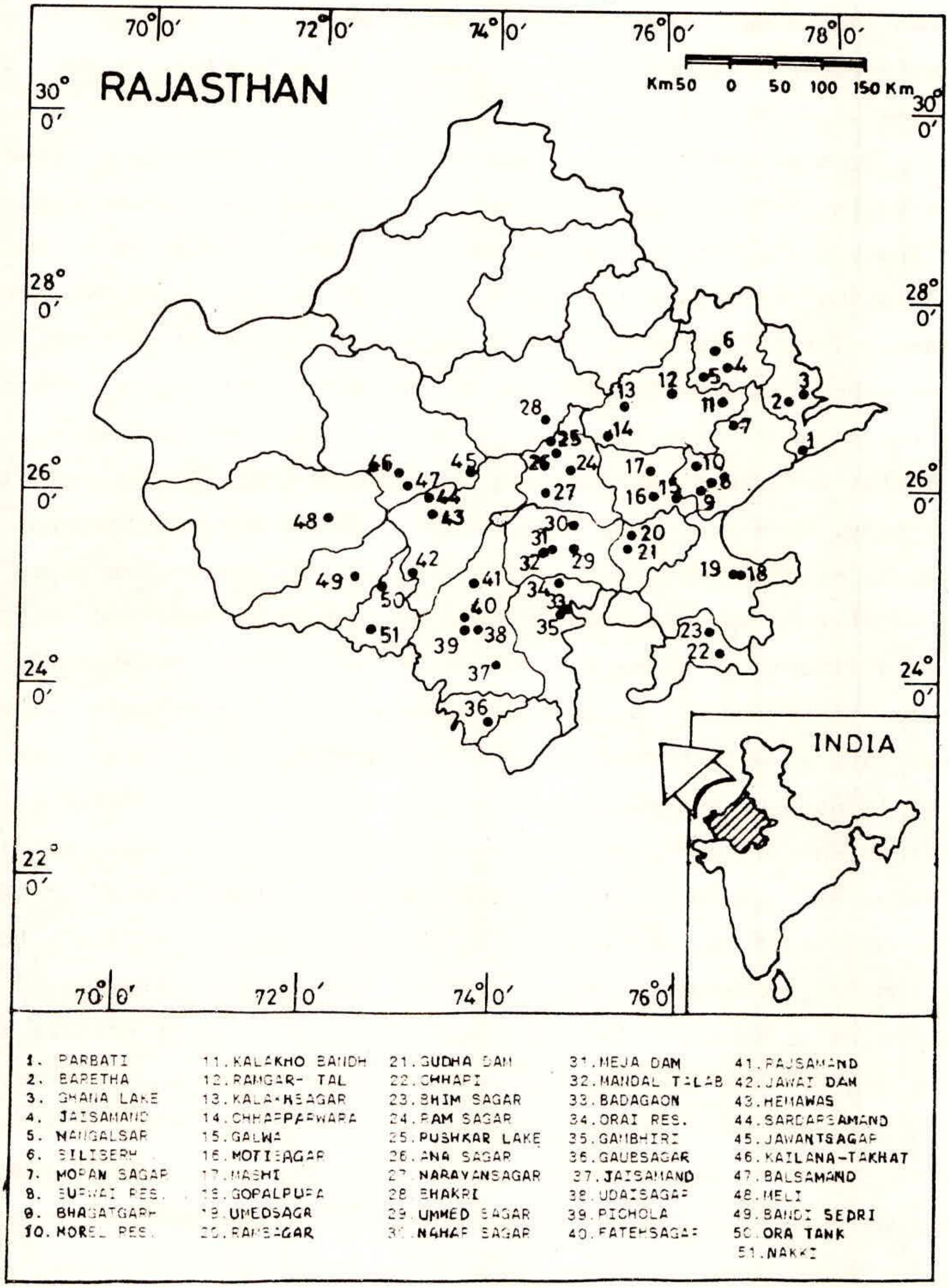
The lentic waterbodies of Rajasthan are designated by various terms in different parts of the state like talab, lake, bandh, sarovar, sagar, samand, jheel etc. Some of the water bodies are referred to as lakes or reservoirs by some, ponds by others and tanks by still others. There are instances where big water bodies have been referred to as ponds or tanks and the smaller ones referred to as lakes. These observations make it clear that there is an apparent confusion about the usage of terms for the different lentic waters. This appears to be for the following reasons: (1) often the terms are being used according to their conventional nomenclature without considering its technical validity, (2) most of the people who have used this terms are not hydrologists and definitely not lake hydrlogists. Most of them being ecologist or biologists or limnologists, are more interested in the study area rather than technicalities of the designation of the water body, (3) there is no unique and precise hydrological definition of lake in existence as yet. Consequently, often lakes, ponds and reservoirs are considered synonymous although there are certain hydrological differences which differentiate these waterbodies from each other (Khobragade & Bhar, 1993).

What is a lake? What differentiates it from the other lentic water bodies? The matter of a precise definition of a lake is yet to receive sufficient attention. As early as in 1952 Zumberge defined a lake as "an inland basin filled with water". But this definition was too general and as is obvious, includes ponds also in its scope, without making any differentiation between the two. Since tanks and reservoirs are easy to differentiate, being artificially created , the problem really is to differentiate a lake from a pond, both of which are natural in origin. So, Welch (1952), in the same year, suggested some size restriction while differentiating lakes from ponds. The former, he suggested "should have an area of open, relatively deep water, sufficiently large to produce somewhere on its periphery, a barren wave swept shore". In contradiction are ponds which according to Welch are "very small, very shallow bodies of standing water in which quiet water and extensive occupancy by higher aquatic plants are common characteristics". Obviously, very small basins such as stream-cut potholes or tiny solution pits in limestones must be excluded from the definition of a lake, but exactly where the cutoff in size comes has never been defined accurately as pointed out by Zumberge & Ayers (1964). Zumberge and Ayers (1964), on the lines of Welch, defined the 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". However, even this definition is not adequate and as they have themselves suggested, "a really quantitative definition may well require some recognition of Welch's stipulation of a wave-swept shore, possibly expressed in terms of some numerical index containing maximum wave size". Such an index is yet to be established even after three decades after its suggestion. It should be remembered that the maximum wave formation in lakes is determined not only by its size and depth but by other factors also like the wind velocity, wind direction, fetch, lake orientation etc. The involvement of many parameters appears to have made the development of a simple universal relationship between the lake morphometry and the maximum wave size a rather complex job. Its development in near future also does not seem plausible as the studies on waves in lakes in the world context are too meager and are yet to find favour with the lake hydrologists. This aspect of the hydrodynamics of lakes appears untouched as far as Indian lakes are concerned and no research on this aspect is reported so far.

There are a few other attempts at defining a lake (Nace, 1978; Mark & Goodchild, 1982 and Kuusisto, 1985 etc). But most of these definitions are also inadequate as they fail to establish a clearcut demarcation line between a lake and a pond, and the criterion to do so. Thus, the definition given by Zumberge and Ayers (1964) still remains the most acceptable definition. This definition has three elements. Firstly, (although not specified by them) to be called a lake, the waterbody has to be natural. Secondly, the area of the waterbody should be large enough and the lake be deep enough to cause waves in it. Thirdly, the waves so caused should be strong enough so as to affect the shore of the lake thereby not allowing the formation of vegetation along the periphery of the lake.

Are the lentic waterbodies of Rajasthan lakes, reservoirs, tanks or ponds? It will, of course, be depending on the individual waterbody but there are a few natural waterbodies in Rajasthan like Nakki at Mt. Abu and Jalore in Jalore. Are they ponds or lakes? The definition of pond above makes it clear that to be a pond a waterbody (natural) should have extensive aquatic plants, although this characteristic can not be considered as essential because it will depend upon the geological age of the waterbody. More over, the demarcation line between the lake and a pond, as said earlier, still does not exist as far as the size of the water body is concerned. Unless this problem is solved first, it is difficult to classify them as lakes or ponds. However, if we follow the definition of lake as given by Zumberge & Ayers (1964) these natural waterbodies appear more as ponds rather than lakes, as it is doubted whether their small size permits the formation of a barren shoreline due to wave action. Thus, if one goes by the existing definition of a lake given above, probably none of the water bodies of Rajasthan can be classified as a lake. Most waterbodies, however, seem to fall under the category of reservoirs as most of them are created artificially by damming the river flows. This implies that modern big reservoirs, although large and deep, can not be referred to as lakes as they are not natural in their origin not to talk of the small and medium reservoirs. As far the definition of tank is concerned, a tank is

FIG. 1 LOCATION MAP SHOWING SOME MAJOR AND IMPORTANT FRESHWATER BODIES.



a small artificially dug reservoir and as such to identify it is relatively easier and although majority of the major waterbodies are manmade, most of them are not artificially dug to categorize them as tanks.

Thus, most of the waterbodies of the state are manmade reservoirs either small, medium or big. However, in the absence of complete morphometric data about the waterbodies alongwith the information about their origin, it is difficult to classify them at present even with the existing definitions of lakes and ponds. Nomenclature based on literature or traditions is expected to be erroneous. Hence some technical lapse as regards the nomenclature is admitted in this report also.

3.0 Major and important freshwater lakes

The preceding discussion makes it aptly clear that there are almost no natural freshwater lakes in Rajasthan. However there are many artificial lakes (reservoirs) in the State which can be considered as lakes for the study purpose. However, the fact remains that these bodies are expected to behave hydrologically a little differently than the natural lakes owing to the difference in hydrological setting.

A location map showing some of the major artificial lakes and some minor but important waterbodies of Rajasthan is presented in Fig. 1. Basin maps (indicating water spread area) of some of the major freshwater waterbodies of the state are shown at the end of the report (Fig. 17). For lack of information it is not possible to give detailed description about all the waterbodies. However, a few major and important ones are described below. The word lake wherever used should be considered to mean artificial lake (mostly reservoir or tank) unless not otherwise specified.

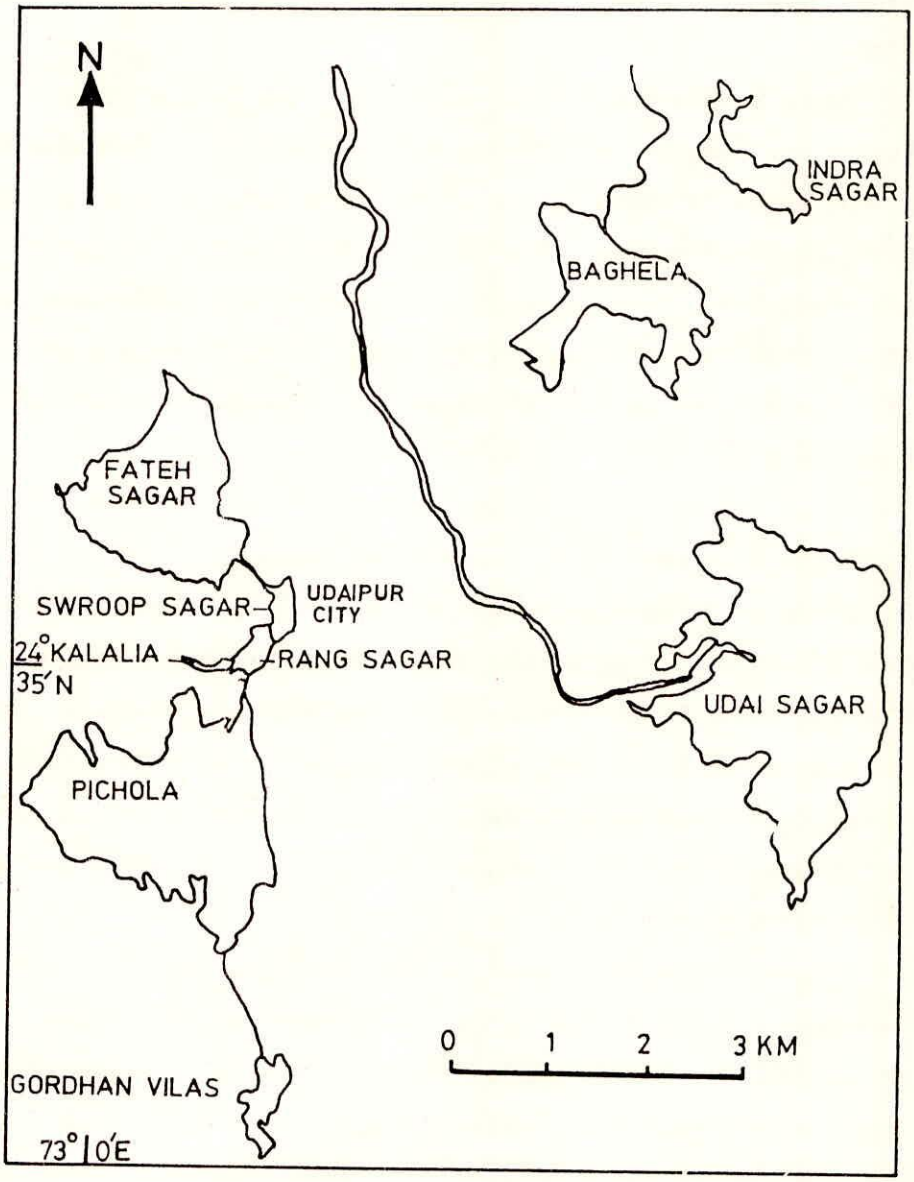


FIG. 2 SOME FRESH WATER BODIES AROUND UDAIPUR (AFTER VYAS ET. AL., 1989)

The report does not give description of modern big multipurpose dams which are of recent origin.

3.1 Udaipur Lake System

3.1.1 General

Udaipur (24^{o} 35' N latitude and 73^{o} 42' E longitude) lies at an altitude of 587 m above sea level. The Udaipur lake system is a collection of a few interconnected reservoirs, ponds and tanks viz. Pichola, Swaroopsagar, Fatehsagar, Badi, Madar, Rangasagar and Udaisagar besides a few other small tanks. Together they form the lake system. Of these only Pichola, Fatehsagar and Udaisagar are relatively big in size and the rest are small reservoirs. Some of the freshwater bodies located in and around Udaipur are shown in Fig. 2. All these lakes are primarily owned by Deptt. of Irrigation, Govt. of Rajasthan. However, since they are drinking water bodies, the Public Health Engineering Deptt. also has a control over their use and maintenance. Out of the above lakes, Udaisagar is situated about 15 kms away from the city and is under the control of Hindustan Zinc, a public sector undertaking. All the lakes of Udaipur form a chain in the saucer shaped Udaipur valley. The four interconnected lakes viz. Pichola, Fatehsagar, Swaroopsagar and Rangasagar are situated in the municipal limits of Udaipur. A layout of these lakes is shown in Fig. 3. Of these the Pichola is the largest and is sloping from north to south slowly tending towards the Rangasagar. This narrow portion at the mouth of Rangasagar is silted to become shallowest. This then further expands to form its main body by inundating the surrounding hill-slopes. The flow continues further, narrowing initially but expanding again to form the lake Swaroopsagar. The waste weir of this lake opens into Fatehsagar. The layout of the

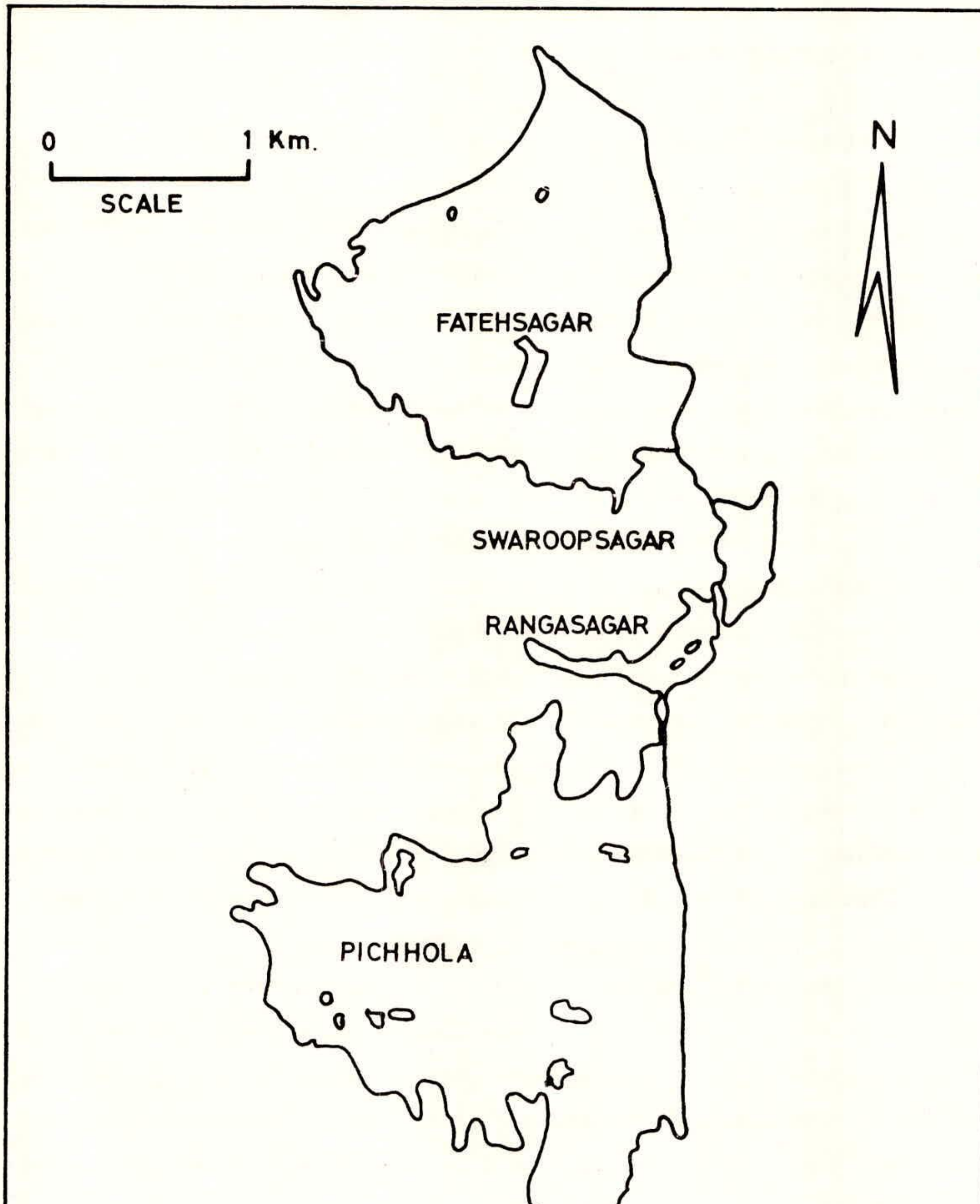


FIG. 3 - LAYOUT OF UDAIPUR LAKES
(AFTER RAO & DURVE, 1989)

first three lakes is comparable to a tea kettle (Rao et al., 1988) wherein the main body of the kettle is the lake Pichola. Rangasagar forms the base of the kettle outlet and hence excessively silted whereas the lake Swaroopsagar forms the last portion of the outlet tube.

All components of Udaipur lake system, particularly Pichola and Rangasagar are reported to be under stress owing to human pressure. There are numerous domestic sewage effluent discharge sites along their shores. Bathing ghats, on the eastern side of Pichola and Rangasagar, are used by residents of the area for bathing, washing and religious activities. All these activities are responsible for the pollution in these waterbodies.

The different componets of Udaipur lake system are discussed in next section.

3.1.2 Ahar-Berach river system

The Udaipur lake system arising out of the river Berach and its tributaries is an integral component of the upper Berach Basin. The river Berach is a tributary of Banas and meets Banas on its right bank near Bigod of Bhilwara district. The reservoirs Pichola, Swaroopsagar, Rangasagar, Madar, Udaisagar, Vallabhnagar, Badagaon and Bagolia tank are all located on this river and its tributaries. It originates from the hills on north of Udaipur near Gogunda where it is known as Ahar. It flows south east past Dedla and close to Udaipur falls in Udaisagar and issuing from there is known as Udaipur-ka-nallah. When it reaches the open country, it is recognized as Berach and after flowing for about 90 km in north-east direction in the district it leaves its boundary near Akola village in Vallabhnagar tehsil and flows to Chittorgarh and Bhilwara Districts. The main tributaries of the Berach river are

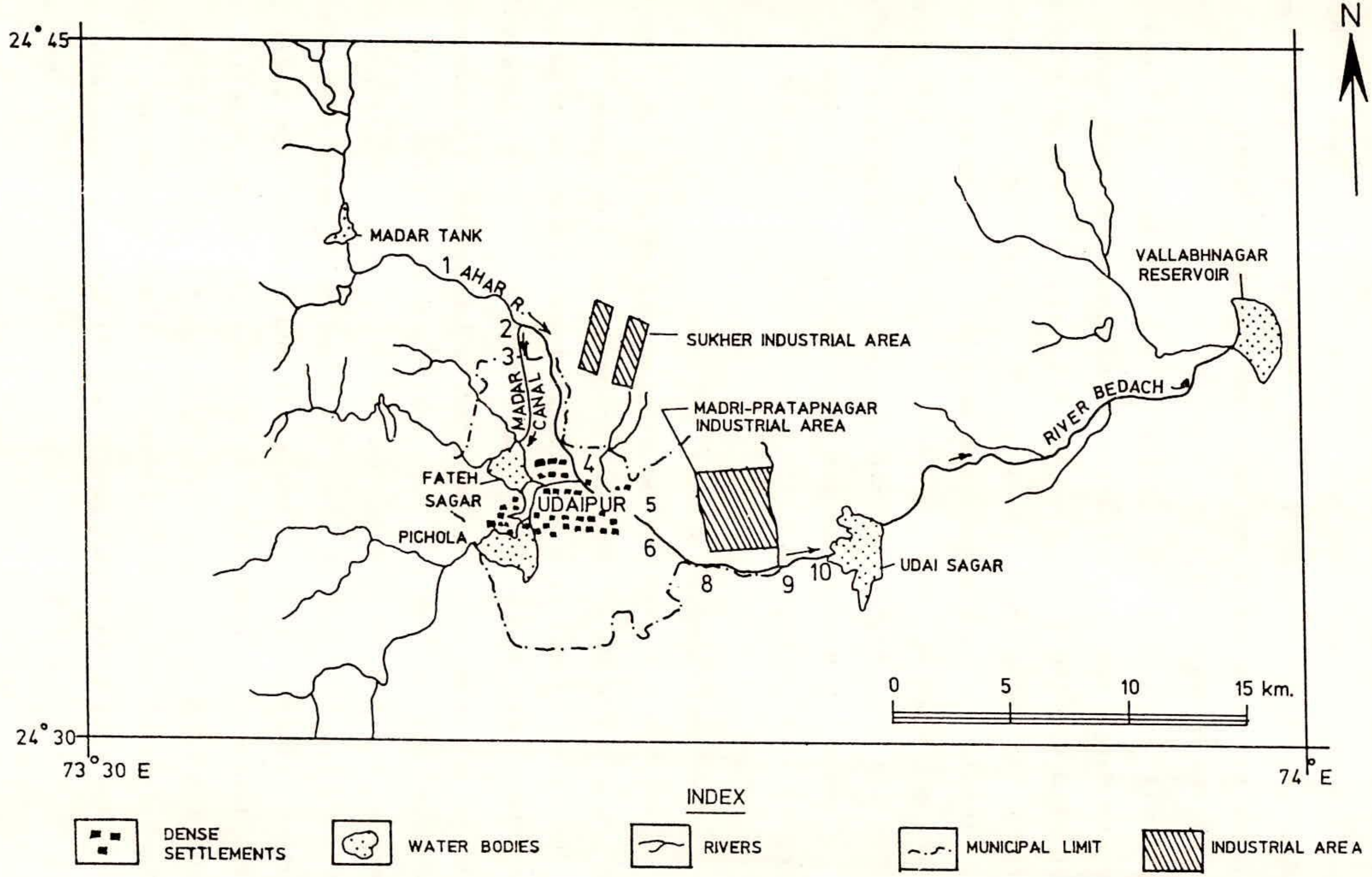


FIG. 4 DRAINAGE SYSTEM OF AHAR / BERACH RIVER FROM MADAR TANK TO VALLABHNAGAR

Wangli, Wagan, Gomti and Orai, all of which join its right bank.

The stretch of Berach basin covering drainage area upto Vallabhnagar reservoir is 1250 sq.km. Fig. 4 shows the drainage system of river Ahar/Berach from Madar tank to Vallabhnagar reservoir.

3.1.3 Catchment characteristics of Udaipur Lakes

Location of Udaipur district is such that it lies on the all India major divide separating Ganga system falling into Bay of Bengal and Mahi-Sabarmati system of India falling into Gulf of Cambay. Ridge line of watershed of Lake pichola is a line which is bifurcating the above system. The catchment area of Udaipur lakes lies in the Girwa plain of the Udaipur platue. It is surrounded by high hills. The average height of the area is between 650 to 900 m. The highest point in the catchment area is at 990 m and the lowest, near Bari Pal, is 585 m in the Pichola lake above msl (Purohit et al., 1991). The catchment area of both Pichola and Fatehsagar lakes is drained by two small rivers namely Kotra and Amarjok which enter in river Berach near village Nai and ultimately drains into Pichola.

The Udaipur lake region formed the essential part of the most ancient Gondwana table land of the peninsular India. The main rocks of the area are phyllities and quarzites. The soils of the area are dark brown and black coloured. Nearly half of the total cultivated area has deep to moderate deep fine textured soils with very gentle slopes. Soils of the remaining area are shallow to moderate deep with undulating topography. The pH of the soils is in general neutral to slightly alkaline . Total soluble content is normal. Organic carbon and available nitrogen are usually low (Zheel Sanrakshan Samiti Rep., 1994). The clay content in the

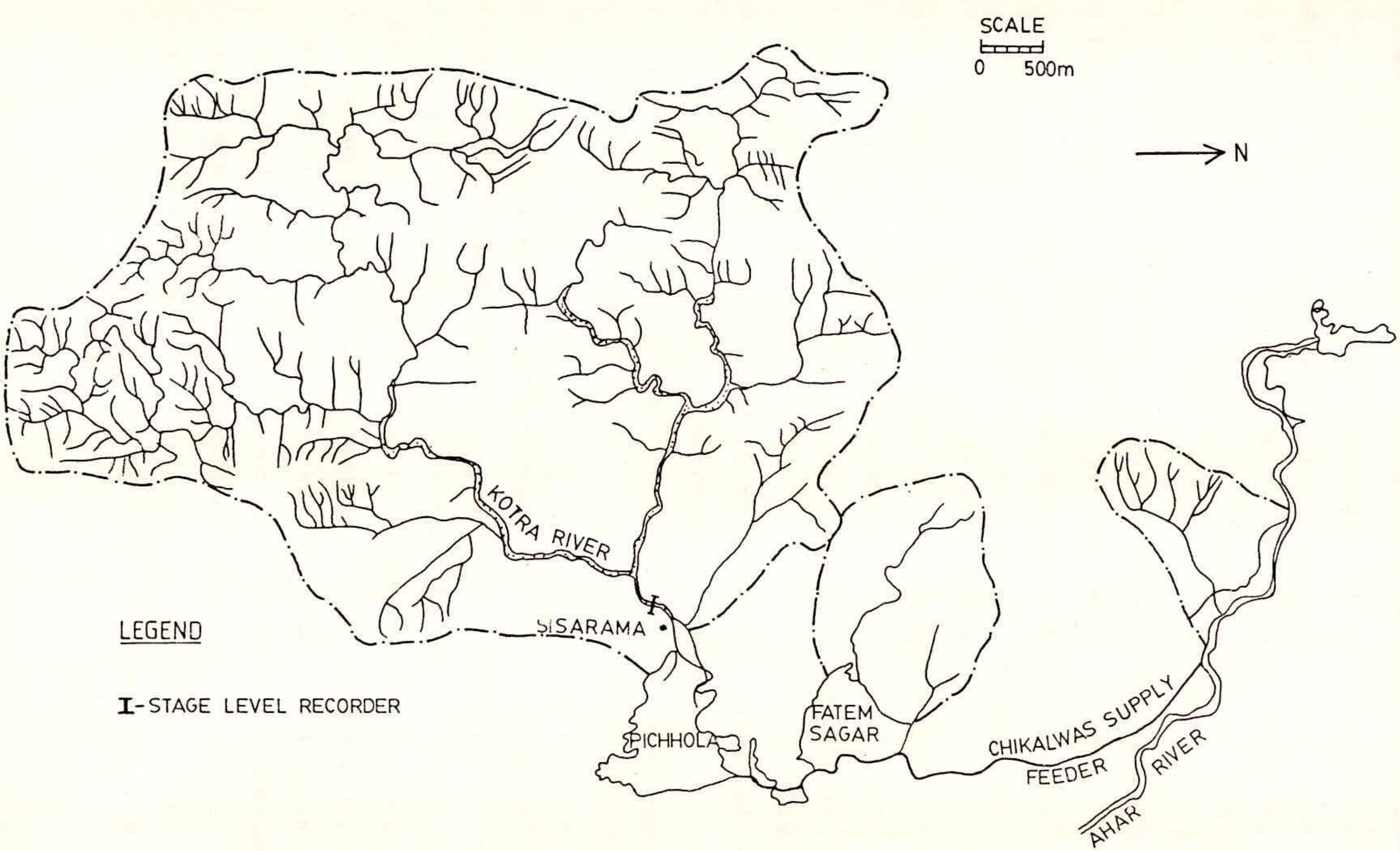


FIG.5 CATCHMENT AREA OF FATEHSAGAR AND PICHHOLA LAKES
(AFTER PUROHIT ET AL, 1991)

soils of Pichola and Fatehsagar catchment area ranges from 20 to 30%. (Purohit et a., 1991). The vegetation in the catchment area is very scanty.

The individual catchment of Fatehsagar is very small and has no significant contribution to the reservoir. However, there is some discrepancy over the individual catchment area of these lakes as reported by different workers, especially in case of Fatehsagar. For example the catchment of Fatehsagar according to Purohit et al., (1991) is only 19.11 sq.km whereas it is 53.66 sq. km according to Durve (1980). The catchment area of the Pichola (including Swaroopsagar and Rangasagar) and Fatehsagar is shown in Fig. 5. Table 1 presents the aerial aspects of Pichola catchment area.

Table- 1. Aerial aspects of Pichola catchment area (after Purohit et al., 1991).

Area (sq.km)	Perimeter (km)	Drainage density (km/sq.km)	mean slope (%)
130.054	22.50	0.15	3.04

According to the Zheel Sanrakshan Samiti report (1994), the catchment of the six waterbodies of Udaipur viz. Pichola, Fatehsagar, Chhota Madar, Bada Madar, Badi lake and Chikalawas dam cover 70 revenue villages. The general slope of the watersheds is from S-W to N-E directions. Topography is very undulating. The average length and breadth and the catchment area data are given in Table 2. Land use for the Pichola catchment is presented in Table 3.

Table - 2. Catchment data for Udaipur Lakes
(after Zheel Sanrakshan Samiti report., 1994)

S.No.	Waterbody	Length (km)	Breadth (Approx.) (Km)	Area (Sq.km)
1.	Pichola	8.50	15.00	127.00
2.	Fatehsagar	6.25	3.75	23.25
3.	Bada Madar	11.00	6.50	72.90
4.	Chhota Madar	7.50	3.50	25.34
5.	Badi lake	6.00	3.00	18.20
6.	Chikalwas feeder	14.50	4.50	64.50

Table - 3. Land use in Pichola catchment area
(after Purohit et al., 1991)

S.No.	Land Use	Area (Sq.km)	Area (%)
1.	Forest Area	16.25	12.50
2.	Irrigated Area	5.85	4.50
3.	Unirrigated Area with fallow land	17.85	13.73
4.	Cultivable waste land including pasture	24.42	18.78
5.	Waste land	65.68	50.50
	Total	130.05	100.00

3.1.4 Climatology of Udaipur Lakes

The catchment area is a sub humid climatic region. The winter season from December to February is followed by summer season which lasts till about middle of June. The period from middle of June to September is the period for south-west monsoon bringing rain. The maximum air temperature in Udaipur reaches about 43^{o}C in May-June although temperature as high as 45.4^{o} was recorded on 27 April 1958. The minimum is noticed during Dec-Jan.

During this period the temperature may at times drop to -1.5^{o}. According to a D.S.T report (1995), the average temperature of Udaipurcity during 1972-1990 comes to $23.32^{o}C$ with variations from 1.5 to $44.5^{o}C$.

The normal annual rainfall in the area is reported to be 635 mm. The average annual rainfall at Udaipur town for the period 1957-1980 was, however, 622.4 mm. Most of the rainfall occurs during the monsoon months of June-Sept. Distribution of the rainfall is uneven and shows vide variations between year to year. The highest rainfall of 1222.76 mm was recorded during 1917 where as years 1936 and years 1966 recorded minimum rainfall of 300.4 mm and 297.30 mm respectively. Recently during the drought year of 1987 the rainfall was only 263.00 mm.

Except in the brief south-west monsoon season when the relative humidities are generally about 70 percent or more the air is generally dry. The summer months are driest of the year when the humidities go down to 20 to 25% particularly in the afternoon. However, variations in relative humidity are reported to be between 7.93 to 97.77 percent by a D.S.T. project report (1995). Winds are generally reported to be light with some strengthening in the later half of summer and the south-west monsoon season. In the period from May to September winds blow from directions between and west. In the post monsoon season the winds are predominantly from directions between north west and north-east. Winds are variable in the cold season, but winds from direction between east and south are rather rare. By the beginning of summer south westerly or westerly winds begin to blow and they become predominant with the advance of the season. Dust storms and thunderstorms sometimes occur in the hot months. Table 4 presents the average climatic data for Udaipur whereas the average annual rainfall for Udaipur town for the period 1957-80 is presented in Table 5.

Table - 4. Average climate data for Udaipur

Month	Temp. °C		Relative Humidity		Mean Wind speed km/hr
	Mean daily Max.	Mean daily Min.	8.30 hrs IST(%)	17.30 hrs IST(%)	
Jan.	24.2	7.8	66	40	2.2
Feb.	27.6	9.7	55	29	2.6
Mar.	32.3	15.1	43	24	3.6
Apr.	36.0	20.2	34	23	4.6
May.	38.6	24.9	38	25	6.3
Jun.	35.9	25.3	63	48	7.4
Jul.	30.7	23.9	78	70	6.3
Aug.	29.30	22.9	81	75	4.7
Sep.	30.90	22.10	76	65	3.7
Oct.	32.0	18.9	62	42	2.3
Nov.	29.1	11.0	57	39	1.5
Dec.	26.3	8.3	63	40	1.5
Avg. Annual	31.1	17.5	60	43	3.9

(Source : Rajasthan District Gazetteers : Udaipur, 1979, courtesy : Irrigation Deptt., Udaipur)

Table- 5. Annual precipitation at Udaipur town during 1957-80

Year	Precipitation (mm)	Departure from average precipitation (mm)
1957	617.20	- 4.84
1958	751.70	+ 129.66
1959	857.00	+ 235.26
1960	517.00	- 104.44
1961	641.10	+ 19.06
1962	483.80	- 130.24
1963	851.00	+ 229.26
1964	627.80	+ 5.76
1965	600.90	- 21.14
1966	297.30	- 324.74
1967	873.30	+ 251.26
1968	624.30	+ 2.26
1969	509.20	- 112.84
1970	764.50	+ 142.46
1971	388.30	- 233.74
1972	373.30	- 248.74
1973	1095.50	473.76
1974	402.20	- 219.84
1975	597.00	- 25.04
1976	576.00	- 46.04
1977	483.10	- 138.94
1978	797.00	+ 174.96
1979	576.00	- 46.04
1980	623.00	+ 1.36

Average = 622.04 mm

(Source : Irrigation Deptt., Udaipur)

3.1.5 Components of Udaipur Lake System

The Udaipur lake system, as earlier said, is a collection of many small fresh waterbodies most of which are medium to small reservoirs. A description of Pichola, Swaroopsagar, Rangasagar, Fatehsagar and Udaisagar are described in this section. A few of the remaining waterbodies are described in the next section.

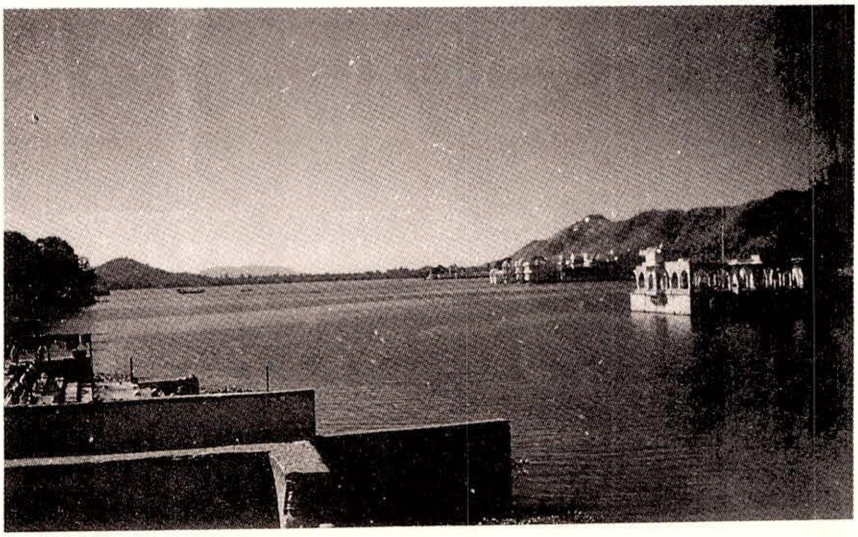


PLATE-I A VIEW OF PICHOLA LAKE, UDAIPUR

3.1.5.1 Pichola

It is a medium size manmade reservoir located at 24°34'N latitude and 73°41'E longitude (Plate 1), at an altitude of 587 m above the msl in the west of Udaipur city. It is the oldest and the biggest of the waterbodies of Udaipur city. It has got its name from a small village Picholi nearby and was initially constructed by a Banjara chieftain towards the end of 14th century (1382-1418 A.D.). Its embankment was further raised by Rana Udai Singh in 1560 who established the town of Udaipur on its bank. The lake has two islands and many islets. Along the eastern bank is the long range of the city palace and to the south is the hill known as Eklingarh. A great masonry dam holds the water back from the Samor Gardens. At the northern end of the lake is the old town with numerous ghats.

The reservoir is mainly rainfed. River Sisarama, a tributary of river Kotra is the chief source of water for this reservoir. As far as the morphometry of the reservoir is concerned, there is a considerable variation in the values reported by different workers. The length of the lake is about 4 km and its width is about 2.4 km (Vyas, 1968). According to Kumar and Sharma (1991) the maximum length, maximum width and mean width of the reservoir is 3.6 km, 2.61 km and 1.93 km respectively. The water spread area of the lake fluctuates yearly and seasonally. Thus, according to the Raj. Poll. Prev. and Cont. Board report (1986) & Madhusudan et al. (1984), it is 10.8 sq. km while a value of 6.96 sq. km. is given by the Zheel Sanrakshan Samiti report (1994), Vyas et al (1989) and Kumar and Sharma (1991). The topographic map (1971-72) puts it at 3.20 sq. km. The average depth of water is 5.6 m (Madhusudan et al, 1984). It is 4.5 m according to Kumar and Sharma (1991). The maximum depth of the reservoir is 10.5 m according to Zheel Sanrakshan Samiti report (1994) and Vyas et al. (1989) and 9.15 m according to Madhusudan et al. (1984). According to Kumar and Sharma (1991) it is 8 m. The maximum depth is towards the west where Kotra river drains into the lake forming an ever extending delta indicating an utter absence of a gradient and slope. The deltaic situation is accentuated because of excessive silting in the area over the years (Zheel Sanrakshan Samiti report, 1994). As mentioned earlier, there is some variation in the catchment area values reported by different workers. The catchment area of the reservoir is 130.054 sq. km as per Purohit et al., (1991). It is 142.40 sq. km according to the Irrigation Deptt., Govt. of Rajasthan. This figure, of course includes the catchment area of Swaroopsagar also. According to the Zheel Sanrakshan Samiti report (1994), it is 127.00 sq. km. It is not known whether this also includes the indivisual catchment of Swaroopsagar also or not. Storage capacity of the lake according to Vyas (1968) is 485 million cubic feet (13.73 Mcum). It is about the same as per Irrigation Deptt (13.67 Mcum) where as it is 13.08 million cu. m according to Kumar and Sharma (1991). The lake has a shoreline of 12.9 km and a shoreline development index of 1.38 (Kumar and Sharma, 1991). On its eastern boundary the lake is connected to Swaroopsagar through Rangasagar.

Although constructed primarily for irrigation, of late, this lake has become the main source of drinking water for Udaipur city. It has been reported that of the total civil water supply to the Udaipur city 80 % demand is met from Pichola alone. Besides, the reservoir has other uses such as bathing, washing of clothes, fishing, irrigation, recreation and socio-cultural activities.

The lake is reported to be eutrophic and the process has been accentuated by the reckless denudation of surrounding hills of the forest wealth. The reservoir dried completely in 1973 exhibiting its heavily silted bottom (Durve & Rajbanshi, 1976). In the year 1980 it almost got choked up with a water hyacinth which was cleared by massive human efforts of Udaipur citizens (Madhusudan et al., 1984). Approximately 14 % population of Udaipur, comprising mostly of the weaker sections of the society inhibit the unhygenic marginal area of the reservoir. These people use the shores for relieving themselves. It has been estimated that every day average 675 persons use the shores of Pichola for the purpose (Madhusudan et al., 1984). Because of this and other reasons the lake is getting highly polluted. This aspect has been dealth with in section 6.0.

Activities like agricultural and construction, increasing tourist trade, deforestation and trade activities in the catchment area, ineffective scouring/dredging of the lake deposits, washing, bathing and live stock entries, domestic waste disposal from the surrounding and siltation has aroused concern for this multipurpose waterbody.

3.1.5.2 Swaroopsagar

Swaroopsagar (Plate 2) is a very small reservoir. It lies to the southwards of Rangasagar. It is the ultimate part of the Lake Pichola and provides a combined waste weir to Rangasagar and Pichola and connects these two with Fatehsagar through a canal. On the eastern side of it there is a masonry dam which has become a convenient site for open defecation.

The salient features of Pichola Swaroopsagar Complex is given in Table 6.

PLATE-2 A VIEW OF SWAROOPSAGAR, UDAIPUR

Table- 6. Salient features of Pichola-Swaroopsagar Lake Complex (Source :Irrigation Deptt., Raj. Govt., 1996)

1.	District	Udaipur
2.	River Basin	Berach
3.	Catchment Area (Sq. miles)	55.00
4.	Normal Rainfall (mm)	635.00
5.	Yield (Mcft)	4494.00
6.	T.B.L.(ft)	105.00
7.	M.W.L. (ft)	98.00
8.	F.T.L.(ft)	95.00
9.	Sill Level (ft)	84.00
10.	Gross Capacity (Mcft)	483.00
11.	Dead Capacity (Mcft)	165.00
12.	Live Capacity (Mcft)	318.00
13.	Culturable Command Area (Ha)	580.00
14.	Irrigation Potential (Ha)	400.00
15.	Type of Dam	Masonry
16.	Length of Waste Weir (ft)	225.00
17.	Flood Discharge (Cusec)	19923

3.1.5.3. Fatehsagar

It is a medium sized perennial reservoir somewhat pear shaped in its outline (Plate 3). It is situated in the north-west of Udaipur city at an altitude of 587 m above msl. The latitude is $24^{o}35'$ E and longitude is $73^{o}42'$N. It was first constructed in the year 1678 A.D. and latter renovated in 1889 A. D. by Maharana Fateh Singh and Duke of Connaught.

The lake basin is mainly calcareous in nature (Zheel Sanrakshan Samiti report, 1994). It is reported to be 2.6 km in length from north to South and 1.8 km from east to west with a maximum depth of 13.4 m (Zheel Sanrakhan Samati report, 1994; Rajasthan Pollution Prevention & Control Board report, 1986; Durve, 1980 and Kumar & Sharma, 1991). Its maximum depth, like any other reservoirs, lies towards the dam side. The mean width is 1.5 km (Durve, 1980). Although little deeper at the dam end, for most

PLATE - 3 A VIEW OF FATEHSAGAR LAKE,UDAIPUR part the reservoir is a shallow waterbody. The Mean depth is 5.4 m according to Kumar & Sharma (1991) and Raj. Poll. Prev. And Cont. BoardRep (1986) but Durve (1980) calculated it as 3.0 m. Total water spread is 4.0 sq. km approximately as per the Zheel Sanrakshan Samiti report (1994) whereas according to the topographic map of 1970-71 it is 2.30 sq. km. There is a considerable discrepancy in the values of Catchment area reported for lake Fatehsagar as already mentioned before. Thus, according to Zheel Sanrakshan Samiti report (1994, page 8) the reservoir commands a catchment area of about 53.66 sq.km. At other place (page 11) the same report gives a value of 23.15 sq. km (2315 ha) for its catchment area. According to Durve (1980) also, the catchment area is 53.66 sq. km where as a value of 15.53 sq. km (6.00 sq. miles) is considered by the Irrigation Deptt, Rajasthan. Purohit et al. (1991) have given a figure of 19.11 sq. km. The length of shoreline is 8.5 km and the shoreline development is 1.20. The water level in the reservoir is reported to show wide seasonal fluctuations.

Seasonal runoff from the catchment empty into the lake. Main feeder canal of the lake comes from another reservoir called Madar, situated at a higher altitude about 15 km away. Besides this, several seasonal nallas also contribute to the lake. The reservoir is connected to Swaroopsagar through a canal. The reservoir is surrounded by hills. The dam lies on the eastern side. The length of the dam is about 800 m. The western bank has agricultural fields. The reservoir also has a small island which has been converted into a public garden.

Initially constructed for irrigation purpose, the water of the reservoir is also being used for drinking purpose. Agricultural and construction activities, increasing tourist trade and deforestation in the catchment area are some of the important factors influencing the trophic status of the lake. The reservoir serves as a receptacle for the organic matter and domestic wastes. Although eutrophic like Pichola the degree of eutrophication is reported to be less for Fatehsagar (Kumar and Sharma, 1991).

The morphometric parametrs of the reservoir as given by Durve (1980) are presented in Table 7. Table 8 gives other salient features of the reservoir.

Table - 7. Morphometric features of Fatehsagar
(after Durve, 1980)

1.	Water spread	4.00 sq. Km
2.	Maximum depth	13.40 m
3.	Calculated mean depth	3.00 m
4.	Mean depth/max. depth	0.402
5.	Maximum length	2.60 km
6.	Maximum width	1.80 km
7.	Mean width	1.50 km
8.	Length of shore line	8.50 km
9.	Shore line development	1.20

Table-8. Salient features of Fatehsagar
(Source : Irrigation Deptt., Govt. of Raj., 1996)

1.	River Basin	Berach
2.	Catchment Area (Sq. miles)	6.00
3.	Narmal Rainfall (mm)	635.00
4.	Yield (Mcft)	54.00
5.	T.B.L.(ft)	497.00
6.	M.W.L. (ft)	492.00
7.	F.T.L.(ft)	490.00
8.	Sill Level (ft)	458.00
9.	Gross Capacity (Mcft)	427.00
10.	Dead Capacity (Mcft)	180.00
11.	Live Capacity (Mcft)	247.00
12.	Culturable Commnd Area (Ha)	680.00
13.	Irrigation Potential (Ha)	410.00
14.	Flood Discharge (Cusec)	3834.00

3.1.5.4 Rangasagar

Although called lake, Rangasagar is a very small reservoir. It was constructed by Amar Singh Badava during 1761-73 and is also called Amarkund after him (Rao & Durve, 1989). It is situated in the middle of the chain of lakes of Udaipur. The latitude is $24^{o}34'$ N and the longitude is $74^{o}40'$ E. It has a length of 1030 m, width of 245 m and a maximum depth of 7 m.(Vyas et al., 1989). The water spread area of the reservoir is only 0.136 sq. km (Rao & Durve, 1989). It has an average transparency value of 66.98 cm which indicates a low water clarity (Rao & Durve, 1989). It provides a watery connection between Pichola to its southern side and Swaroopsagar on its north eastern part. The lake is reported to be highly eutrophic and fast approaching the hypereutrophic stage, although it gets partially purified by the incoming waters of Pichola and Swaroopsagar.

Almost since its existence Rangasagar has catered to the domestic and agricultural needs of the dense habitation settled around it. This is well indicated by a series of bathing ghats and temples located around it.

Morphometric details of Rangasagar are given in Table 9.

Table- 9. Morphometric parameters of Rangasagar (after Rao & Durve, 1989 and Vyas et al.,1989)

1.	Length	1030 m
2.	Width	245 m
3.	Maximum depth	7.00 m
4.	Water spread area	0.136 sq. km.
5.	mean depth to max. depth ratio	0.598
6.	Vol. Dev. Index	1.79
7.	Shoreline Dev. Index	2.08

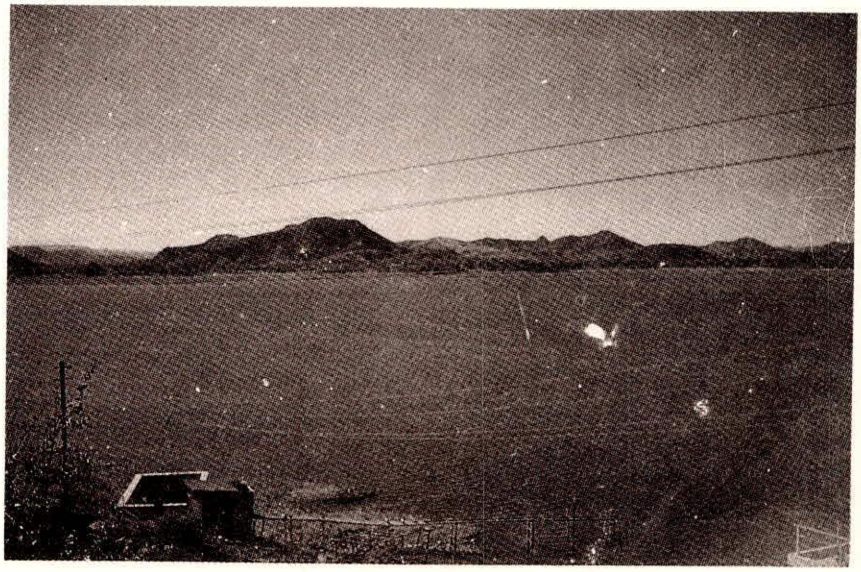


PLATE-4 A VIEW OF UDAISAGAR LAKE,UDAIPUR

3.1.5.5 Udaisagar

Its a medium sized artificial reservoir located at a distance of 13 km from Udaipur at $24^{o}33'$N latitude and $73^{o}47'$ E longitude (Plate 4). The reservoir was constructed in the year 1559-65 A. D. by Maharana Udai Singh across the river Berach. It is about 4 km long and 2.5 km broad (Vyas et al.,1989). The lake covers an area of about 10.4 sq. km and it has a depth of 10.7 m (R.P.P.C.B., 1986). The Ahar river falls into it and the surplus water falls from waste weir forming the source of river Berach. Thus the river Ahar terminates in it and the reservoir is the birth place of Berach river.

The water of the reservoir is mainly used for irrigation, fishing, and drinking purpose. Besides, Udaisagar also provides water to the Hindustan Zink Ltd for its Debari Zink Smelter Plant and to Udaipur Cement Factory, Dabok and other allied industries. The reservoir is the intake source for industrial effluents and also receives domestic waste water.

Salient features of the reservoir are given in Table 10.

Table- 10. Salient features of Udaisagar
(Source : Irrigation Deptt., Raj. Govt., 1996)

1.	River Basin	Berach
2.	Catchment Area (Sq. miles)	185.00
3.	Normal Rainfall (mm)	635.00
4.	Yield (Mcft)	783.00
5.	T.B.L.(ft)	536.00
6.	M.W.L. (ft)	534.00
7.	F.T.L.(ft)	528.00
8.	Sill Level (ft)	504.00
9.	Gross Capacity (Mcft)	1100.00
10.	Dead Capacity (Mcft)	125.00
11.	Live Capacity (Mcft)	975.00
12.	Culturable Command Area (Ha)	6450.00
13.	Irrigation Potential (Ha)	194000.00
14.	Flood Discharge (Cusec)	56160.00

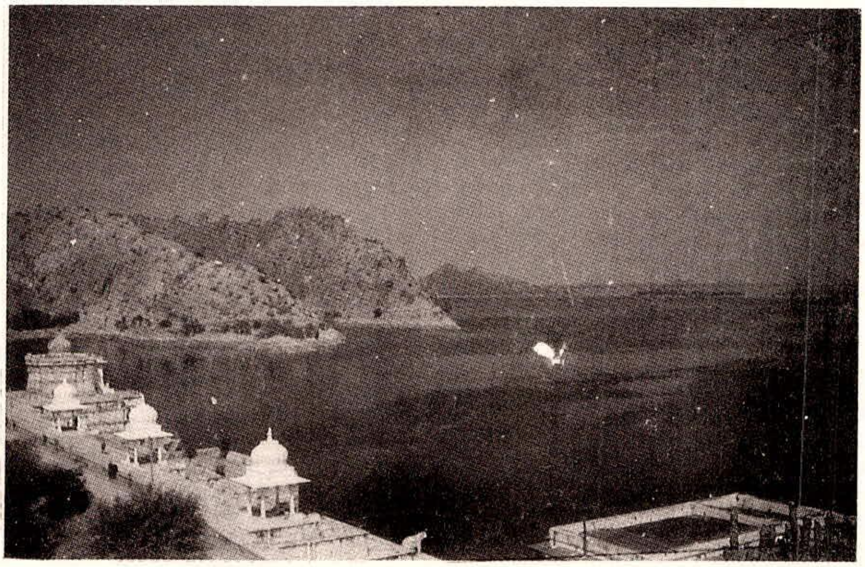


PLATE-5 A VIEW OF JAISAMAND LAKE,UDAIPUR

3.2 Jaisamand

Also known as Dhebar Lake, its a beautiful, big, manmade reservoir located at a distance of about 50 kms south-east of Udaipur on Udaipur-Banswara state highway (Plate 5). The latitude is 24°14'N and the longitude is 74°02'E. It was constructed in the year 1685-91 during the reign of Maharana Jai Singh- II of Mewar, across the Gomti river after whom the lake has been named. It was one of the largest artificial freshwater waterbodies in the country till the creation of modern multipurpose dams.

The original purpose of the creation of this lake was recreation and preservation of wild life. Till 1954 no attempt was made to make use of this vast source of water for irrigation. It was only during 1954 to 1961 that a canal system was constructed to serve culturable command area of 16645.5 ha. The average actual yield received in the lake over the period 1959-1978 was of the order of 162.4 MCum. There are two main canals one each on the left and right banks.

Water level data on the lake (Table 11) indicate that the lake exhibits vide fluctuations in its water level. The major factor responsible for the fluctuation seems to be not the withdrawal of the water from the lake but the rainfall in particular years. Thus, during the drought years like 1986, 1987 etc the water levels in the lake were very low.

The salient features of Jaisamand reservoir are given in Table 12.

Table - 11. Maximum water level attained during 1981-93 in Jaisamand (Irrigation Deptt., Raj. Govt., 1996)

S. No.	Year	Maximum water level (ft)
F.T.L.		27.50
1.	1981	11.95
2.	1982	7.00
3.	1983	17.90
4.	1984	22.00
5.	1985	14.60
6.	1986	13.10
7.	1987	12.10
8.	1988	7.00
9.	1989	21.75
10.	1990	27.50
11.	1991	27.50
12.	1992	20.40
13.	1993	17.31

Table - 12. Salient features of Jaisamand
(Source : Irrigation Deptt., Govt. of Rajasthan)

1.	District	Udaipur
2.	River Basin	Som
3.	Catchment Area (Sq. miles)	1813.00
4.	Normal Rainfall (mm)	686.00
5.	Yield (Mcft)	5260.00
6.	T.B.L.(ft)	305.10
7.	M.W.L. (ft)	303.43
8.	F.T.L.(ft)	299.47
9.	Sill Level (ft)	293.83
10.	Gross Capacity (Mcft)	20000.00
11.	Dead Capacity (Mcft)	6084.00
12.	Live Capacity (Mcft)	13916.00
13.	Culturable Command Area (Ha)	16000.00
14.	Irrigation Potential (Ha)	11890.00
15.	Length of Waste Weir (ft)	20
16.	Flood Discharge (Cusec)	36900
17.	Type of Dam	Both sides earth filling

3.3 Rajsamand

Rajsamand (Plate 6 & Fig. 6) is a medium sized reservoir, artificially created in the year 1671 A. D. by Maharaja Raj Singh of Mewar across river Gomati; a tributary of Banas. It is located at Kankroli in Rajsamand district at a distance of about 65 kms from Udaipur on the Ajmer road. The latitude and longitude of the reservoir are $25^{o}04'$ N and $73^{o}48'$E respectively. There are two canal systems one each on the left and the right bank. Modernization of the canal system was taken up during 1978-79 to increase the culturable command area. At present the culturable command area of the lake is 9990 Ha.

The water level in the reservoir fluctuates. The water at full tank level is 30 ft. In 1981 the maximum water level reached was only 1.9 ft whereas in 1982 it was 7.65 ft. It was 10.17 ft in the next year and again reduced considerably to 3.60 ftduring 1984. The drought years of 1987, 1988 and 1989 recorded the lowest values of maximum water levels reached in the past decade (1980-90). The maximum water levels reached during these years were 0.94 ft, 0.59 ft and 0.50 ft respectively. The maximum water level reached during the period 1981-93 was 20.40 ft during 1992.

Table 13 presents the salient features of Rajsamand.

Table - 13. Salient features of Rajsamand
(Source : Irrigation Deptt., Govt. of Rajasthan, 1996)

1.	District	Rajsamand
2.	River Basin	Banas - I
3.	Catchment Area (Sq. miles)	2.00
4.	Normal Rainfall (mm)	508.00
5.	Yield (Mcft)	704.00
6.	T.B.L.(ft)	1848.00
7.	M.W.L. (ft)	1840.00
8.	F.T.L.(ft)	1835.00

PLATE - 6 A VIEW OF RAJSAMAND LAKE, RAJSAMAND

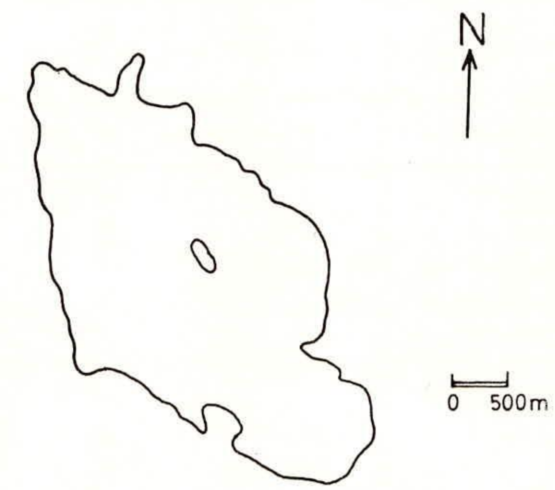


FIG.6. BASIN MAP OF RAJSAMAND; RAJSAMAND, SHOWING WATER SREAD AREA (1971-72)

Table 13 contd.....

9.	Sill Level (ft)	1805.00
10.	Gross Capacity (Mcft)	3786.00
11.	Dead Capacity (Mcft)	300.00
12.	Live Capacity (Mcft)	3486.00
13.	Culturable Command Area (Ha)	9990.00
14.	Irrigation Potential (Ha)	2860.00
15.	Length of Dam (ft)	1200.00
16.	Length of Waste Weir (ft)	1340.00
17.	Flood Discharge (Cusec)	53580.00

3.4 Ramgarh Tal

It is a large reservoir (Plate 7 & Fig. 7) located at about 35 km north-east of Jaipur among the hills through which the Banganga river passes before entering the plains. Its latitude is $27^{o}03'$E and longitude is $76^{o}04'$N. It was initially called Crosthwaite Sagar after Sir R.J. Crosthwaite who laid its foundation stone in 1897. Later the name was changed to Ramgarh Sagar by Maharaja Man Singh. It is managed and maintained by the State PHE Deptt and the Irrigation Deptt.

The reservoir covers an area of 12.3 sq.km. (Sharma et al., 1978). It has a mean depth of 4.6 m and a maximum depth of 18 m (Sharma et al., 1978). The catchment area of the reservoir is about 760 sq. km. Climatological conditions in the catchment area are typical subtropical. The wind speed varies from 2 km/hr to 15 km/hr, but is generally higher during summer and just before monsoon (Rajasthan Pollution Prevention & Control Board report, 1986). High temperature and wind speed are responsible for heavy evaporation losses. The water levels in the reservoirs fluctuate and it is considerably lowered during the drought years. The water level at the full tank level is 61.25 ft. However, during the drought years of 1987, 1990 and 1992 the maximum water levels

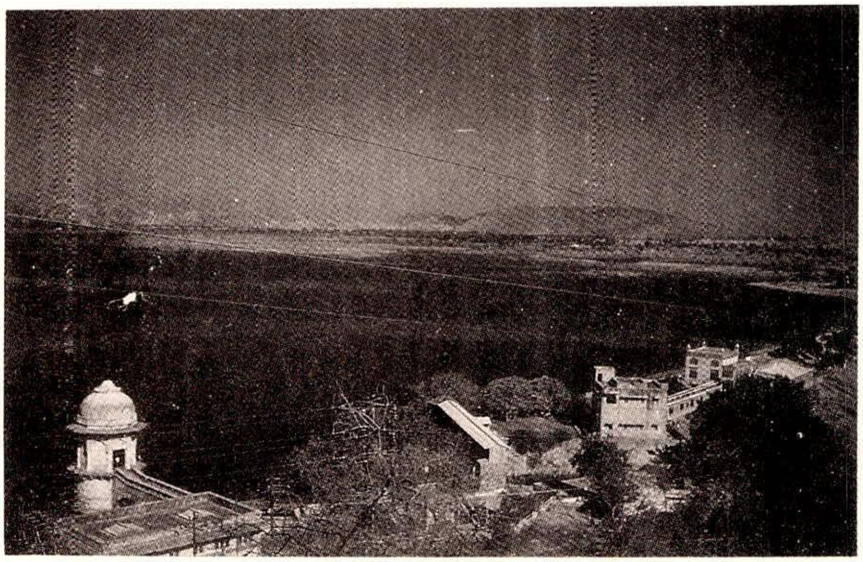


PLATE - 7 A VIEW OF RAMGARH TAL, JAIPUR

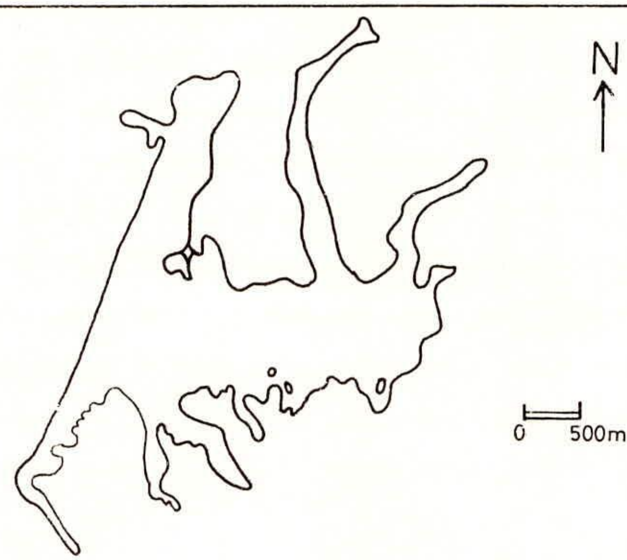


FIG. 7. BASIN MAP OF RAMGARH TAL SHOWING WATER SREAD AREA (1967-68)

recorded in the reservoirs were 28.17 ft, 18.67 ft and 19.33 ft respectively. Table 14 shows the salient features of the reservoir.

Table - 14. Salient features of Ramgarh Tal
(Source : Irrigation Deptt., Govt. of Rajasthan, 1996)

1.	District	Jaipur
2.	River Basin	Banganga
3.	Catchment Area (Sq. miles)	297.00
4.	Normal Rainfall (mm)	533.00
5.	Yield (Mcft)	205.00
6.	T.B.L.(ft)	1280.00
7.	M.W.L. (ft)	1265.00
8.	F.T.L.(ft)	1261.00
9.	Sill Level (ft)	1200.00
10.	Gross Capacity (Mcft)	2083.60
11.	Dead Capacity (Mcft)	0.00
12.	Live Capacity (Mcft)	2083.00
13.	Culturable Command Area (Ha)	12130.00
14.	Length of Waste Weir (ft)	380.00

The water of the reservoir is mainly used for drinking water supply to the city of Jaipur. It is also used for irrigation in downstream regions. Considerable silting of the reservoir is reported to have occurred during last few decades. The lake is reported to be oligotrophic.

3.5 Sardarsamand

Sardarsamand is a big reservoir located at Pali, 55 km south of Jodhpur, in western Rajasthan ($25^{o}50'N$, $73^{o}29'E$) at the confluence of Sukri and Guhiya rivers which are tributaries of Luni. The altitude is 215.18 m above msl. It is the biggest body of water in the arid region of western Rajasthan. It was brought into existence during 1899-1905 by the then ruler of erstwhile

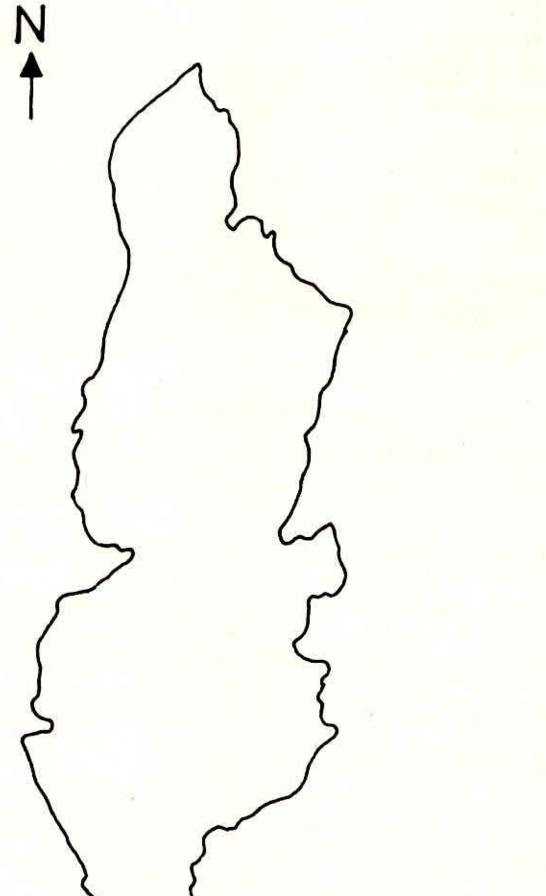


FIG. 8 BASIN MAP OF SARDARSAMAND; PALI, SHOWING WATER SPREAD AREA (1970-71)

Jodhpur State, Sir Sardar Singh (Saxena, 1982).

The surface area of the reservoir is 36.0 sq.km and its maximum depth is 7.6 m (Khan et al., 1990). The capacity of the reservoir is 88 million cu. m (Khan et al., 1990). Saxena (1982), however, has reported the capacity of the reservoir as 222.80 million cu. m.

The reservoir has spread in the east and its western end is limited by the hills and a dam. Three sides of the reservoir i.e., in east, north and south, are the plain lands, mostly under agricultural operations. The river basin and sub-basin of this rainfed reservoir are Luni and Guhiya river basins respectively. The catchment area is 1634.11 sq. km (Khan et al., 1990). However, according to Saxena (1982) the gross catchment area is 2,073.89 sq. km. The lower catchment consists of sandy to sandy loam soils with compact zone of lime concretion at depth ranging from 0.5 to 1.0 m. The infiltration rates are high but the water holding capacity of the soils is low (Khan et al., 1990). The catchment area, besides cultivated crops, is having scanty wild vegetation, chiefly typical xerophytic (Saxena, 1982).

The average annual rainfall at Pali is 380 mm, with coefficient of variation of 40-70% About 80% of the annual rainfall is received from June to September. The annual mean maximum and minimum temperature are 33.8^{o}C and 18.7^{o}C respectively. The annual evaporation is very high (3072 mm) (Khan et al., 1990). The water is used for irrigation, fishing, domestic and recreation purposes.

The lake basin map of Sardarsamand showing the water spread extent is given in Fig. 8 while the morphometric details of the reservoir are given in Table 15. The other salient features are given in Table 16.

Table-15. Morphometric details of Sardarsamand

(after Saxena, 1982)

1.	Maximum length, km	9.45
2.	Maximum width, km	5.04
3.	Mean width, km	3.85
4.	Maximum depth, m	7.62
5.	Mean depth, m	5.79
6.	Surface area, sq, km	36.41
7.	Volume, M cu.m	222.80
8.	Gross Catchment area, sq. km,	2,073.89

Table-16. Salient features of Sardarsamand
(Source : Irrigation Deptt., Govt. of Rajasthan,1996)

1.	District	Pali
2.	River Basin	Guhiya, Bandi
3.	Catchment Area (Sq. miles)	800.00
4.	Narmal Rainfall (mm)	394.00
5.	Yield (Mcft)	2848.00
6.	T.B.L.(ft)	741.00
7.	M.W.L. (ft)	736.00
8.	F.T.L.(ft)	731.00
9.	Sill Level (ft)	706.00
10.	Gross Capacity (Mcft)	3115.64
11.	Dead Capacity (Mcft)	00.00
12.	Live Capacity (Mcft)	3115.64
13.	Culturable Commnd Area (Ha)	10336.00
14.	Irrigation Potential (Ha)	8562.00
15.	Type of Dam	Earthen
16.	Length of Dam (ft)	33000.00
17.	Length of Waste Weir (ft)	2800.00
18.	Flood Discharge (Cusec)	90240.00

3.6 Ghana Lake

The Ghana lake (Fig. 9 & Plate 8) is located in the Keoladeo Bird Sanctuary between $27^{o}7'6''$ N-$27^{o}12'2''$ N latitudes and $77^{o}29' 5''$ E-$77^{o}33'9''$ E longitudes, about 5 kms south-east of Bharatpur, on the extreme western edge of the Gangetic basin. It

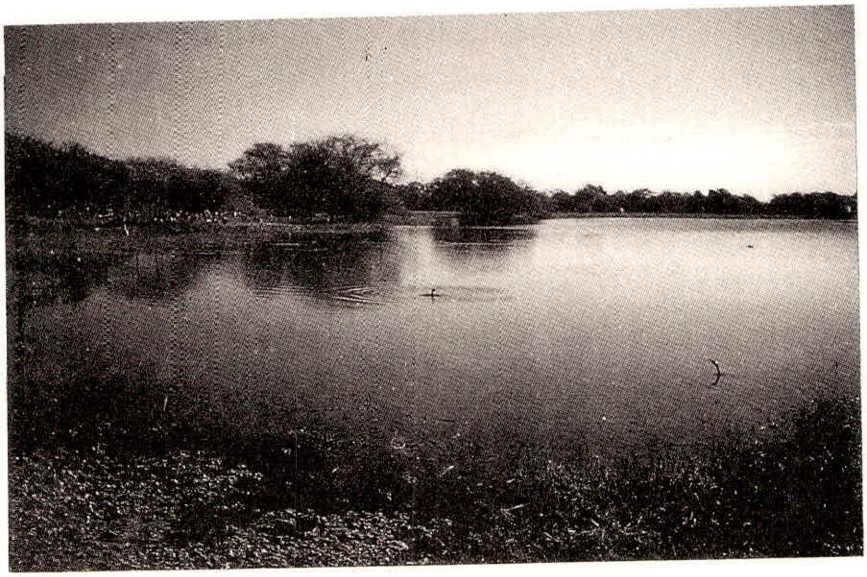


PLATE - 8 A VIEW OF GHANA LAKE, KEOLADEO BIRD SANCTUARY, BHARATPUR

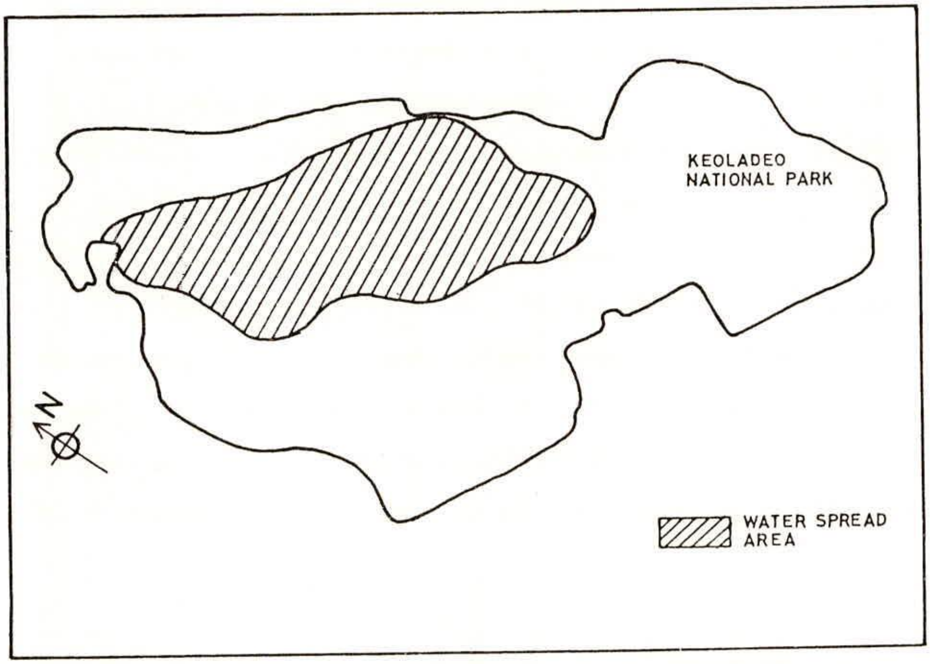


FIG. 9 KEOLADEO NATIONAL PARK SHOWING WATER SPREAD AREA OF GHANA LAKE (AFTER VIJAYAN, 1991)

is 50 kms west of Agra and 180 kms south of New Delhi. Truly speaking its not a lake but patches of water filling the low lying (174 m above msl) natural depressions spread over a vast area, 28.32 sq.km. (R.P.P.C.B., Rep., 1986) in the park which becomes lake in the rainy season. Construction of Ajanbund, a temporary reservoir, about a km from the present border of the park, about 250 years ago and the subsequent flooding of the area marked the beginning of human involvement in the conversion of this natural depression into a permanent waterfowl reserve (Vijayan, 1991).

The terrain of the lake area is almost flat with elevations varying from 173 to 176 m and a gentle slope towards a central depression. The water is drawn into the park in monsoon from the Ajanbund. The water spread area is called Mansarovar. It is only about 5 sq. km. according to Raj. Poll. Prev. and Cont. Board report (1986); and 9 sq. km (900 ha) according to Vijayan (1994). However, the water spread area does not remain constant and it heavily fluctuates. It is maximum during rainy season and minimum during summer. The entire water area is divided into 10 water compartments separated by earthen dykes in which sluice gates are built at strategic locations to regulate the water supply. The lake is shallow. The depth of water in the lake is restricted to 1.5 m (Rajasthan Pollution Prevention & Control Board report, 1986). Although water loss through infiltration is minimal, most is lost by evapo-transpiration which is very high during the hot and dry summers, leaving only a few pools in the central, deeper portions of the park (Vijayan 1991).

The wetland compartments are surrounded by forest cover of about 7000 acres (R.P.P.C.B., 1986). The soil of the area is thick alluvium with sandy, saline patches in the terrestrial area (Vijayan, 1994). Groundwater levels within the park and in the low lying areas nearby are relatively higher (Vijayan 1994). According to local people the frequent occurrence of droughts has probably lowered groundwater levels in recent years, resulting in shift of the cropping pattern towards cash crops, which require less water.

The climate of the area is subhumid to semi-arid, but has remained mostly semi-arid during the 19981-91 decade (Vijayan 1991). Bharatpur experiences climatic extremes from a hot, dry summer (April to June) to a cold winter (November to January) and short monsoon (July to September) and post-monsoon (September to October) seasons. Spring season, although not conspicuous, is experienced in February-March. The temperature ranges from a minimum of $0^{o}C$ to $2^{o}C$ in winter to a maximum of $48^{o}C$ to $50^{o}C$ in summer. The southwest monsoon, which sets in towards the end of June extends up to September with occasional slight showers in October. The mean annual rainfall is about 650 mm according to Vijayan (1991), but averaged only 500 mm in the 1980s with more frequent droughts than in other decades of the second half of this century (Vijayan 1991). According to Premavati (1989) the normal annual rainfall at Bharatpur is 673.5 mm out of which 88.63 % (596.9mm) is received during the monsoon season, 4.49% (37 mm) occurs during winter and 5.88 % (39.6 mm) occurs during the hot summer. The annual average number of rainfall days are 35.8 whereas the intensity of rainfall per rainy day is 18.91 mm (Premvati, 1989). Humidity increases with the beginning of monsoon making the climate muggy. Monthly temperature and relative humidity data for Bharatpur is given in Table 17.

Table-17. Monthly temperature and relative humidity at Bharatpur (after Premavati, 1989)

Months	Max. Temp. ^oC	Min. Temp ^oC	Relative Humidity (%)
January	22.7	7.1	59
February	26.7	9.8	51
March	32.7	15.4	44
April	38.7	21.5	34
May	42.2	26.4	30
June	41.9	30.4	40
July	35.0	27.1	71
August	33.1	25.8	79
September	33.3	24.1	74
October	33.3	18.5	62
November	29.5	17.6	53
December	24.4	7.4	60

The source of water, its quantity and quality are major factors affecting the Keoladeo wetland. The Gambhir and Bangaga river systems, at the confluence of which the National Park is located, bring in water to it. Water from the Gambhir is brought into the Ajan bund through Pichuna canal, and from Banganga through Uchain canal. Of late, supply from the latter has become rare and from the former, less in quantity. Water brought into the Ajan bund is retained there for a few days for the silt to deposit and then released into the park.

The lake supports a great variety of duck weeds, fish and migratory birds thus providing abundant food for the water birds. It was declared as a sanctuary in 1956 and National Park in 1981. Studies conducted by Mahajan et al., (1979-80), (vide Raj. Poll. Prev. & Cont. Board report, 1986) revealed that lake has, very high productivity. According to an estimate, in one square kilometer 200-2500 pairs of birds nestle, which need 4-5 tonnes of fish and food every day. This gives an idea about the need and generation of the food quantity in the lake.

4.0 Some important minor freshwater bodies

Apart from the major freshwater bodies, a few of which have been described in the previous section, there are numerous small and minor freshwater bodies all over Rajasthan. Many of these, being the only source of water in this water scarce state, are a very valuable natural resource. There are others which are significant either from the socio-cultural point of view like Pushkar lake or tourism point of view like Nakki pond. Some, although small, are the only source of water in the region. Some of these are discussed in this section.

4.1 Pushkar Lake

Its a closed waterbody, a small reservoir, northwest of Ajmer at a distance of 11 km (Plate 9 & Fig. 10). It is located at $26^{o}29'$ N latitude and $74^{o}33'$ E latitude. Placed in the centre of the Pushkar lake valley, Pushkar Lake is an irregular elliptical body which is surrounded by hills except in the east where the sands have drifted over the marshland from the plains of Marwar. Pushkar town is situated on the bank of the lake. There are numerous temples, places of the former Maharajas and ghats around the lake. Gau ghat is the most frequently visited part of the lake. The water is used for bathing and other socio-cultural activities. The various religious rituals performed at these ghats add organic matter to the lake in the form of offerings. Because of the availability of the food, fish abound in the lake. The water is also used by cattle for drinking. Capacity of the reservoir being too small, the water is not used for irrigation purpose.

PLATE-9 A VIEW OF PUSHKAR LAKE, PUSHKAR

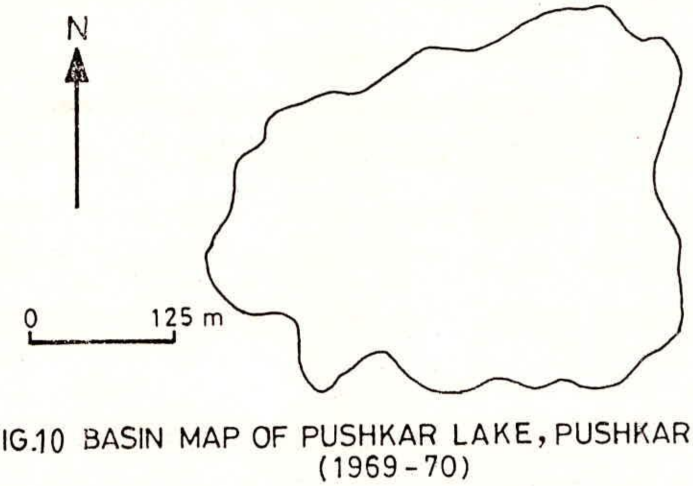


FIG.10 BASIN MAP OF PUSHKAR LAKE, PUSHKAR
(1969-70)

The lake is not fed by any specific stream. Runoff water from the nearby hills and agricultural lands, enters the lake at a point where the Jaipur ghat is located (Parvateesam & Mishra, 1993). The lake stretches a water coverage of about 5 km with a depth varying from 18'-32' (Rajasthan Pollution Prevention & Control Board report, 1986). The water spread area of the lake is less than 0.1 sq. km. The salient features of the lake are given in Table 18.

Table-18. Salient features of Pushkar lake
(Source : Irrigation Deptt., Raj. Govt.,1996)

1.	Catchment Area (Sq. miles)	8.50
2.	Normal Rainfall (mm)	514.00
3.	M.W.L. (ft)	103.10
4.	F.T.L.(ft)	100.00
5.	Sill Level (ft)	72.00
6.	Gross Capacity (Mcft)	28.00
7.	Dead Capacity (Mcft)	0.00
8.	Live Capacity (Mcft)	28.00
9.	Type of Dam	Masonry

The Pushkar lake valley (Ajmer Valley) is located in the Aravali range. Over the Arvali hills of Pushkar region the rains occur around the second week of July to late August. Pushkar lake lies in the semi arid (25-50 cm) rain belt. In spite of high humidity (97 %) and temperature, the rainfall show highly erratic pattern owing to probable existence of inversion in upper atmosphere (Datta et al., 1994).

Data on the maximum water levels in the lake reveal that the water levels fluctuate. The maximum water level at full tank level is 28.00 ft. The data from 1981-93 shows that the maximum water levels recorded every year from 1981 to 1986 was always above 20 ft. After that there has been a decline. In the drought year the water levels decline considerably. Thus, the maximum water levels reached during 1987, 1991, 1992 and 1993 were only 7.67 ft, 8.84 ft, 5.50 ft and 7.67 ft respectively. The maximum water level recorded for the period 1981-1993 was 25.75 ft in 1984.

Pushkar lake, despite the semi arid climate and the closed nature of its basin has remained a freshwater body unlike the other closed basins of arid region of Rajasthan which are all saline. Sinha (1977), has tried to explain this peculiarity on the basis of the lake-groundwater interaction. According to him, although the lake apparently looks closed there is a sub-surface flow of water from Pushkar lake to the river Saraswati. Because of this interaction the water in Pushkar does not remain stagnant and as such salts never get concentrated. Consequently the lake remains a freshwater one.

4.2 Nakki

Its a small natural waterbody, a pond, at Mount Abu, situated 1219 m above msl, in Sirohi district (Fig. 11). It is said to be of volcanic origin. It is surrounded by hills except at the western end. A dam has ben constructed on its west to increase its capacity. This pond is shallow on eastern side but is about 20 to 30 ft deep near the dam. Mount Abu on which the lake is located is regarded as part of the Aravali hills. (R.P.P.C.B. report, 1986).

Mt. Abu, being a tourist place, the pond water is mainly used for recreation. Being a hill station there is no industrial development in the area. Only some area around the lake is served by sewer lines.

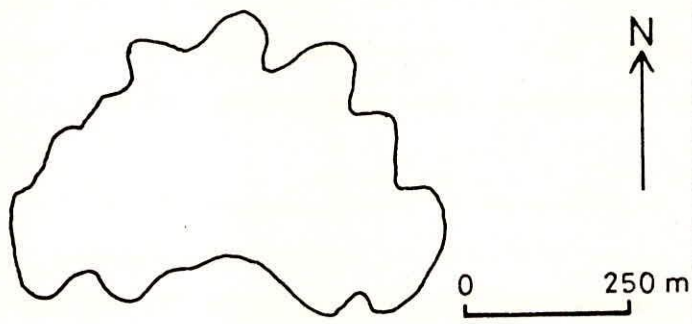


FIG. 11 BASIN MAP OF NAKKI POND, MT. ABU (1959-60)

The climate in the area appears to have undergone some changes in recent past. Thus, according to the Raj. Poll. Prev. and Cont. Board report (1986) "the trend of rainfall reveals that 120" rainfall has now reduced to 50" only. Similarly, maximum temperature has also increased considerably". However, the report does not specify the period during which these rainfalls were recorded. Thus, if 50" raifall, as reported in the report, is considered for mid eighties, there appears to be a decrease of about 10" rainfall in about two decades time because Misra (1967) has reported a rainfall of about 150 cm (60") for Mt. Abu. This calls for the conservation of nature. The rain fall and location of the lake are such that sufficient flushing and dilution of water takes place seasonally but being a closed it is vulnerable to many deteriorating effects. Pollution of the lake has been a point of concern (R.P.P.C.B., Rep. 1986). The average clarity of the lake water is 117 cm and based on this parameter the lake is moderately eutrophic (Sharma & Durve, 1990).

4.3 Waterbodies of Ajmer region

Ajmer district is centrally located in the state of Rajasthan between $25^{\circ}38'$ and $26^{\circ}58'$N latitudes and $73^{\circ}52'$ and $75^{\circ}22'$ E longitudes. It is bounded on the north and west by Nagaur and Pali district respectively which form a part of the desert zone of Rajasthan and by Bhilwara, Jaipur and Tonk districts on the south and east side respectively which appear to be comparatively humid regions of Rajasthan. In topography the district can be classified as more or less a plain surface interrupted with low hills. The adjoining Beawar region comprises irregular terrain with a rocky surface while Kishengarh has large stretches of sandy areas (Yadav & Bharadwaj, 1979). Climatically, Ajmer, being located on the Aravali range, may be described as possessing a moderate climate, compared to the two regions on either side of the Arvali range. The area to its west is characterized by extremes of temperature, severe drought, high velocity winds and low relative humidity. The region to the east and south shows considerable variation in the amount of rainfall and temperature distribution. The average annual temperature in Ajmer is 26.7^{o}C with maximum temperature of 44^{o}C and minimum temperature of 3^{o}C (Datta et al., 1994). There are many waterbodies in the region, a few of which have been described below.

4.3.1 Anasagar

Located in the north-west side of Ajmer city at 26^{o}28' N latitude and 74^{o}38'E longitude, this beautiful reservoir is a perennial waterbody (Plate 10 & Fig. 12). It was created by King Arnoraja during 1135-1150 (Ghulati, 1992). The length of the reservoir is 3.0 km and its width is 2.5 km. It has a depth of about 7.5 m and area of 7.5 sq. km (Sharma, 1996). When full the reservoir has a circumference of about 13 km (Ghulati, 1992). (about 10 km according to Parvateesam & Mathur, 1992). According to Parvateesam and Mathur (1992), the maximum depth is only 4.5 m when full.

Geologically the catchment area is rich in granite, limestone, mica schists and quartzite. The soil is red and yellow and is characterized by $CaCO_3$. The soil is alkaline with low salt content (Sharma, 1996). Development of urban centre and irrigated cultivation are the main land uses in the catchment area (Sharma, 1996).

The lake is facing ill-effects of day to day practices

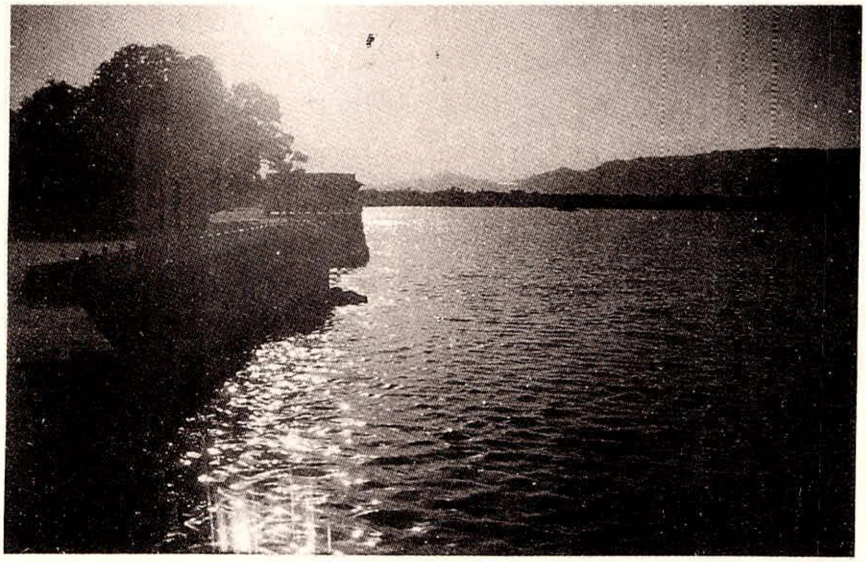


PLATE - 10 A VIEW OF ANASAGAR LAKE, AJMER

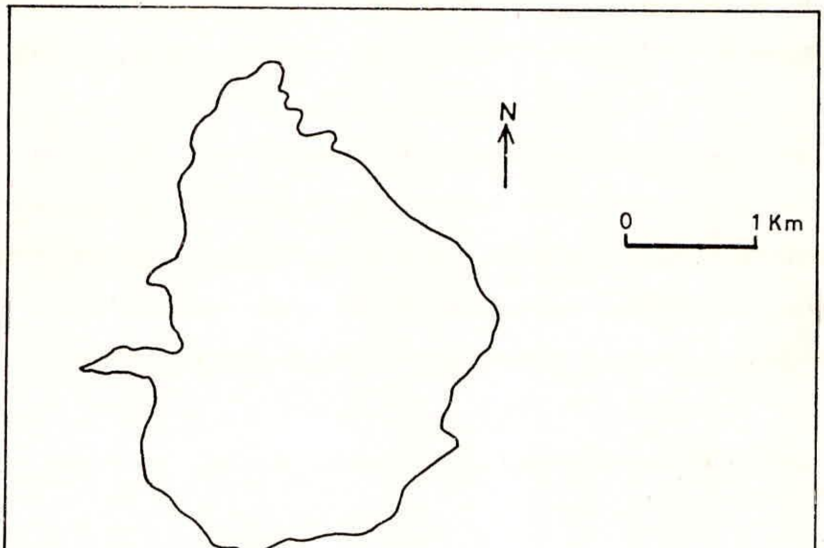


FIG. 12 BASIN MAP OF ANASAGAR, AJMER (1969-70)

like farming and agricultural run-off, cloth washing, automobile washing, sewage waste disposal and urban settlements (Srivastava & Sharma, 1993). The water is also used for cattles for bathing and drinking. On one side there is a nallah which bring organic matter into the lake. All these have caused the pollution of the lake water. Deforestation in the catchment area has accelerated the sedimentation in the reservoir. Fisheries are abundant throughout the year (Yadav & Bharadwaj, 1979). The lake has a secchi depth value of 30-60 cm (Sharma, 1991) which indicates low clarity. The lake is managed by municipal board.

4.3.2 Foysagar

Foysagar (Plate 11 & Fig. 13), a small manmade reservoir, is located near Ajmer. It has a length of about 2.0 km and breadth of about 2.0 km giving it an area of about 4.0 sq. km (Sharma, 1996). The depth of water is about 8 m (Sharma, 1996). Major land uses in the catchment area are grazing and agriculture. Soil of its catchment is made up of hard clay loam with sandstone and marble stones (Sharma, 1996). The water of the lake is used for cloth washing, cattle bathing and recreational activities. It is a comparatively undisturbed lake having slightly turbid water

4.3.3 Budha Pushkar

Its a small shallow natural p the northwest of Ajmer at a distance of 15 km in a desolated sandy area. The length of the pond is 0.25 km and the width is also about 0.25 km giving it a surface area of 0.0625 sq. km. The depth is about 8 m (Sharma, 1996). The soil in the catchment area is sandy. The lake is managed by the railway board and its water is used for the railways.

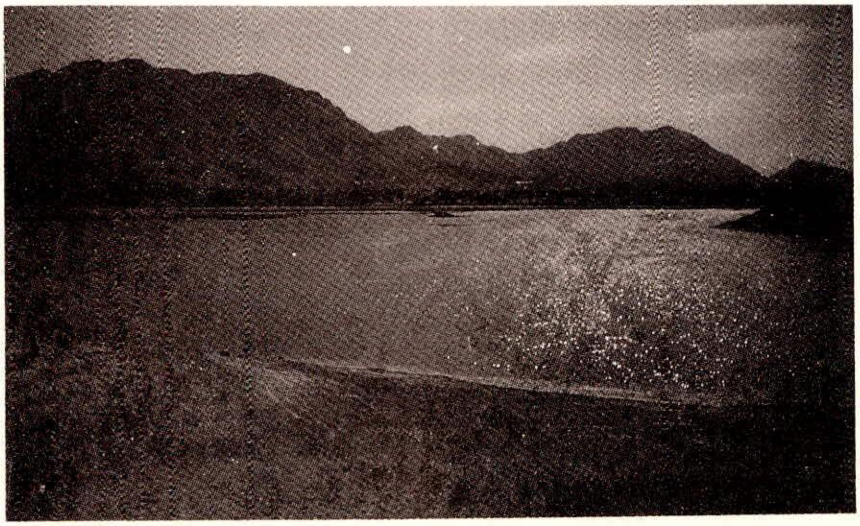


PLATE-II A VIEW OF FOYSAGAR LAKE, AJMER

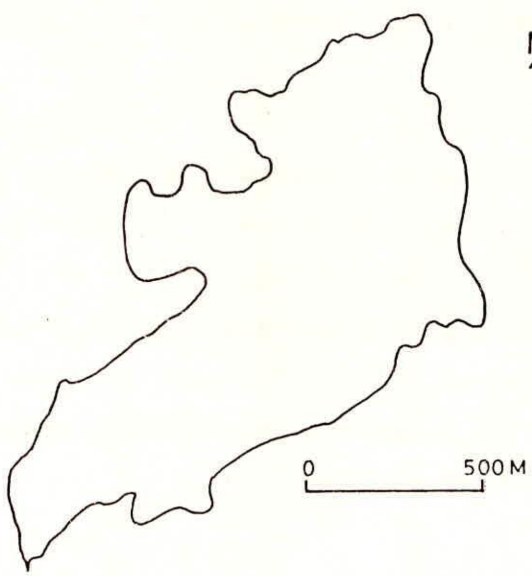


FIG. 13 BASIN MAP OF FOYSAGAR, AJMER (1969-70)

Agriculture is the main feature operating near the margins along with grazing, brousing and some disturbances by human activities. Due to shifting sand dunes in the vicinity of lake, continuous deposition of sand at the bottom and margins takes place, making it shallower and thus transiting it towards the terrestrial habital (Srivastava & Sharma, 1993).

4.3.4 Kishengarh tank

It is a tank situated adjacent to Kishengarh Railway station about 35 kms on north-east side of Amjer and is surrounded by many factories. On one side there is an area used by washermen. The tank is highly polluted (inorganic pollution) due to washing of clothes and discharge of factory wastes (Srivastava & Sharma, 1993).

4.3.5 Other minor waterbodies

Vishalsagar is a small tank in Ajmer. It was built during 1152-1163 (Ghulati, 1992). Beer tank with undisturbed waters lies about 11 km to south-east side of Ajmer city. Srinagar tank is situated on the east side of Ajmer city.

4.4 Waterbodies of Jodhpur region

Jodhpur district is a semi-arid region covering an area of about 22,660 sq.km. It lies on the eastern fringe of Indian desert. Jodhpur, ($26^{o}1'$ N latitude and 73^{o}E longitude, 241 m altitude) commonly called the 'The Sun City of India' because of the maximum hours of Sunshine i.e. 3,285 hours in year (Saxena, 1982), has several kinds of small and large water bodies in and around it, largely catering to the needs of local population. Some of these are described below.

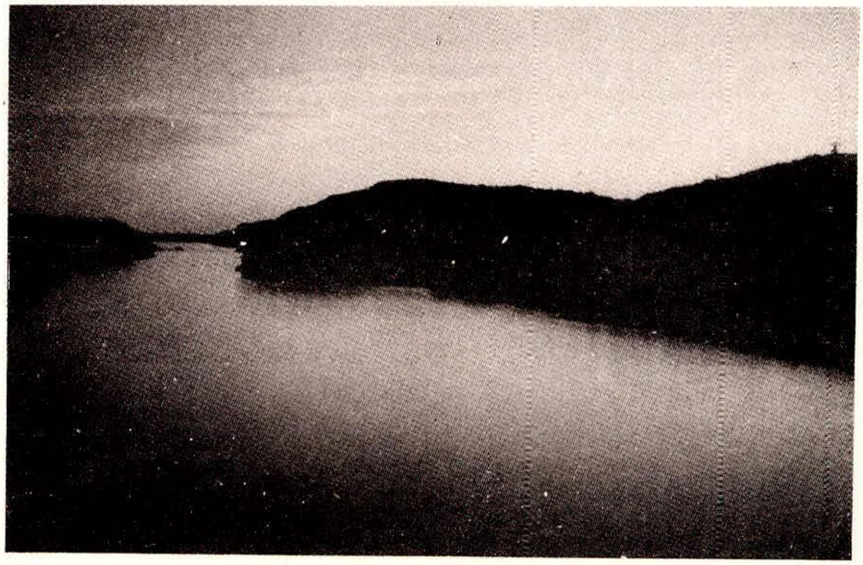


PLATE-12 A VIEW OF KAILANA LAKE, JODHPUR

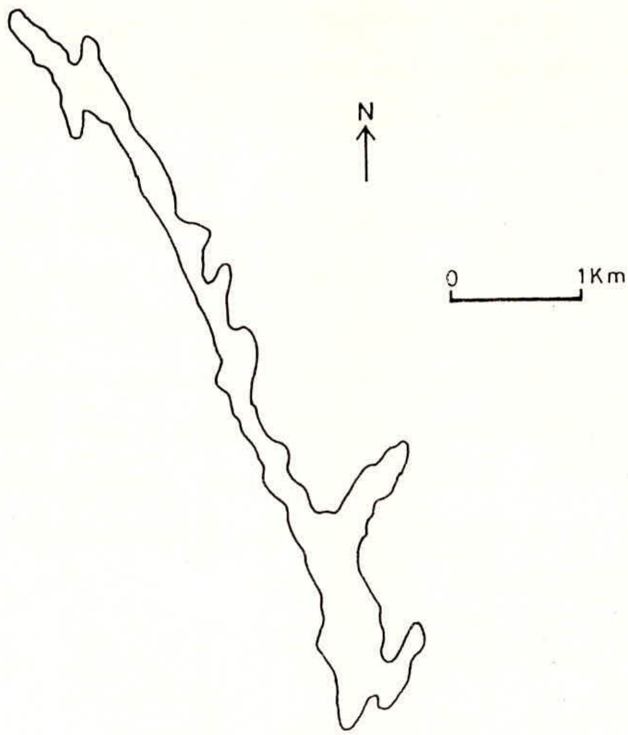


FIG. 14 BASIN MAP OF TAKHAT SAGAR, JODHPUR (1960-61)

4.4.1 Kailana Takhat Sagar

It is a manmade, elongated, rainfed resrvoir (Plate 12 & Fig. 14). It is situated on the north-west about 10 kms from the city on Jodhpur-Jaisalmer road. It was constructed by constructing an impoundment in the hilly terrain in 1893 (Chaudhary, 1990). The latitude is 26°18'N and the longitude is 72°58'E. Average depth of the lake is 17.68 m. Its capacity is 4.73 million cu. m. and the submergence area is 74.92 ha (Bangani,1996). The lake is long, about 5 km in length. This lake is perennial and rises to its full capacity during rainy season. It gradually dries up with the advance of the dry period. Depth of the lake varies from 3 m to 27 m. (Dwivedi, 1984). It receives water from catchment area of Kailana-Jodhpur-Mandor platue during rains. The catchment area of Kailana (excluding Takhatsagar) is 47.6 sq. km but due to sandstone mining activities 7.13 sq.km has already been disturbed. This catchment has got 7 sub catchments (Bangani, 1996). Generated runoff is being carried out to the common point by a feeder canal constructed according to contour. Small gradient of canal is 0.03 - 0.2 % (Bangani, 1996). After 1970 water is also received from Jawai dam, located about 170 km from the lake, during the rest of the period of the year through an open channel. Water losses from Kailana lake due to seepage are very little but that due to evaporation are more (Chaudhary, 1990). It is mostly surrounded by rhyolitic rocks and a variety of xerophytic plants (Dwivedi, 1984). The lake serves mainly as a drinking water storage for Jodhpur and occasionally a bathing site.

Takhat Sagar, is an adjoining sister body of Kailana. It was constructed in 1937-38 by damming the flow from flood gates of Kailana. It has a capacity of 6 Mcum. (Bangani, 1996). The maximum length is 2257 m and the maximum width is 1098 m (Chaudhary,

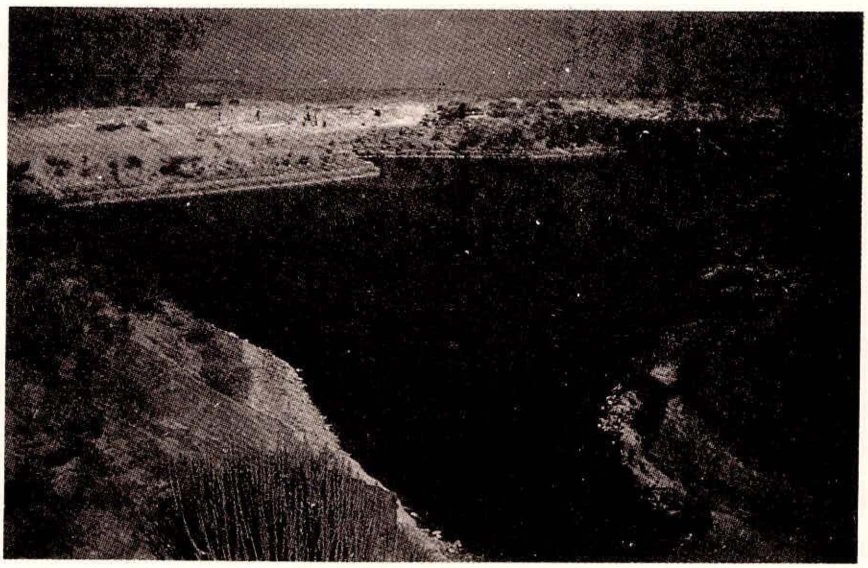


PLATE - 13 A VIEW OF BALSAMAND, JODHPUR

1990). The average depth is 21.14 m (Bangani, 1996). It is used for filling the water transported from Jawai dam which is used as a drinking water supply source for the city.

The Kailana catchment area has bare hard rock belonging to land use capability class VIII. The area in depression has coarse colluvial deposits mixed with sand. Soil cover is practically non-existent. It is made up of gravel and rocks with loamy fine sand to fine sandy loam soil of 15 to 20 cm depth in pockets overlying fractured rock surface. Moderate to steep slopes on bare hard rock surface contribute significantly to the soil erosion by flashy runoff water in monsoon. Therefore, the soil is poor in nutrient content and organic matter (Sharma, 1988).

4.4.2 Balsamand

Balsamand (Plate 13) is a small manmade, rainfed reservoir located at a distance of 8 km north of Jodhpur. It is said to be the oldest artificial lake in Rajasthan. It is situated between 26°1'N latitude and 73°1'15"E longitude at a height of 241 m. It has a maximum depth of 12.6 m in the centre (Jakher et al., 1981). Average depth is 11.4 m and the capacity is 7.79 Million cu. m (Bangani, 1996). Capacity wise it is the biggest of all the waterbodies of Jodhpur. It is a narrow triangular lake in a valley and lengthens out 1020 m in the north east-south westerly direction (Dwivedi, 1984). Its two banks are surrounded by steep rocky hills on the north and south sides, whereas on the north-eastern side there is an artificial bandh. The catchment area of the lake is barren rocky terrain on which cattle and goats graze. The vegetation of the area is xerophytic and lithophytic (Dwivedi, 1984). The water is used for household and gardening. It is privately owned.

4.4.3 Gulabsagar

Gulabsagar is a small masonry tank with fortified walls situated in the heart of old Jodhpur city. It is approximately 87 m x 120 m in area (Dwivedi, 1984). Average depth is 10.3 m and the capacity is 0.13 million cu. m (Bangani, 1996). Considerable silting has taken place over many years. This artificial tank is fed with the rain water through a pucca canal, collecting water from the rocky drainage basin of north Jodhpur and overflow from Balsamand lake of the same region (Dwivedi, 1984). Previously it received water from narrow channels also but these have been completely blocked by dumping domestic waste (Chaudhary, 1990). Attached to this tank is a very small waterbody called Gulabsagar ka Bachchá. It is 7.6 m deep and has a capacity of 0.03 Mcum (Bangani, 1996).

The tank once served as a multipurpose water-body for drinking, irrigation of public gardens, bathing, swimming, washing and other socio-cultural activities. A big stretch of the feeder canal passes along the urban habitats and receives a substantial bulk of domestic sewage, garbage and debris. With the flow of rain water, almost every thing present in the canal is washed away and poured into this pond. The highly polluted water is of little use now.

4.4.4 Chhittar

This is a natural pond and situated at the foot of 'Umaid Palace' in the south-east of Jodhpur city. It lies on 26^{o}N latitude and 73.1^{o}E longitude. It is irregular in shape with an area of about 8,000 sq. m. Maximum depth of the pond is 4 m in the centre. The pond is rainfed, having no definite inlet or outlet. Barring an impoundment on its north-east, it has a rocky drainage basin which is full of xerophytic vegetation (Dwivedi, 1984). The pond is used freely for bathing and washing clothes. Cattle use it for drinking.

4.4.5 Padamsagar

Padamsagar is a small, rainfed tank situated near the Jodhpur Fort in the interior of the city. The capacity of the reservoir is 0.6 million cu. m. (Bangani, 1996). It has a lower elevation than other waterbodies of the region (Chaudhary, 1990). It is 216.41 m long but is narrow with the width ranging from 0.13 m to 54.85 m. The mean surface area is 5,951.2 sq. km and the maximum depth is 20 m. (Chaudhary, 1990). The average depth is 13.87 m (Bangani, 1996). It is surrounded by hillocks on three sides and on the fourth side there is a pucca dam-wall. A ghat of 22.9 m is built on the southern side. It is a multipurpose water-reservoir catering to the needs of local population.

4.4.6 Ranisagar

Ranisagar is a sister body of Padamsagar. It is a small tank situated at the foot hill of Jodhpur Fort in the old Jodhpur city. It has a capacity of 0.1 Million cu.m. The average depth is 16.15 m (Bangani, 1996). According to Sushil (1989), however, the depth at the deepest point varies from 7 m to 9 m on (Table 19). This figure does not tally with that of Bangani. The maximum length and the maximum width are 137.0 m and 87.0 m respectively according to Sushil (1989). It is triangular in shape and is sheltered from the winds on the east by the high Fort-wall and on the west by the old city wall and rocky terrain. Its southern end is built into a pucca-ghat while the northern end is open, rocky, uninhabited terrain from which run-off water fills the reservoir during the monsoon. It serves mainly as a drinking water source to the local population. Occasionally water from this reservoir is pumped out to supply the Fort. Nearly 60 wells in the downstream side are getting recharged from both Ranisagar and Padamsagar. The catchment of both these tanks together is 33 ha (Bangani, 1996).

Some morphometric parameters of Ranisagar, as reported by Sushil (1989), are given in Table 19. From the table it can be seen that there is an apparent contradiction between the values of maximum volume and; the values of maximum depth, maximum width and maximum length from which the maximum volume is estimated. With the given values of maximum depth, length and width, the value of maximum volume comes out to be atleast about 3500 times less than what the author has reported (Table 19). Similar is the case with the computation of maximum surface area.

Table-19. Morphometric features of Ranisagar (after Sushil, 1989)

1.	Maximum length	137.40 m
2.	Maximum width	80.00 m
3.	Maximum depth	9.00 m
4.	Minimum depth	7.00 m
5.	Maximum surface area	5,139.00 sq.m
6.	Minimum surface area	1,845.60 sq.m
7.	Maximum volume	35,73,21,119.30 cu.m
8.	Minimum volume	6,43,229.83 cu.m

4.4.7 Lalsagar

Lalsagar is a very small, rainfed, reservoir situated about 7 km from the city of Jodhpur. It has a capacity of 8 mcft (Nema, 1989).The surroundings are rocky-cum-sandy with pucca dam on one side. It is a multipurpose water-body. Previously it was used for irrigation but the surrounding agricultural area has now been converted into a colony. It is privately owned and is managed by a trust.

4.4.8 Fategsagar

Fatehsagar is a small, rainfed, pucca water tank. It lies in the midst of Jodhpur city. It is highly polluted due to opening of sewage and household wastage drains. It has a capacity of 0.14 Mcum and a depth of 8.3 m (Bangani, 1996).

4.4.9 Climatology of Jodhpur waterbodies

The climate of Jodhpur district is arid to extremely arid. The aridity index for the district varies from 70 to 87 and it increases from southeast to northwest (Sharma, 1988). The standard monthly normals of various climatological parameters in respect of Jodhpur are mentioned in Table 20. The mean monthly maximum and minimum temperature in winter varies from 24.6^{o}C to 27.9^{o}C and 9.5^{o}to 12.0^{o}C, respectively. The lowest extreme temperature recorded at Jodhpur during 1931-60 is -2.2^{o}C in the coldest month of January. Similarly mean monthly maximum and minimum temperatures in the summer vary from 33.3^{o}C to 41.6^{o}C and 17.1^{o}C to 28.5^{o}C, respectively (Table 20). Wind speed normally remains low during post-monsoon and winter season. Based on climatic normals (1931-1960), the lowest and highest mean monthly wind speed has been recorded during October-November and May-June, respectively (Table 20). The maximum velocity of wind is about 140 km/hr (Saxena, 1982). Dust storms commonly occur in May and June. On the average, 8.3 dust storms per year occur at Jodhpur (Sharma, 1988).

The mean annual radiation is highest (511 cal/sq.cm/day) in the western Rajasthan and exceeds 650 cal/sq.cm/day during the peak summer season. The peak flux of radiation is received at

12-14 hours (at noon) throughout the year. In winter months (November, December, January and February) radiation is received from 7 to 19 hours, in summer (March to June) radiation period is extended from 6 to 20 hours and in monsoon season (July to October) radiation period is same but total radiation is reduced from 625.24 cal/sq.cm/day in May to 369.90 cal/sq.cm/day in August and is slightly higher (442.72 cal/sq.cm/day) in September. Reduced radiation in August is due to cloudy weather and maximum quantum of annual precipitation is usually recorded in this month. Total radiation in winter varies from 338.6 to 363.2 cal/sq.cm/day while in summer it ranges from 417.02 to 625.24 cal/sq.cm/day (Sharma, 1988).

There is a large year to year variability in the amount of rainfall. Rainy days are the days receiving 2.5 mm or more rains. The bulk of the rainfall (82.3%) in a year occurs in three months from July to September (Sharma, 1988). The number of rainy days has been recorded from 2.7 to 28.5 per annum (Saxena, 1982). Normally monsoon recedes at the end of September, but in deficit years it may recede much earlier. The trend of total annual precipitation as well as monthly rains is erratic. Table 21 presents the values of total annual rainfall at Jodhpur during the period 1976-86. Average value of rainfall, potential evapo-transpiration and moisture index of Jodhpur for the period of 1901 to 1980 are mentioned in Table 22.

Table- 20. Climatological data (1931-60) for Jodhpur (after Sharma, 1988)

Month	Air Temp, °C				Humidity		Mean wind speed (kmph)
	Mean of daily		Extremes		Relative Humidity (%)	Vapour Pressure (mb)	
	Max.	Min.	Highest	Lowest			
Jan.	24.6	9.5	32.8	-2.2	50	7.0	8.9
Feb.	27.9	12.0	38.3	-0.6	44	7.3	8.8
Mar.	33.3	17.1	41.8	5.0	35	8.5	9.8
Apr.	38.3	22.4	48.0	9.4	31	10.8	10.2
May	41.6	27.3	48.9	17.2	43	18.5	15.0
Jun.	40.1	28.5	47.8	19.4	60	25.9	18.5
Jul.	35.7	26.8	45.6	19.4	75	29.0	16.6
Aug.	33.2	25.2	42.9	20.6	81	28.6	12.9
Sep.	34.7	24.1	42.8	17.8	74	25.5	10.6
Oct.	35.7	19.6	42.2	10.0	49	14.5	6.6
Nov.	31.4	13.9	37.2	5.6	38	7.7	5.8
Dec.	26.7	10.7	33.3	0.6	48	7.3	7.3

Table- 21. Total annual rainfall (mm) at Jodhpur for the period 1976-1986 (after Sharma, 1988)

S.No.	Year	Total rainfall (mm)
1.	1976	639.6
2.	1977	353.2
3.	1978	373.7
4.	1979	755.4
5.	1980	259.5
6.	1981	320.5
7.	1982	417.2
8.	1983	512.6
9.	1984	231.1
10.	1985	214.1
11.	1986	249.1

Table - 22. Mean annual rainfall, potential evapo-transpiration and moisture index for Jodhpur (after Sharma, 1988)

period	Annual rainfall		Mean potential evapotrans-piration, (mm)	Moisture index	
	Mean	C.V.(%)		mean	C.V.(%)
1901-80	372.9	50.9	1843	-79.8	13.1

4.5 Minor waterbodies of Udaipur region

Besides Pichola, Fatehsagar, Udaisagar, Swaroopsagar and Rangasagar which have been discussed in section 3.1.5 there are numerous other small and medium freshwater bodies in and around Udaipur. These include Vallabhnagar reservoir, Indrasagar, Baghela tank, Kalalia talab, Bari lake, Madar tank, Govardhan Vilas tank, Daya etc. A brief introduction of few of them is presented here.

4.5.1 Indrasagar

Referred to as tank, this waterbody is situated in the north-east of Udaipur town about 21 km away from it. It is elongated in shape with an area of 0.32 sq. km and a maximum depth of about 13 m (Vyas et al., 1989).

4.5.2 Govardhan Vilas Tank

It lies on Udaipur-Ahmedabad highway, about 2.35 km south of the Udaipur town. It covers a surface area of about 0.9 sq. km during the rains. The tank is totally rainfed. The catchment area is about 2.56 sq. km. The capacity at full tank level is 0.33 million cubic metres (Vyas et al., 1989).

4.5.3 Baghela Tank

It is situated in the north - northeast of Udaipur city, 21 kms away on the national highway No.8, towards Nathdwara. The tank area is about 100 ha (Vyas et al., 1989).

4.5.4 Daya

It is an elongated shaped reservoir located near village Palna in Sarada tehsil of Udaipur district, 35 km away from Udaipur along the Udaipur-Jaisamand road. Its latitude is 24^{o}15'10"E and the longitude is 73^{o}48'55" N. The altitude is 351.75 m. It is constructed across the river Daya. It has a water spread area of 309 ha and a shoreline of about 16 km. The maximum depth of the reservoir is 26.56 m. The men depth is 14.8m. It has a maximum length of 1078.30 m and a maximum width of 1130.00 m. The storage capacity of the reservoir is 11.20 M cu.m The shoreline development index is 2.532. The catchment area is 100.35 sq. km. The catchment area is semi hilly and rocky. The average annual rainfall in the catchment is 600.00 mm (Gupta, 1991).

4.6 Gaibsagar

Its a small, shallow reservoir at Dungarpur town (Plate 14). It was created in the first half of 15 th century by Maharwal Gopinath, also known as Maharwal Gaiba, after whom it is named. The latitude and longitude at which it is located are 23^{o}45' N and 73^{o}53'E respectively. The reservoir used to be main source of water supply during the years after its completion and till 1970 its water was used for catering the needs of Dungarpur town. After that it ceased to be a potential source either for industrial or domestic purpose. Presently the water is mainly used for public bath and washing of clothes. The reservoir has a waste weir. Surplus water escapes from Gaibsagar and following the natural topography terminates into Sabela tank, located in the north-west

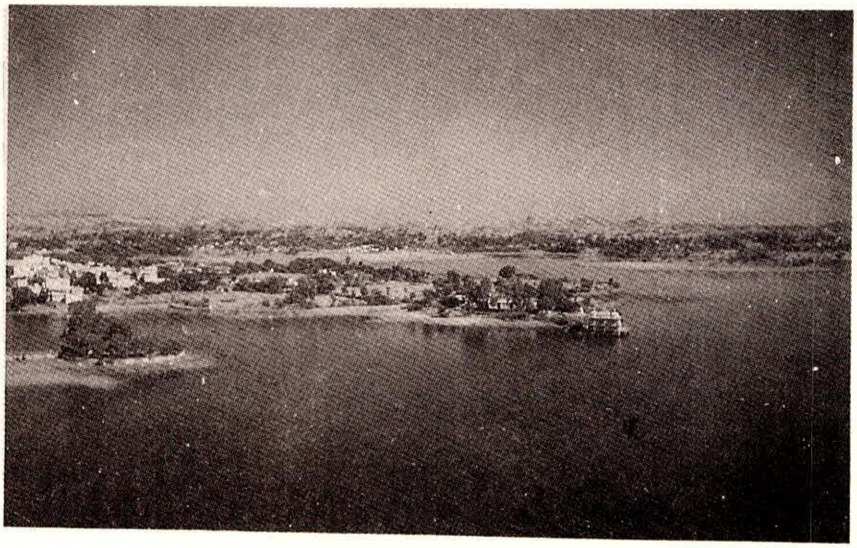


PLATE - 14 A VIEW OF GAIBSAGAR, DUNGARPUR of the town. It is privately owned.

Some physical feature of Giabsagar are given in Table 23.

Table- 23. Some physical features of Gaibsagar
(Source : R.P.P.C.B. report, 1986)

S.No.	Feature	Measurements
1.	Pal (ghat) length	300 m
2.	Distance of water coverage (From Pal to bank towards industrial area)	1000 m
3.	Depth of water at Pal	3.9 m
4.	Depth at a distance of 400 m (From Pal towards industrial area)	3.3 m

4.7 Mansagar (Jalmahal)

Located about 6 km north of Jaipur, Mansagar is a small reservoir surrounded by Nahargarh and Kilangarh hills on its north and north-east. It is the biggest waterbody of Jaipur. It was constructed by three Maharajas of Jaipur State in succession and was completed in 1734 A.D. (Rajasthan Pollution Prevention & Control Board report, 1986). It is also known as Jalmahal Lake because of the presence of a small palace in the midst of this reservoir (Plate 15). It has an area of 1.23 km, maximum depth of 6.4 m and mean depth of 2.7 m (Sharma, 1978). The main source of water is the run off from the hills and surrounding upland areas during the rainy season. Natural runoff from the hills is approximately 2.0 Mcft whereas seepage and evaporation losses are of the magnitude of 30 to 80 Mcuft (R.P.P.C.B. report, 1986).

Table 24 gives the morphometric parametrs of Mansagar.

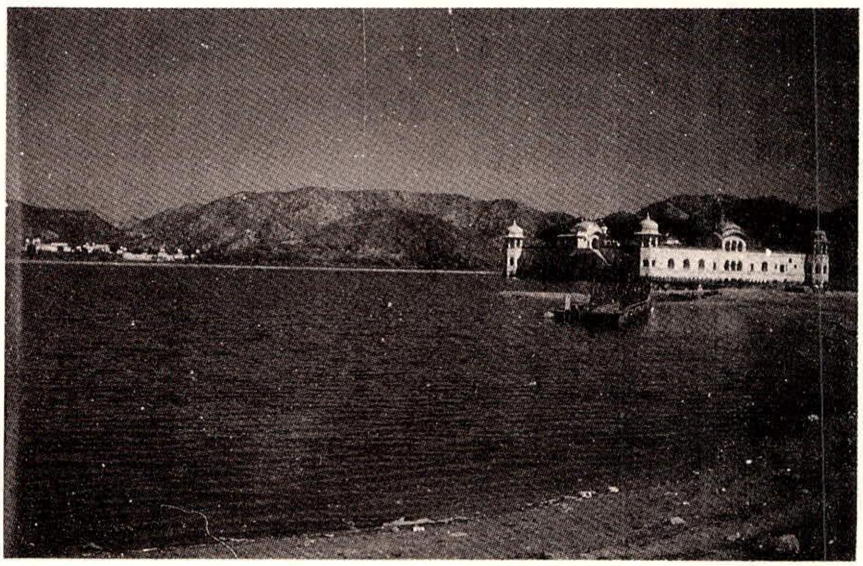


PLATE-15 A VIEW OF MANSAGAR (JALMAHAL), JAIPUR

Table - 24. Morphometric parametres of Mansagar, Jaipur
(Source : R.P.P. C.B. report, 1986)

1.	Drainage area, sq. km	26.88
2.	Max. length, m	1842.00
3.	Max. depth, m	6.69
4.	Surface area at full capacity, sq. km	1.27
5.	Mean depth, m	2.14
6.	Mean breadth at full capacity, m	689.00
7.	Drainage area/lake area	21.16
8.	Volume of lake at full capacity, Mcu m	2.72
9.	Total discharge, M cu m / yr	18.66
10.	Index of lake performance = $\frac{\text{Vol. of lake at full capacity}}{\text{Shoreline at full capacity}}$	459.00

Once it was a clean water reservoir. but now it is an abandoned highly polluted waterbody and receives sewage from the city of Jaipur through an open drain. It also receives wastes (reported to be 100-125 kl/day) from a milk processing plant on its west. Sometimes during the rainy season of 1975, Eichhornia crassipes, a water hyacinth, got introduced into it and spread rapidly to cover more than 80% of the area with in three years (Sharma et al, 1978)..Deforestation in the catchment area has accelerated the sedimentation in the reservoir and it is reported that the capacity of the reservoir has been drastically reduced.

4.8 Lakhotia

Lakhotia, is a small reservoir, located on the north side at the foot of Pali city, which comes in the western part of Rajasthan and passes through three seasons namely summer (March-June), Monsoon (July-October) and winter (November-February). Lakhotia is a manmade, rain-fed, perennial reservoir roughly tringular in shape having a maximum length of

1825 m on the east-west direction and a breadth of 950 m on the north-south direction with a maximum depth of 4.5 m (Khatri, 1992a). The lake also receives water through a channel coming from an adjacent temporary impoundment 'Lahoria', situated on its eastern side. The loss of water is due to evaporation and seepage. The vegetation around the vicinity of the reservoir is mainly confined to the southern side consisting of xerophytic shrubs and trees. The colour of the water is generally yellowish green due to muddy nature of the bed (Khatri, 1992a). Its northern limits are marked by the boundary wall of Umed Textile Mills premises while the southern border is encircled by a series of Pucca ghats. On the eastern bank are dharmashals and temples and the western side has a spillway.

4.9 Chhata Lake

Situated in the tropical monsoon climatic regions of Rajasthan, 100 kms south-south east of Delhi, these are three discrete water bodies; Nari, Sankhi and Kamai. Nari and Sankhi are natural ponds while Kamai is a tank. The total area of the lakes is 3,000 ha. They are situated at an altitude of 190 m between $27^{o}45$ N latitude and $77^{o}40$E longitude. They are fed by monsoon runoff and irrigation canals. Sankhi is shallower and saline with maximum depth of 30 cms. Lake Nari is slightly brackish with maximum depth of 60 to 80 cms. All the three water bodies usually dry up in May (Wolstencroft et al.).

4.10 Gandhisagar

The Gandhisagar pond is a perennial, natural ,depression located almost in the centre of Bhilwara at $25^{o}28$'E latitude and $74^{o}15$'N longitude. The length is 400 m, breadth 200 m and the depth is about 2.5 m. The surface area is 0.05 sq. km (Sharma, 1996). The average annual rainfall in the catchment area is 650.75 mm (Sharma, 1996).

It receives effluents from two major woollen mills. The effluents released from these industries are the wastes from various processes in which chemicals are used. Thus the pond is highly polluted. The lake also receives urban wastes from nearby colonies (Ojha & Sharma, 1994). High pollutional load has rendered this waterbody useless however, the sediment in the pond is used for brick manufacturing.

5.0 Saline lakes of Rajasthan

5.1 General

Saline lakes are characteristic features of the closed lake basins of most desert and arid regions. As observed by Rankama and Sahama (1959), "in semi arid and arid regions, where the amount of precipitation is only moderate or small, the soluble weathering products of rocks remain in the soil or are transported to depressions, where the rate of evaporation is too rapid to allow the accumulation of any considerable body of water. There great quantities of dissolved matter are deposited and finally form alkaline or salt lakes or even dry salt beds".

The Thar desert of Rajasthan also has many saline lakes. These include Sambar Lake near Jaipur and Ajmer, Didwana Lake, Kuchaman Lake , Degna Lake, Phulera Lake, Talchhappar Lake in Churu district, Lunkaransar Lake in Bikaner etc. Most of these lakes are playa lakes i.e. they are a very shallow sheets of water which exist only during the rainy season and dry out more or less completely in the hot season leaving the salt beds. Of these the Sambhar lake is very big. Most others are more a salt producing area than lakes. Some of the major saline lakes are described in section 5.4

5.2 Origin of salinity of saline lakes

Although, as said above, the causes of origin of salinity in the saline lakes are mostly the closed nature of the lake basins and the climatic factors such as high temperature causing heavy evaporation rates which often exceed the precipitation, there does not seem to be any agreement on this issue by various geologists and workersas far as the saline lakes of Rajasthan are concerned . Attempts are being made by geologists to find out the cause of salinity from the mid nineteenth century onwards. Various theories and hypotheses have so far been put forward. However, till recently, very few of them have been based on actual field investigations. Sinha, (1977) has made a review of these theories. The various theories are briefly described here.

The earliest attempt to explain this deposition came from A.O. Hume of the Inland Customs in its 1867-68 report (Holland & Christie, 1909). He attributed the origin of these deposits to the drying up of an inland sea or as 'the washings of countless ages out of the surrounding Permian formation' Adam in 1869-70, in report of Inland Custom Deptt. as mentioned by Holland and Christie (1909), suggested that brine springs in the bed of the Sambhar lake account for its salinity. Dr. Noetling in 1902 attributed the salinity to 'subterranean saline spring arising along a fault plane hidden by the mass of silt which now forms the bed of the lake'. Holland and Christie (1909) justifiably refute these suggestions emphatically as being without any supporting evidence and being inconsistent with the geology of Aravali schists (Sinha, 1977).

According to the "In Situ Origin " theory proposed by Blanford (1876) there exist tertiary beds of granite and gnessic rocks of the Aravallis under the thich deposit of silt. Chemical weathering of these rocks gives rise to sodium salts, which are gradually dissolved and move upwards to the surface. Geological explorations do not support this view (Gopal & Sharma, 1994).

N.N. Godbole (1952, 1972), strongly advocated a marine origin of these salt deposits. The lakes according to him are the remnants of residual lagoons from the receding Tethys seas. Though nowhere mentioned by him, this was a revival of Hume's ideas of the nineteenth century. Later, U.B. Mathur, K.K. Verma and S. Mehra (1975) of the Geological Survey of India (GSI) also supported the marine origin for these deposits (Sinha, 1977). However, J.B. Auden (1952) of the GSI discussed the possible marine origin of the salinity and systematically negated the idea on the basis of information about the regional tectonics, geology and physiographic factors. The chemical composition of most of these brines is also reported to be radically different from sea brines. Very recently Ramesh et al, (1992), based on the measurement of stable oxygen and hydrogen isotope ratios from water samples collected from the lakes of Sambhar, Didwana and Kuchaman, suggest that there is no evidence for the marine origin hypotheses. According to them the water in the lakes is of meteoric origin.

Linked up with the theory of marine origin is the theory of a 'halite bed' at Didwana by Khandelwal (1975) and its subsequent support by Paliwal (1975). In fact, based on this premise, Mathur et al. (1975) cite this as an additional evidence for the marine theory. This theory does not bear scrutiny after a careful analysis of the environmental conditions and field studies. Studies initiated by the Desert Geology Division of the GSI clearly contradicted the occurrence of such a halite bed (Sinha, 1977).

Holland and Christie (1990) also refer to older suggestions of the origin of these deposites from ancient rock salt deposits. However, no geological evidences have been forthcoming in support of such a contention (Sinha, 1977).

Holland and Christie (1909) referred to the possibility of the salt being brought into these areas from the irrigated tracts of Punjab by the percolating groundwaters. Saxena and Seshadri attributed the salinity of these lakes to sub-soil percolations from Khewra and Mandi, through percolating groundwaters as stated by Godbole (1972). However, according to Sinha (1977) "such long distance transportation along with sluggish groundwater flows calls for extremely permeable and prolific aquifers, which do not occur with any appreciable continuity in this zone. Furthermore, most of the main lakes are in a regime of consolidated metamorphics of Delhi Aravali supergroup, with but a thin veneer of alluvial/aeolian material. Moreover, the relative altitudes of these lake deposits and the elevation of the aquifer horizons from the Punjab region also preclude the possibility of any salt migration towards these lakes".

Holland and Christie (1909), on the basis of actual field investigations, concluded that the salt was derived from wind-borne saline matter coming from the Rann of Kutch. However, Dr. Pramanik (1954) of the Meteorological Department found, on investigation of the saline content of air samples in Rajasthan, that there is little or no support to that hypothesis. The theory has also been severely questioned by Godbole (1952, 1972) and criticized by several other workers. Auden (1952) is reported to have given an excellent critique of this idea. According to Sinha (1976), however, there may be serious doubts on the overall applicability of the concept, in so far as the total salinity of the lakes is concerned, but as a mode of partial source of salt input, there seems to be no possible doubt.

Thus, despite various theories and hypotheses, the problem of origin of salinity appears to be still unsolved. Sinha (1977) thought that the case of the problem of salinity has been overstated and made unnecessarily complicated by many proponents. According to him "it is in the geomorphic setting of the desert and these inland basins that the solution of the problem has to be sought" To quote him, "the essential prerequisites for the creation of conditions for such salinity are very much in existence in the arid environment of Rajasthan. Parallel cases are numerous from various arid regions of the world. It is, therefore, unrealistic to seek evidences which are lacking or propound ideas that are not conformable with the realities of the situation. Why delve in the realms of the obscure, where the explanation, prima facie, is available in the observed objective situation?" It is, however, conceded by him that painstaking experiments and investigations are essential to qualify the sources and define the exact interplay of other environmental factors in creating the situation.

5.3 Chemical composition of saline lakes

Table 25 gives the analysis of saline salts in the water of some of the saline lakes of Rajasthan as analysed by Krishnan (1982). Since the units and the period (months) during which the values are recorded are not specified by the author, it is not possible to get true idea of salinity. However, certain generalisations can be made. It can be seen (Table 25) that the Sambhar Lake contains practically no magnesium salts while they are prominent in Pachpadra Lake. Potassium salts are absent in Pachpadra and Didwana lakes. Sodium sulphate is present in Sambhar, Didwana and Kuchaman but not in Pachpadra. According to Krishnan (1982) these peculiarities are probably to be explained by the peculiarities in the salt content of the local soils and drainage.

Table- 25. Composition of saline matter in Rajasthan saline lakes (after Krishnan, 1982) (units are not specified by the author)

Saline matter	Sambhar	Kucahman	Didwana	Pachpadra
NaCl	87.30	84.20	77.2	85.2
KCl	0.13	--	--	--
$MgBr_2$	0.05	--	--	--
$MgCl_2$	--	--	--	1.90
Na_2SO_4	8.60	10.50	20.60	--
$CaSO_4$	--	0.50	--	2.9
$MgSO_4$	--	2.60	--	9.4
Na_2CO_4	3.80	--	0.60	--
$NaHCO_3$	--	--	1.60	--
$CaCO_3$	--	0.50	--	--

However, it should be remembered that since the physico-chemical parameters of the water are affected by the time and depth at which samples are taken, which in turn depend upon the rainfall in a particular year, it is not possible to compare the results of different investigations or arrive at any specific conclusions. The catchments of the four main streams flowing into the Sambhar Lake differ considerably in the salt content of their soils and accordingly stream water salinity levels also vary greatly (Gopal & Sharma, 1994). During July and August, the lake is relatively less saline, registering less than 2 ppm salinity (Gopal & Sharma, 1994) which gradually increases through the winter, partly due to evaporation and and partly due to generation of salts from the lake sediments. As the lake starts drying in summer salinity increases sharply and salt crystalization starts. Baid (1962) observed a maximum salinity of 164 ppt in April whereas Jakher et al.(1990) recorded salinity as high as 267 ppt in May.

5.4 Major saline lakes

5.4.1 Sambhar Lake

The Sambhar Lake lies on the border of Jodhpur and Jaipur, between latitudes $26^{o}52'$ to $27^{o}2'$N and longitudes $74^{o}54'$ to $75^{o}14'$E, about 64 km to the west of Jaipur city. It is at an elevation of 360 m above sea level. It is elliptical in shape with its long axis running east-northeast to west-southwest (Fig. 15). It is the largest inland saline lake in India. Its surface area varies greatly, depending upon the amount of water entering the lake in a particular year. At full capacity it covers an area of 190 sq. km (Gopal & Sharma, 1994). According to Krishnan (1982) the surface area is 240 sq. km. Sambhar is a shallow lake, reaching only about 3 m at its deepest, with an average depth not exceeding 0.61 cm. The maximum length of the lake basin is 22.5 km, while the width ranges from 3.2 km to 11.2 km. According to Krishnan (1982) it is 32 km long. The lake bed is almost flat, with a slope of less than 10 cm per km (Gopal & Sharma, 1994).

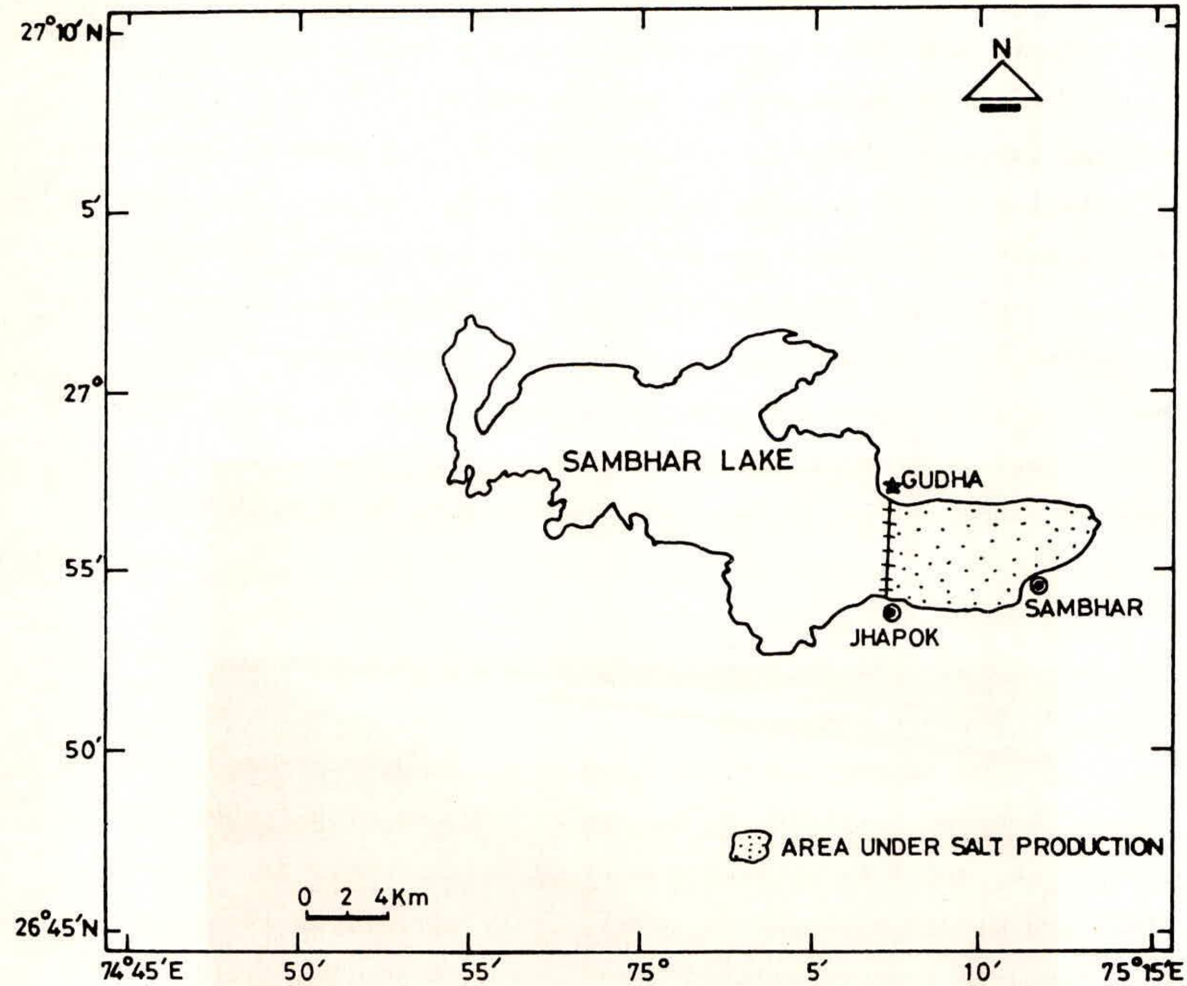


FIG. 15 BASIN MAP OF SAMBHAR LAKE

Most of the lake basin lies in Jaipur and Nagaur districts and only a small portion in Ajmer district. To the northwest and west of Basin the Aravali ranges rise abruptly to heights exceeding 500 m with outcrops in the form of hillocks scattered along the northern and southern periphery of the lake. In fact, the Sambhar Lake basin which occupies a depression in the Aravali schists appears like a valley within the Aravali ranges.

The lake basin is divided into two unequal Parts by a 5.16 km long dam between the settlements of Jhapok to the south and Guhda in the north. The western part is a natural, undisturbed, continuous sheet of water. The eastern part, which is used exclusively for salt extraction, covers 76.8 sq km (Gopal & Sharma, 1994). It comprises two large reservoirs for holding the brine, a series of canals, and salt pans. All these salt pans can be approached by the narrow bunds that separate them (Plate 16). After the brine reaches a certain level of concentration, it is transferred from the western part of the lake to the reservoirs through two sluice gates in the dam.

The lake has an extensive catchment spread over 7560 sq km. most of which lies to the north and north east of the lake, extending up to Sikar district (Gopal & Sharma, 1994). The catchment area is 5600 sq. km according to Biswas et al. (1982). The principal source of water to the lake is local precipitation and drainage from the catchment. The big catchment area of the lake has four large streams viz. Roopangarh, Mendha, Kharian and Khandel besides numerous rivulets. However, their supply to the lake is limited because of aeolian activity in the region and man-made dams constructed for irrigation purposes. Of these rivers, currently only the Roopangarh and the Mendha seem to supply water to the lake and even the flow in these streams is

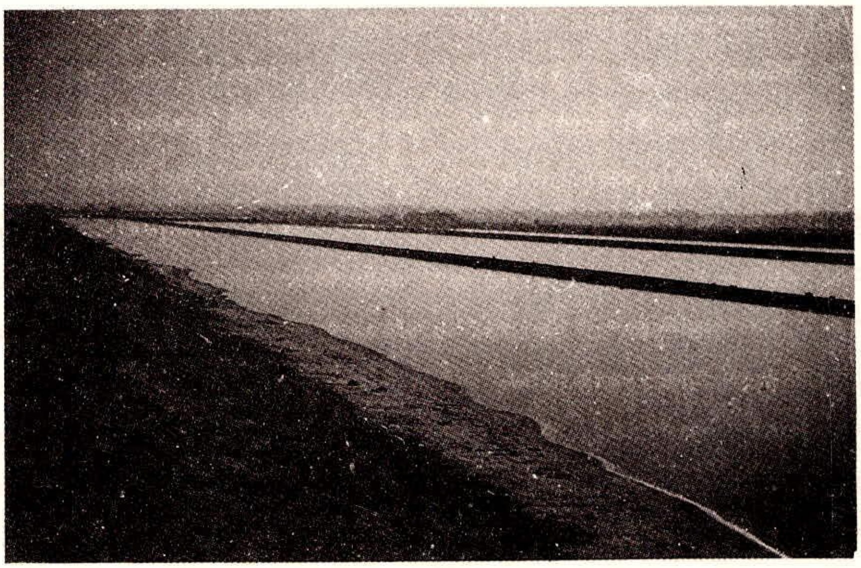


PLATE - 16 A VIEW OF SAMBHAR LAKE, SAMBHAR, SHOWING SALT PANS highly seasonal and occurs only for a few days during the southwest monsoon i. e. June-September (Yadav, 1995). River Mendha, the largest feeder stream, originates in Sikar district runs southwest and west before entering the lake from the north. The river drains an area of about 3600 sq. km i.e. about half of the total catchment of Sambhar Lake (Gopal & Sharma, 1994).

Sambhar Lake lies just to the east of the Aravali. The climate of the region is therefore typical subtropical monsoonic. The mean monthly maximum temperature during summer rises to above 40°C whereas the mean minimum winter temperature remains about 11°C (Gopal & Sharma, 1994) Climatic data from the three meteorological stations (Jaipur, Sikar and Ajmer) close to the Sambhar lake show that January is the coldest month with minimum temperature of about 6-8°C and May is the hottest month with maximum temperature ranging between 39-41°C (Yadav, 1995). However, the maximum daytime temperature during May-June often crosses 49°C whereas during winter the minimum temperature often drops below 0°C (Gopal & Sharma, 1994).

The maximum average relative humidity during the monsoon season is about 76% in the month of July and minimum of about 15-20% during summer months before the onset of monsoon. Information of wind regime indicates that the diurnal average speed varies from 4 to 12 kmph (Mar-July) and minimum being at 2-3 kmph during the winter (Dec-Feb) (Yadav, 1995). Evaporation is about 110 cm (Misra, 1967).

The rainfall which annually averages 54cm, occurs almost entirely during the period July to September (Gopal & Sharma, 1994). A characteristic feature of the climate is the extreme temporal variability in precipitation. The rainfall record of more than a century shows that both the total annual rainfall and its period of occurrence and intensity during the season exhibit wide variations, resulting in frequent spells of drought and flood. The rainfall, which has often been as low as 16 cm (in 1939, for instance) exceeded 100 cm in 1892, 1893, and 1917. According to the data compiled by Aggarwal (1951), as much as 15 cm rain had fallen during July and 31 cm rain within five days in September 1884, causing severe floods. Heavy rainfall in the years 1892 and 1917 was, however, relatively evenly spread over the rainy season. Again, in 1929, more than 44 cm and 51 cm of drain at Jhapok and Nawa settlements respectively, occurred within five days during the last week of July. Another example of intense rain was recorded in July 1949 when more than 13 cm rain fell within three hours and again about 17 cm within 24 hours. In contrast, during dry years, rainfall was often well distributed over the whole season, registering only 3.5 cm in a month. Flash floods which have become fairly regular in recent decades-in 1968, 1971, 1974, 1975, 1977, 1981 and 1983- were due not to excess rain but to high intensity of rainfall on certain days (Gopal & Sharma, 1994).

From the field observation, it is evident that water table of the adjacent groundwater is generally 5-10 m above the lake bed. However, at places within the river basin (for example near Roopangarh town), groundwaters is available at 20-30 m above the lake bed. This indicates a significant hydraulic gradient that favours the groundwaters flow towards the lake basin in addition to the surface run-off during the monsoon season. The groundwaters of this region show considerable variations in their salinity, among these the low salinity waters are used for irrigation and domestic purposes (Yadav, 1995).

The lake basin is estimated to contain 65 million tons of salt (Misra,1967). It is generally dry in summer leaving a small marshy patch. The saline mud in the lake is 22 m deep (Krishnan, 1982). It has been worked for common salt since long. It is estimated that in the upper 4 m of the mud in the lake, whose average salt content is about 6 per cent, there would be roughly one million tons of salt per sq. km. of area (Krishnan, 1982). It is the single largest inland salt source in the country and accounts for about 8.7 per cent of the total salt produced in India (Misra, 1967). The Sambhar lake source has a distinct advantage over others, since its salt deposits are inexhaustible with large annual production and the salt produced is also of good quality (Misra, 1967).

5.4.2 Didwana Lake

This lake, actually a salt producing area of about 10 sq. km, is located about 50 km northwest of the Sambhar lake. The depression is surrounded by sand hills on all sides except in the west where an isolated spur of the Aravallis forms its western boundary. Didwana town is located at the northeastern end. Within this depression, two dams have been constructed from one end to the other to minimize the inflow of surface water towards the centre of the depression where salt manufacturing is carried on (Misra, 1967). The bed of the depression shows the presence of black clay. The brine springs in this depression has a brine density of 20 Be. The climatic and physical conditions are well suited for manufacturing salt in this area. The May temperature is about 46^{o}C, and average annual rainfall is only 37 centimetres. (Misra, 1967).

5.4.3. Pachpadra Lake

The Pachpadra Lake is located about 128 km southwest of

Jodhpur. The lake basin is a depression with an area of about 83.2 sq kilometres. The rain water leaches out salts from a catchment area of about 910 to 1,040 sq km and carries them to sub-soil in this depression. The climatic and physical conditions favour salt manufacturing. The summers are very hot. Rainfall in the area is scanty (28 cm annual) and the annual rate of evaporation is about 150 centimetres. Rectangular pits are dug in the basin to reach the brine. The largest number of salt pits are in the western part of the depression and the salt works are located at Hiragarh and Bara Sambra. Other salt works are at Posali and Chota Sambra in the eastern section. The salt at Pachpadra corresponds more to the sea salt.

5.4.4. Talchappar Lake

Talchappar salt lake (27°52'N latitude and 74°27'30"E longitude is a simple elliptical lake situated near Devani, Churu District, Rajasthan. This saline lake is nearly 4-5 km in length and 3 km in breadth and is bounded on its south south-west direction by obstructed, stabilized sand sheets and dunes resting against the Gopalpur quartzitic hills. Presently this area receives an annual mean monsoonal precipitation which varies from 281 to 503 mm with an average rainfall of 367 mm. The mean monthly summer temperature varies from 40°to 45°C whereas the mean monthly winter temperature is as low as 2°to 10°C. Dust storms of severe intensity and of long duration are common. Climatically, this area is semi-arid. The lake is surrounded by short shrub copice vegetation. Presently, the brine in the sub-surface rocks is at 10 m level. (Achyutan & Reddi, 1993). The brine from this lake is pumped out and is used for salt extraction.

6.0 Major problems in the lakes

To give a detailed account of the problems faced by all the so called lakes of Rajasthan is not possible for unavailability of information. Each waterbody will have different threats depending upon its ecological setting, the land use in the catchment and the extent and impact of human activities alongwith other environmental factors. However, as a general rule most significant problems in the lake appear to be the heavy pollution in many of these waterbodies and subsequent deterioration of the water quality. With the industrial development and urbanization and exploitation of the water resource for variety of uses, this problem is obvious. Since most of the studies are concentrated on this aspect they are easily in limelight too. However, many lakes are expected to fast loosing their original capacity due to heavy siltation and sedimentation continues to be a threat for them. Threat to the ecological environment of some of the ecologically significant lakes like Ghana has also been reported. Some of the problems are already referred to in the report.

Social and economic factors affect water quality of the lakes of Udaipur. To quote from the Zheel Sanrakshan Samiti report (1994) "most of the hotels (53 in numbers) alongwith 6000 residential houses accommodating 33,000 population are located on lake slopes releasing all sorts of dirt and drain water into the lake complex. Even the garbage collected from the roads, dirt thrown from the houses, debris of the dilapidated houses, small-sized dead animals are thrown on the banks of the lakes. Slopes have about 300 hanging latrines, 73 ghats used for bathing and washing, 45 drain spots, 53 hotels, 42 garbage spots and 118 open air defecation spots which release a shocking quantity of pollutants into the lakes. The barren hills from all the sides pour tons of eroded soil in the lakes each year" The lakes are thus subjected to organic contamination and sedimentation. Municipal sewerage-lines open directly into the lakes and thereby increase the bacterial material and organic load. The ghats situated on the banks of the lakes are traditionally used for bathing purpose and also for washing clothes. This releases large amount of detergents into lake waters daily, which increases its phosphate content. Similarly, increased commercial activity, especially of hotels in the vicinity of lakes, has also contributed considerably to water pollution. In the catchment area of Fatehsager lake, chemical effluents from synthetic fibre mills are discharged every day in a drain which carries water to Fatehasagar. The boating activity has spread oil layer near Navghat, Pilighat of Pichhola and boat booth of Fatehsagar. In summers, vehicles are washed between the filter house and a hotel site of Fatehsagar (Zheel Sanrakshan Samiti, Rep., 1994). The Zheel Sanrakshan Samiti report al mentions the number of spots from where the pollutants are being discharged in these lakes. It also gives the figures of the amount of solid wastes actually being discharged into the lakes. However, the time unit for these amounts (whether daily, monthly or yearly etc.) has not been specified hence it is difficult to get a true picture of the actual pollution in the lake. According to Madhusudan et al. (1984) on an average about 2.1 metric tons of organic matter is poured daily into the lake Pichola, the yearly figure being 76.50 mt. The entry of this organic matter is from 40 different points situated all around the lake but especially at its eastern boundary. The amount of liquid waste getting into the lake every year is 3-6 million cubic meters. (Madhusudan et al., 1984). Rao & Durve, (1989), have also reported the amount of organic matter and

Phosphate being received by Rangasagar. However, they have also not mentioned the time period. All these facts regarding pollution of lakes amply illustrate the disastrous condition of the Udaipur Lake System and call for an urgent remedial action. It has been reported that the people residing along the shore are suffering from many water borne diseases. It should be remembered that these lakes especially the Pichola, are the chief sources of drinking water for the city of Udaipur. Apart from the disastrously heavy pollution the lakes are also facing threats to their very existence due to sedimentation. Studies conducted by Purohit et al. (1991) reveals that the lake Pichola has lost 2.34 Mcum capacity in a span of 15 years during 1973-1988 . During the same period the capacity of Fatehsahar has been reduced even more (2.91 Mcum). There is a considerable reduction reported in the submergence area of these lakes also. With the present rate of sedimentation the lakes are expected to extinguish in less than a century time. Deterioration both in terms of quality and quantity has been reported for Udaisagar also. The lake is reported to receive high organic load from the industries especially the Udaipur Distillery. It is reported that the industries were directed to instal treatment plants but not all have complied with the directives.

Water is a very valuable natural resource everywhere, more so in the water scarce arid region of western Rajasthan. However, conservation of these natural resources does not seem to have been paid serious attention in this region. According to the survey conducted by Mahnot & Rajpurohit (1990), 27 surface waterbodies in and around Jodhpur have already become non functional in recent past. Of these 23, including 11 ponds, have been already destroyed for ever and 4 abandoned due to their non suitability for further use. Many of the lost ponds like Phoolalo, Jagatsagar and Bakhatsagar have been converted into parks. The others are converted into urban areas. The catchments of another 11 functional ponds have also been reported to be partially lost due to urbanization and industrialization. It is expected that these will also meet the same fate as the lost ones. Although quality wise the waterbodies are not reported to be very poor the rate at which they are getting destroyed is really alarming and needs an urgent attention.

The Ghana (Mansarovar) Lake at Bharatpur is facing threat to its ecological environment and consequently, its very existence because of the paucity and uneven supply of water. In 1987-88, the effect of drought was obvious when the wetland dried out completely and dead and dying animals were observed even during the end of the winter season. Groundwater had to be pumped into the central, deeper areas to sustain some aquatic life and for providing drinking water to animals during the spring and summer (Vijayan, 1994). The situation is more or less the same even today. The two rivers, namely Banganga and Gambhir, which have been traditionally supplying water to the park have increasingly become undependable. The supply from the river Banganga has already been stopped about a decade ago because of the growing pressure on its waters for irrigation and other human uses. Hence the river Gambhir which originates from Karaul Hills is the only source at present. Getting water from this river is also becoming increasingly difficult as a large quantum of it is being used along its course for irrigation. Construction of Panchna dam has compounded the difficulties. The situation further deteriorates with decrease in rainfall and during drought. The paucity of water has been changing the ecology of the park.

Succession of wetland vegetation to woodland, which has already begun at a rapid rate as a result of the removal of the primary consumers (buffaloes, whose entry has ben banned in the park), has become more intensified. Some of the wetlands areas have already reported to have changed into woodland.

Alongwith the quantity, the quality of water inside the park, which is determined by the biogeochemical processes occurring in the system, show variations in different years. As the water dries up in the summer the concentration of salts in creases. During 1987 a considerable increase was noticed because of large scale pumping out of groundwater to maintain the minimum required level of water to support life.

The diversity of species in lake water indicates that succession is in progress and due to closed recycling process, the lake has attained high fertility degree. Due to the shallow depth of waters and deposition of dead organisms, eutrophication has been reported to be in progress. Macrophyte population contribute to the debris and organic matter build up in the lake (R.P.P.C.Board report, 1986). Thus the lake requires a comprehensive ecological management.

Pollution is reported in Pushkar lake also. The lake became vulnerable to pollution due to heavy influx of construction around the lake, tourist arrivals, cattle fairs, indefined sewer system, submergence of ashes, performance of rituals and other religious activities (R.P.P.C.B., 1989). However, at present the lake water quality is reported to be good on an average except at a few places like the ghats and it is high time to take preventive measures before the quality starts detiriorating.

The Aansagar Lake of Ajmer is under multifold pressure of urban sewage waste discharge, cloth washing and flow of detergents and automobile servicing and deforestation in the catchment areas (Sharma,1991). Because of the excess sedimentation rate, the Budha Pushkar lake of Ajmer has been considerably reduced as far the capacity is concerned. Similarly Gandhisagar in Bhilwara has been rendered useless due to very high pollution load. Jalmahal Lake in Jaipur which was once a clean water reservoir has now been highly eutrophic. Many other waterbodies of the State are reported to be either eutrophic or even hypereutrophic.

7.0 Status of hydrological research

7.1 Need for the hydrological study of lakes

Lakes are catalysts in the development of a region. Lakes serve a variety of purposes. Their waters are used for drinking and other domestic purposes, irrigation, industries, recreation, transport, power generation etc. Unfortunately this popularity of theirs is responsible for their deterioration, both quantitative and qualitative. Proper conservation and management of these valuable resources have become all the more inevitable in the present industrial age. For this a complete hydrological study of the lake is needed. Such a study is also essential to understand the ecological behavoiur of lakes in totality. A comprehensive hydrological study of the lakes involves study of the hydrological characteristics of the lakes and its catchment, morphometric studies of the lakes, evaporation and water balance of the lakes, sedimentation studies, thermodynamics and hydrodynamics of lakes, interaction of the lakes and groundwater in the surrounding catchment, pollution, water quality and eutrophication of lakes etc.

Morphometric and bathymetric features of lakes which are functions of geology, geography and cultural (human) impact determine the productivity status of the lakes and as such the morphometric indices (mean depth to maximum depth ratio, volume development index, shoreline development index etc) are useful indicators of the trophic status of lakes. However, it should be noted that the various indices are of limited use unless other facts like biological and limno-chemical characteristics of lakes are well understood (Cole, 1979). The ratio of mean depth to maximum depth indicates the shape of the lake basin. The shoreline development index is a pointer of productivity status of lakes. It also speaks of the nature of shoreline and shape of the lake.

Lake water is supplied for variety of uses including the developmental programmes. For the success of these programmes a regular, timely and required supply is essential. This is possible only with an accurate estimation of the available water at any specific time to meet these demands. Any underestimation or overestimation may lead to inefficient use of the lake water which is undesirable and may even hamper the developmental activities. The significance of the water balance studies lies here. The water balance studies enable us to plan the various uses of lakes. For example, some uses like recreation and navigation require constant water level and other uses like hydropower and water supply require it to be full. To maximize the flood control potential of a lake it should remain empty.

The assessment of the water balance in lakes is also an important prerequisite to calculate nutrient budget vis-a-vis to assess the causes of lake deterioration and to suggest ameliorative measures. Water balance study helps to find the response of lakes to changes in catchment. Deforestation, conversion of grassland into cropland, intensification of agricultural production, land amelioration etc. are energy input into a catchment. This energy input affects microclimate and reduces evapotranspiration thus increasing runoff and siltation viz. nutrients input (Bhar & Khobragade, 1993). Eutrophication in the lake is the result of such nutrient enrichment. All this knowledge is used to develop and conserve lake basin and adjoining catchment area which would increase the life span of this otherwise transitory feature of the earth and lake water could be gainfully harnessed to meet the various requirements of the community.

Untill recently, the ground water component of the lake system has been ignored or considered unimportant relative to other components of the hydrologic system. The interaction of lakes and groundwater is the least understood component of lake hydrology. Groundwater flow is next to impossible to measure directly and must be estimated from a knowledge of local gradients of the water table and aquifer properties (Strahler and Strahler, 1973). But groundwater flow is of utmost importance in lakes which do not have inlets and outlets (seepage lakes or closed lakes like Pushkar and saline lakes of Rajasthan) in which water passes out as ground water discharge lowering the watertable because of which these lakes may come across extreme drop of water level and occasional complete emptying also (Reid and Wood, 1976). Seepage lakes not only lose water by groundwater but are recharged by groundwater only (Thurman, 1985).

The significance of eutrophication studies hardly needs any emphasis. Eutrophication denotes the nutrients status of a waterbody. It describes the effects of nutrients on general water quality conditions of the waterbody. Eutrophication is generally considered undesirable since the effects of eutrophication can interfere significantly with use of lake water. Consequently, eutrophic waters have more constraints on their general usage than do oligotrophic waters with lower nutrient levels, although increased productively at all trophic levels inherent in the eutrophication process can be a positive feature under some conditions like fish production. Some water uses sensitive to the effects of eutrophication are drinking water supply, industrial uses, stock watering, irrigation & recreation.

Relationship between the temperature and lake water is a striking phenomenon exhibited by lakes even in tropical conditions especially if they are high altitude lakes with sufficient depth and volume. This relationship is observed in the seasonal variation and development of thermal stratification. The study of the thermal behaviour of lakes is important because the knowledge of temperature distribution is a basic requirement for all ecological and water quality models. Temperature affects many biological and chemical processes. As a matter of fact the thermal structure is the frame for all biological life. Vertical transport of different chemical species is mainly due to diffusion. The transport rates by diffusion is strongly related to temperature gradients. The diffusion process, thus, is expected to be different in lakes exhibiting stratification than the ones without stratification. Almost all lakes are receiving some kind of pollution or warm water, sewage etc. The vertical temperature distribution has a dramatic effect on how pollution is spread in the lake.

The energy of the Sun is the prime force driving all the ecosystems including the lake ecosystems. As such any attempt to understand the ecology of the lake requires study of the energy input in the lake from Sun. It should be mentioned here that although most of the present studies on lakes in Rajasthan are concentrated on the limnological and ecological aspects, there are hardly any attempts (with very few exceptions like Sushil, 1989) to study the energy transfer within the lake ecosystems. Most of these studies end up with linking the physico-chemical parameters of the lake water with the fauna and flora of the lake.

Sedimentation along with the deterioration in water quality is the most severe problems for most of the lakes in India. The problem is more so in Rajasthan. Sedimentation studies are essential to estimate the quantitative reduction in the lake capacity thereby enabling to predict the life of the lakes. Sediment also bring with them nutrients which enhance the eutrophication thus hampering the quality of water also. Sedimentation and eutrophication are thus often related. From the lake managementnt point of view the lake sedimentation studies are of utmost importance. The response of the lake to climatological or manmade changes is recorded in its sediments, in their composition and in the rate at which they are accumulating. Lake sedimentation studies help in linking the various factors which influence the sedimentary processes of the lake making it easy to understand how and under what circumstances they may be characterized. Further the relationship between the particle size,composition and geochemical bahaviour, if developed, can be helpful to gain proper appreciation of the role of the lake sediments in hydrologic cycle of the lake systems. Analysis of lake sediments provides information about the actual contribution of the sediments in the deterioration of lake water quality by knowing the amount of nutrients and toxic metals added by it. It also tells about the contribution of sediments to the overall heat budget of the lake.

Thus, it can be observed very easily that most of the processes in lakes are either interrelated or they atleast affect each other indirectly. So, to understand the ecology of lakes completely mere bio-limnological approach is not adequate. Rather all these hydrological processes need to be studied and interrelated.

7.2 Present status of the hydrological research

Lake hydrology is a relatively new field in India and as such studies on hydrology of lakes are not much all over India. Whatever studies have been conducted are mostly on the ecological and biological aspects of the limnology. As far as Rajasthan is concerned, the studies on the lakes (and other freshwater bodies also) have been reported mostly in the areas where academic institutions like science colleges and Universities are located. They studied the problems of the lakes from biological or zoological angles and hydrological aspects are not addressed to. Of the various lakes studied, the Udaipur Lakes are relatively more exhaustively studied. As a matter of fact, the Udaipur Lakes are probably the best studied lakes in India after the Kashmir lakes and the Kumaun lakes. Similarly waterbodies of Jodhpur and Ajmer have also received attention of scholars although mostly from the limnological angles. The College of Tech. & Agril. Engg., Udaipur has a separate department on Limnology & Fisheries which has conducted many studies on the water bodies in and around Udaipur. Many PhD , MSc and M.Phil theses have been completed by the Deptt. and the Sukhadia University of Udaipur (Annexure -II). Similarly, many research projects have also been completed (Annexure - III). A separate Zheel Sanrakhashan Samiti • has been established at Udaipur to look into the problems and suggest conservation measures for the lakes of Udaipur. They have recently carried out an exhaustive study about the environmental status of the Udaipur lakes.

Most of the studies, as mentioned earlier, are biased towards the limnological aspects. As far as the hydrological aspects are concerned the studies are almost negligible, barring a few scattered exceptions. However, a beginning in this direction has been already made recently by the Hydrology Division of the Central Arid Zone Research Institute, Jodhpur. Hydrological characteristics of Sardarsamand Lake in Pali - the water yield from the catchment (runoff), evaporation and seepage have been already studied by them. It is further let known that the sedimentation studies etc are also initiated (Khan et al., 1990). It has been reported that Shukla (1987) has made hydrological studies of Rangasagar. However, his work could not be available for reference. These are perhaps the only reported study which are purely on the hydrological characteristics of lakes.

Most of the so called lakes of Rajasthan which are being used for irrigation purpose are managed by the Irrigation Department, Govt. of Rajasthan. Till now no research activities have been conducted by the Department on the hydrological aspects of these lakes. However, it was let known that a beginning in this direction is going to be made in the near future.

It is known that the Desert Geology Division of the Geological Survey of India have conducted research on the problem of origin of salinity of Rajasthan lakes during seventies under the project titled 'Project Lake Salinity' (Sinha, 1977). However the details of the project and information regarding the findings of the project could not be collected. It is said that the Nakki pond in Mt. Abu is of volcanic origin. It is however not known whether it has been confirmed by geological studies.

It is also noted that most of the studies conducted on lakes have been on the water bodies of eastern and southern Rajasthan. This is understandable also as most of the water bodies are located in these areas only. Barring a few studies mostly on the water bodies of Jodhpur and Pali there are hardly any reports of studies on the water bodies of western Rajasthan although some of the places of this region like Bikaner are known to have many playa lakes.

Status of the various hydrological studies conducted like sedimentation, morphometric studies, thermal studies, water quality and eutrophication studies etc. and the reported status of different water bodies with respect to these aspects is discussed in brief below.

7.2.1 Sedimentation studies

Purohit et al.(1991) have conducted sedimentation studies on Pichola and Fatehsagar lakes of Udaipur under the project of Ministry of Environment and Forests, Govt. of India. On the basis of the sedimentation survey of these lakes it has been computed that the capacity of lake Pichola is reduced by 2.34 million cubic meters and that of Fatehsagar by 2.91 million cubic meters during 1973-1988. The submergence area of Pichola lake has reduced by 0.2967 sq. km. while 0.171 sq. km. area of submergence has been lost by lake Fatehsagar due to sedimentation during the same period. Both the reservoirs are fast loosing their capacity. The average rate of reduction in overall capacity in case of Pichola lake is 0.93 per cent per year while it is higher in case of lake Fatehsagar, which is loosing its capacity at a rate of 1.16 per cent per year. It was observed that with the dead storage the lakes are also loosing its capacity in the live storage. It was found that, of the total sediment 31.31 per cent is deposited in dead storage while the remaining 68.69 per cent sediment deposited in the live storage of lake Pichola. In Fatehsagar 78.72 per cent of total sediment is deposited in dead storage and 21.28 per cent in the live storage. This shows that Pichola lake is loosing its live storage faster than the Fatehsagar lake. Till 1988 lake Fatehsagar has already lost 29.26 per cent of its original dead storage and 7.07 per cent of its original live storage. The average sediment inflow rate into lake Pichola was observed to be 1.482ha m/100 sq.km/year, whereas the contribution of Chikalwas feeder canal to lake Fatehsagar was measured to be 0.214 ha m/100 sq. km/year. Of the total inflow of sediment, 0.495 ha m/100 sq.km/year was retained by lake Pichola. The sediment retained in Fatehsagar lake was 1.471 ha m/100 sq.km/year against the total inflow of 0.214 ha m/100 sq.km/year. The remaining inflow of sediment which was retained by Fatehsagar lake was from the link canal of Pichola to Fatehsagar.

Purohit et al., (1991) calculated sedimentation by conducting the contour survey also and it was observed that the capacity of Pichola and Fatehsagar lake is reducing at a rate of 12.04 ha m/100sq.km/year and 12.69 ha m/100 sq. km/year respectively. These values are quite higher than the results obtained from the suspended sediment analysis. This, according to Purohit et al., (1991) indicates that along with the catchment area of these lakes, the sediment is also contributed by the lakes submergence area which is encroached by the local people for farming in the summer.

Thus, if the present rate of sedimentation is allowed to continue the lakes are expected to turn into a swamp or marsh in less than a century time (Table 26).

Table. - 26 Estimated life of Lakes Pichola and Fatehsagar (after Purohit et al., 1991)

S.No.	Capacity of Lake	Life in years	
		Pichola	Fatehsagar
1.	Dead Storage	28	29
2.	Live Storage	69	42
3.	Gross Storage	97	72

Vyas et al, (1989) have reported the analysis of the sediments of Udaipur lakes. The sediments in all the lakes are reported to be alkaline with a pH between 7.6 to 8.6. They have a high organic carbon content. The high organic carbon content in the sediments is reported to be because of the accumulation of detritus and other allochthonous material brought with runoff. Calcium content is also reported to be high. Earlier Vyas et al. (1986) had mentioned decrease in the concentration of nitrate-nitrogen, phosphate-phosphorus, calcium, potassium and magnesium in the sediments of the lakes during winter and increase in their concentration during summer. The decrease in winter was reported to be due to the exponential growth of both micro and macrophytes while the increase in summer was reported to be the result of resorption after the deposition and subsequent partial mineralization of dead macrophytic tissue as these by then enter the declination phase.

No other sedimentation studies on either the Udaipur lakes or any other lakes are reported.

7.2.2 Evaporation, water balance and related studies

A complete water balance estimate is not reported for any lake of Rajasthan. But the various water balance components are reported to have been studied for Sardarsamand, Pali by Khan et al, (1990). The evaporation and seepage losses have been computed by them by using the water balance method. And as they have reported, by using these computed values the inflow to the lake is calculated. However, it is not understood, because the methodology has not been elaborated, how the evaporation and seepage values were estimated using the water budget method in the absence of the inflow data for the lake and again using the computed value of evaporation and seepage losses in the water balance equation, how inflow is estimated. The water yield estimation have been done by establishing the rainfall-runoff relationship. It has been observed by Khan et al. (1990) that most of the runoff inflow to the reservoir occurred in response to a few high magnitude rainfall of more than 50 mm in the catchment area and ranged from 0.1 % to 10 % depending upon the magnitude. The number of such flows are reported to range from 5 to 12 in a year. However, the annual runoff was found to range from 1.2 to 6.8 %. The coefficient of variation of annual runoff and rainfall was found to be 98% and 86% respectively.

Although the Zheel Sanrakshan Samiti of Udaipur in their report (1994) have given water balance values of some of the lakes in Udaipur the complete details of the various water balance components is not given. Also the unit "M" used by them to denote the quantity of water in lakes has not been clarified. It is also not specified whether the water balance computed is on the monthly basis or yearly basis.

Apart from these references there is no mention of any other study related to water balance of lakes of Rajasthan. The evaporation studies which form a significant component of the water balance also doesn't find any mention in any of the studies reported although high evaporation rate is responsible for the absence of water in most of the smaller water bodies all over Rajasthan especially the western part.

7.2.3 Thermal studies

Ganapati (1955 & 1959) and Nassar (1977) had reported that Balsamand exhibits a temporary thermal stratification during day time which is broken during night. However, no such phenomenon for the lake was observed by Jakher et al. (1981).

Thermal studies have been conducted on lakes of Udaipur. It has been reported that a weak thermal stratification was observed in 1975 with a vertical temperature difference of $2^{o}C$ during summer. Condition remained more or less isothermal for most part of the year (Zheel Sanrakshan Samiti report, 1994). In the summer of 1976, maximum thermal gradient observed was $5.9^{o}C$ (Zheel Sanrakshan Samiti report, 1994). A week thermal stratification was again observed in 1994 (Fig.16). Lake Pichola is also reported to show small vertical temperature gradient but not a stable stratification. This is not surprising because both Pichola and Fatehsagar and for that matter most of the freshwater bodies of Rajasthan (with the exception of big reservoirs), are shallow water bodies and are subjected to the action of wind which are often high speed. This is bound to cause the mixing of the water thereby not allowing the formation of a stable stratification. Even in big reservoirs of the eastern and Rajasthan which have a tropical climate, development of thermocline is not expected as the temperature differences in summer and winter are not drastic. However, the deep reservoirs in western Rajasthan may perhaps develop such stratification as the seasonal variation of temperature there are more drastic. It is, however, expected that

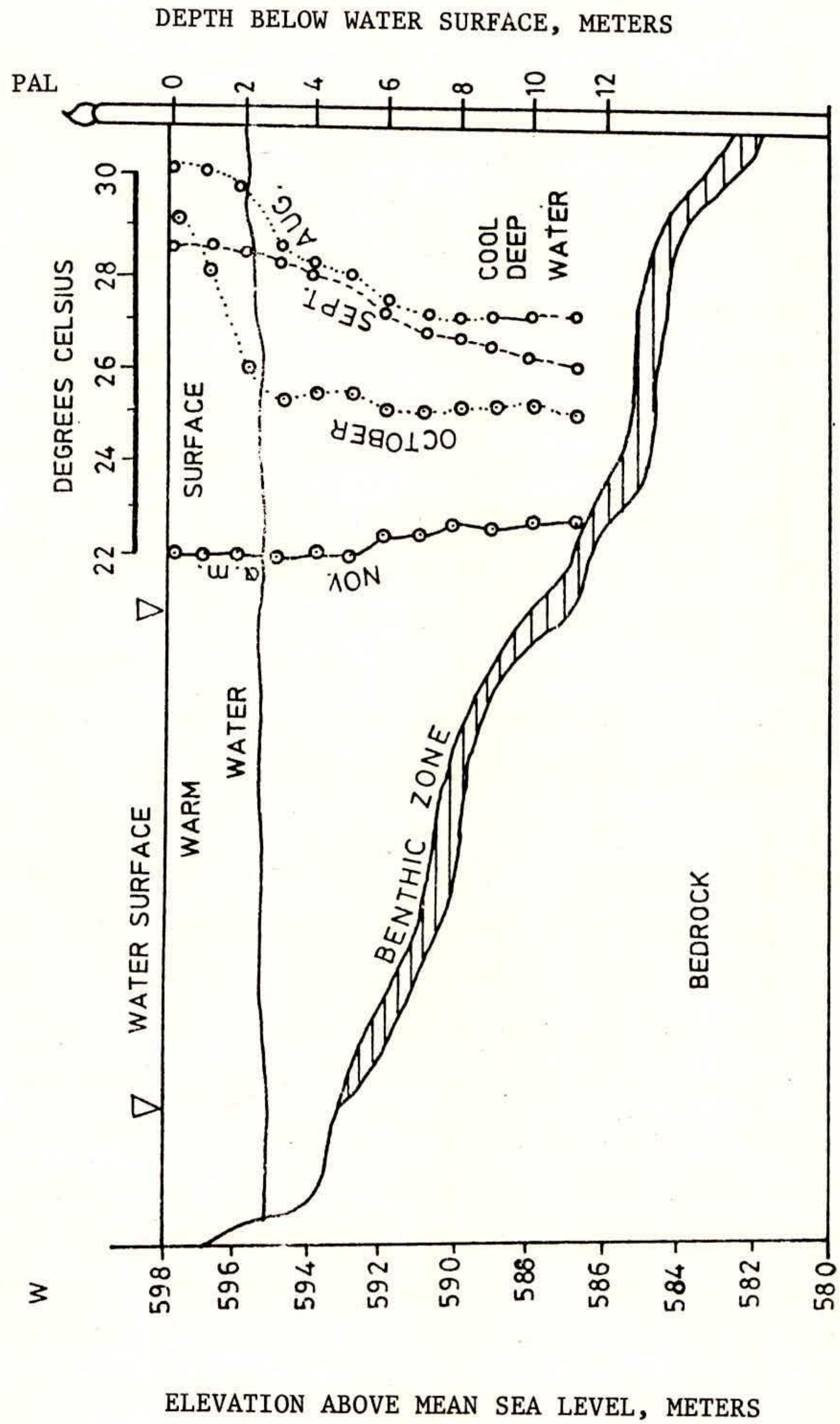


FIG.16 TEMPERATURE-DEPTH PROFILES OF FATEHSAGAR, UDAIPUR (1994)

the daily turn over of water may take place in most of the water bodies as the diurnal variation in temperature throughout Rajasthan are very significant both in summer and winter.

Thus, on the basis of depth wise temperature the Fatehsagar has been classified as third order tropical lake or warm monomictic lake by the Zheel Sanrakshan Samiti (1994) in their report. This classification appears erroneous. Although it is right to call them tropical because of the absence of well defined cyclic temperature versus depth region in most of them; and third order lakes because they are unstratified and their circulation is continuous, it is wrong to call them warm monomictic. As far as the lakes being warm monomictic are concerned, a warm monomictic lake shows only one overturn (being monomictic) and remain stratified in summer. Because development of a stable thermal stratification once in a year (summer) is an essential characteristics of the warm monomictic lakes, the Udaipur Lakes can not be classified as such. The Udaipur Lakes have been classified as typical mountain lakes of subtropical latitudes by Vyas et al. (1989). This classification, though appears to be correct, is probably based on the physical location of the lakes and not their thermal behaviour. It should be remembered that the subtropical mountain lakes often develop stable thermal stratification atleast once in a year. Absence of such a stable thermal stratification in Udaipur lakes is obviously because of the shallow depth and insufficient dimensions. While calling these lakes as mountain lakes it should, however, be remembered that the exact boundary value for the altitude is not yet established. On the basis of their thermal behaviour, the Udaipur Lakes may be called as polymictic lakes where the mixing is continuous, although the data is inadequate for classifying the lakes on thermal basis.

Annual heat budget for Fatehsagar is reported to be 7974 gm calories (Zheel Sanrakshan Samiti report, 1994). Heat budget and detailed thermal studies for Ranisagar of Jodhpur has been conducted by Sushil (1989).

7.2.4 Morphometric studies

Morphometric and bathymetric studies are meagre for waterbodies of Rajasthan with probably the only exception of Rao et al., (1988) although some scattered references are made to some selected characters of some lakes (Sharma & Durve, 1982; Rao, 1984; Rao & Durve, 1989; Kumar & Sharma, 1991, R.P.P.C.B. Rep.,1986; Gupta, 1991 etc.). Rao et al., (1988) have studied the morphometric and bathymetric features of lakes of Udaipur. Their results indicate that morphometric indices D_L (Vol. Dev.) are higher for Udaipur lakes with highest values exhibited by Swaroopsagar and Rangasagar. This indicates that there is a deeper graben along more or less central portion of Rangasagar. This graben is continued into Swaroopsagar where the deepest point is located. The high Dv values for Rangasagar and Swaroopsagar indicate steep sided elongated deep basins. The lower values of Dv in case of Fatehsagar and Pichola are associated with wider expanse of surface area, large shallow basins with aberrant localized depressions.

The ratio of mean depth to maximum depth (Table 27) indicates that Fatehsagar has flatter shape, Pichola has a saucer shape lake basins while Swaroopsagar and Rangasagar indicate 'U' shaped basins thereby confirming the presence of graben. The values are higher and as such indicated relatively deep basin with steep sides suggesting the lakes not to be eutrophic. However, the other parameters biological and chemical have established the eutrophic status of the waters and this disparity according to them is probably due to the existence of graben and impoundment nature of the lakes.

Table - 27. - Morphometric indices for Udaipur Lakes (after Rao et al., 1978).

Lakes	Ratio of mean depth to Max. depth	Shoreline Development index (DL)
Rangasagar	0.598	2.08
Swaroopsagar	0.7587	0.93
Pichola	0.514	1.78
Fatehsagar	0.402	1.20

In case of Pichola the Shoreline Dev. index (DL) is indicative of irregular and sub triangular shape. Rangasagar is elongish with highly irregular shoreline. Swaroopsagar with a low value has circular or sub-circular shape. Fatehsagar is circular or sub circular with the higher than unity value (Rao et al., 1988). The shoreline development indices for all, except Swaroopsagar, confirm their eutrophic status based on biolimnochemical parameters . Since Swaroopsagar is also eutrophic based on the biological and limnochemical parameters, this result according to them is probably affected by the presence of graben and impounding nature of the water as is the case in other indices (Rao et al., 1988). However, it should be remembered that the water spread of the lakes of Rajasthan including the so called lakes of Udaipur show variations in different years and different seasons as referred to already. Consequently, different people have different sets of values for mean depth and maximum depth. This may give different values of the morphometric indices, although most water bodies being reservoir it is expected that the decrease in the mean and maximum depths would be proportionate. It needs to be seen whether the indices estimated and the inference drawn conform with that of Rao et al., (1988).

7.2.5 Eutrophication and water quality studies.

Eutrophication studies are perhaps the best addressed to ones among the various studies reported on the water bodies of Rajasthan. Vyas et al., (1989) have done review of the various studies conducted on Udaipur lakes over a period of 25 years (1964-1989). Based on this review, the physico-chemical parameters of the Udaipur lakes have been tabulated (Table 28). On the basis of these parameters they have further classified these water bodies.

Giving the reference of Jain (1978), Dhakar (1979), Sankhla (1981), Billore (1981) and Vyas et al. (1986), they suggest that in these lakes the temperature, specific conductivity, total alkalinity, free carbon dioxide, dissolved organic matter, hardness and sodium are maximum during summer season. The concentration of phosphate, chloride, nitrate, magnesium and silicates are observed to be maximum during the rainy season while the dissolved oxygen content and transparency are reported to be maximum during winter season. The chloride concentration in all these lakes (Table 28) indicates heavy pollution. This is obvious because the untreated city sewage is thrown directly into the lakes. The various physico-chemical parameters confirm the eutrophic nature of these lakes. Thus the lakes of Udaipur are found to be alkaline, hardwater, nutrient rich, calcareous lakes which have advanced much in the process of eutrophication.

Table - 28. Physico-chemical characteristics of Udaipur Lakes
(after Vyas et a.,1989)
(all values other than those specified are in ppm)

Parameter	Rangasagar	Swaroopsagar	Fatehsagar	Pichola	Udaisagar
Water Temp. (°C)	18.2-34.2	18.8-33.6	13.2-33.9	31.1-33.8	15.3-36.5
Transperancy (m)	0.48-1.15	0.30-0.77	0.48-1.30	0.42-1.19	0.42-0.78
pH	7.26-8.84	7.00-8.88	7.87-9.48	7.80-8.73	8.25-8.81
Turbidity (%)	20-50.6	20.0-60.0	8.0-40.0	6.0-40.0	10.0-52.0
Total Alkalinity	116.7-235.4	120.1-328.96	129.3-217	177.8-233	90-275
Specific Conductivity (mmhos)	0.39-1.50	0.38-0.85	0.26-0.58	0.14-0.5	1.0-1.82
Hardness	214.0-452.8	286.0-457.6	100.1-383.1	229-432	200.2-343
Calcium	6.0-33.07	14.03-32.08	9.21-36.07	5.01-24	22.04-58.1
Magnesium	12.54-31.63	2.46-9.72	3.98-23.82	4.86-24	13.56-29.9
Diss.Oxy.	0.8-8.6	8.14-23.2	8.0-22.8	9.2-23.2	0.8-9.2
Free CO_2	0.0-4.5	0.0-3.8	0.2-9.6	0.0-7.8	0.1-2.0
Chlorides	54.98-189.9	64.96-179.94	82.45-146.3	65.6-124	105-288
Phosphate-Phoshorus	0.20-1.40	0.18-0.96	0.50-0.71	0.27-1.66	0.32-1.68
Nitrate-Nitrogen	0.20-1.22	0.40-1.88	0.70-1.46	0.34-1.19	0.36-1.23
Sodium	10.09-17.54	3.72-42.80	5.0-20.0	3.5-20.0	5.17-10.5
Potassium	5.98-15.34	0.0-13.0	5.0-9.9	1.0-8.5	5.5-9.34
Silicates	1.6-7.8	1.4-8.9	3.2-7.8	1.2-7.2	0.8-6.8
BOD	7.6-14.2	8.2-16.2	4.6-12.0	6.4-13.5	8.3-19.4
Diss.Organic Matter	13.39-35.84	15.67-38.09	10.76-35.4	11.4-40.1	7.69-34.6

The Rajasthan Pollution Prevention & Control Board have carried environmental studies on the selected freshwater waterbodies of the state including their water quality. The water quality parameters of Nakki Pond, Pushkar Lake, Ghana Lake and Gaibsagar, are presented in Tables 29, 30, 31 and 32 respectively. It has been observed by the Board that on an average Gaibsagar has not reached the degree of high enrichment of nutrients and organic load. However, the water towards the receptacle zone of domestic waste water has a high organic load and nutrient. As for Pushkar lake, COD, Phosphate and total concentrations are high near the ghat where disposal of ashes is made otherwise, the water is reasonably good. The result shows that there is a considerable variation in the physico-chemical parameters of the Ghana lake. The causes for such variations are not specified nor the seasonal quantifications specified in the report.

Table - 29. Water quality parameters of Nakki Pond
(Source : Rajasthan Pollution Prevention & Control Board report, 1986)

pH	6.9-7.5
Conductivity, μmhos	80-200
NO_3-N, mg/l	Tr.-4.4
NH_3-N, mg/l	Nil
PO_4-N, mg/l	Nil
Chloride, mg/l	10-40
Total Alkalinity, mg/l	26-58
Total Hardness, mg/l	32-45
Total Dissolved Salts, mg/l	52-128

Table- 30. Water quality parameters for Pushkar Lake (Rajasthan Pollution Prevention & Control Board report, 1986) (all values except those specified are in mg/l)

S. No.	Parameters	Conentration range
1.	pH	7.5-7.9
2.	Colour	None
3.	Oddour	Not Objectionable
4.	Total Hardness	80
5.	Total Alkalinity	60
6.	Chlorides	40-50
7.	Sulphates	3-4
8.	Nitrate	5-10
9.	Iron	Nil
10.	Copper	Nil
11.	Phenolic compounds	Nil
12.	Oil & Grease	Nil
13.	Cadmium	Nil
14.	Chromium	Nil
15.	Canide	Nil
16.	Ammoniacal nitogen	Nil
17.	Phosphates	Nil - 0.15
18.	Sodium	40-50
19.	Potassium	8
20.	COD	8-36
21.	Conductivity	430-480 mmhos

Table - 31. Water quality parameters for Ghana Lake (Source : Rajasthan Pollution Prevention & Control Board report, 1986)

1.	pH	7.0 -9.0
2.	Conductivity, µmhos	310 - 5200
3.	Temperature, ^{o}C	18 - 35
4.	DO, mg/l	7.0 - 9.0
5.	Total Alkalinity, mg/l	90 - 1000
6.	PO_4 P, mg/l	Tr. - 2.00
7.	NH_3-N, mg/l	3.5 - 230
8.	Organic Matter, mg/l	1.0 - 40.0

Table - 32. Water quality parameters of Gaibsagar
(Source : Rajasthan Pollution Prevention & Control Board report, 1986)

S.No.	Parameters	Concentration range
1.	pH	8.0-9.07
2.	COD	35-64 mg/l
3.	BOD_5	14-37 mg/l
4.	TDS	640-960 mg/l
5..	NH_3 - N	Tr.-10.0 mg/l
6.	PO_4 - P	Nil - 2.5 mg/l
7.	Cl	180-200 mg/l
8.	Na	134-156 mg/l

Khatri, (1992a) studied the diurnal variation of phytoplankton in Lakhotia lake, Pali and observed a definite diurnal trend of increase in day time and decrease in night hours at the surface in summer while in monsoon and winter seasons no such trend were observed. Thus, the phytoplankton showed a definite vertical movement in summer. In his earlier studies (1985) he had observed that the phytoplankton population shows three peaks one in each seasons (in June, October & February). The occurrence of three peaks of phytoplankton according to him shows that the lake is in an early stage of eutrophic condition as most of the present characters are of oligotrophic level. In other studies (1992b) he studied the zooplankton population of the lake and found that the lake is maintaining a fairly good population of zooplankton which like the phytoplankton, exhibited three peaks, one each in Summer (April), monsoon (September) and winter (February) seasons. The three peaks show quick turnover of the primary consumers in the lake and provides sufficient food for secondary consumers, the fish. Hence the lake is found to be ideal for pisiculture (Khatri,1992 b).

Jakher et. al. (1981) studied the diurnal variations in the physico-chemical parameters for Balsamand lake, Jodhpur. They observed that the pH showed a gradual increase at the surface during day hours and decrease at night. The same trend was also reported earlier by George (1961), Michael (1964) and Verma (1967) although Sumitra (1971) did not observe any such differences. According to Jakher et al.(1981) the higher pH in day time was probably due to higher rate of of photosynthetic activity of phytoplankton which resulted in removal of half bound CO_2 from bicarbonate leaving certain amounts of Carbonate and thus increasing alkalinities. A direct relationship between dissolved oxygen and temperature was observed as also reported earlier by other workers (Kato, 1941; Michael, 1964; Jana, 1974; Bohra, 1976, and Nasar,1977).

Mohan et al., (1989) studied the trace metals in four freshwater bodies of Jodhpur namely Kailana, Balsamand Fatehsagar and Gulabsagar (Table 33). Zn and Pb concentration was found to be highest in Gulabsagar in July and February respectively while Cu and Cd were highest in Gulabsagar during January and October respectively. The Zn and Cu for Kailana water was below WHO limits throughout the year while Cd was more in rainy season, however, the mean value was found to be under the limits. Pb was higher throughout the year. Balsamand had higher mean Cu, Pb and Cd contents than WHO limits while Zn was within the limits. The higher metallic contents according to them, may be due to the atmospheric inputs, increased evaporation resulting in the death and decay of flora and fauna in the lake during the drought months and the increased quarry activity in the catchment area.

Fatehsagar and Gulabsagar had higher means of Cu, Pb and Cd while the Zn contents were within the maximum permissible limits. The higher metallic content is probably because of the domestic waste. The study reveals that the water of the Balsamand, Fatehsagar and Gulabsagar is not suitable for drinking purpose while that of Kailana be treated before the civil supply (Mohan et al., 1989).

Table - 33. Max. and Mean values of trace metals (ppm) in water bodies of Jodhpur (after Mohan et al., 1989)

water body	Zn		Cu		Pb		Cd	
	Max.	Mean	Max.	Mean	Max.	Mean	Max.	Mean
Kailana	0.35	0.07	0.07	0.02	0.87	0.25	0.04	0.01
Balsamand	0.47	0.38	7.75	7.70	0.46	0.36	0.08	0.04
Gulabsagar	0.62	0.49	8.39	7.96	0.57	0.44	1.02	0.19
Fatehsagar	2.88	2.35	8.07	7.49	1.01	0.46	0.13	0.04

Parvateesam & Mathur (1992) observed a seasonal variation in the physico-chemical parameters of Anasagar, Ajmer. (Table 34). The increase in the temperature during the summer months resulted in high values of free carbon dioxide, chloride, organic matter, phosphate and alkalinity. In winter the low temperature favoured high dissolved oxygen, low nitrogen and conductivity. The monsoon precipitation along with the runoff was found to increase the nitrogen content of the lake water along with increase in total dissolved solids and conductivity. In another study Parvateesam and Mathur (1993) have observed that the variation in the various physico-chemical parameters have a direct effect on the heterotrophic bacterial population in the lake. Sharma and Sharma (1991a) have observed a presence of 100 algal species in the lake. In another study Sharma and Sharma (1991b) found recorded the presence of 123 algal species in the lake.

Table - 34. Seasonal variation in Physico-chemical Characteristics of Anasagar (after Parvateesam et al., 1992) (all values except the specified ones are in mg/l)

Parameters	Monsoon	Summer	Winter
pH	6.5-8.0	7.0-9.0	6.8-7.4
Temp, ^{o}C	25.0-34.0	22.0-38.0	20.0-25.0
Transmission (%)	73.0-92.0	40.0-91.0	65.0-83.0
Diss. Oxygen	2.3-9.2	1.5-8.6	4.55-11.6
Ammoniacal Nitro.	56.0-112.0	14.0-42.0	0.0-35.0
Chloride	32.66-112	136.32-854.8	139.13-151.46
Total Diss. Solids	2000-28000	2400-6200	2000-2800
Ele. Cond.,mhos	302.8-1715.7	252.0-807.4	123.0-147.18
Phosphate,	109.7-438.8	116.24-877.60	87.7-116.24
Free CO_2	0.0-10.2	2.2-13.2	2.2-6.6
Alkalinity	130.0-395.0	350.0-710.0	130.0-395.01
Nitrate Nitro.	0.75-5.9	0.03-1.45	0.05-3.01
Org. Matter	20.28-35.39	18.95-48.60	12.32-17.34

Parvateesam & Mishra (1993) conducted studies on the Algae of Pushkar Lake and recorded 88 algal species in the lake water including the pollution indicating forms. They also observed definite correlation between the various physico-chemical parameters and the abundance and distribution of various groups of algae. Because of the area of the lake and constant agitation of water, no significant variation in the lake water at the different ghats studied was observed, however, in contrast, the physico-chemical parameters as observed by them at three different ghats showed variation.

Parvateesam & Gupta, (1994), have studied the effect of industrial effluent on the physico-chemical characteristics of Hamir Lake, Kishengarh, near Ajmer. Their results show that the water of the lake is alkaline due to the presence of sodium salts and, organic and inorganic matter in the effluents. The concentration of various physico-chemical parameters indicate a highly polluted state of the lake water.

Sharma & Durve, (1990) studied the relationship between water clarity of 26 water bodies of Rajasthan including the small, medium and large reservoirs, temple tanks and rivers. Table 35 presents the average clarity of some of the water bodies as observed by them.

Table - 35. Average clarity and phytoplankton of selected waters of Rajasthan (after Sharma & Durve, 1990)

water body	Location	Average clarity (cm)	Phytoplankton (cells/ml)
Gulabsagar	Jodhpur	41.25	15,495
Nakki Lake	Mt. Abu	117.0	6,340
Baghela	Eklingji	109.5	4,745
Meja	Bhilwara	99.0	2,710
Namna	Madri	106.5	5,100
Oda	Sirohi	99.5	1,665
Jaisamand	Alwar	88.5	3,460
Mansarovar	S. Madhopur	80.0	2,125
Badi	Badi village	172.5	4,380
Pichola	Udaipur	73.5	4,985
Fatehsagar	Udaipur	99.0	3,350
Ramgarh	Jaipur	111.0	5,135
Sambhar	Phulera	38.0	5,005
Gambhiri	Chittore	142.0	1,140
Rajsamand	Kankroli	148.5	7,070
Jawai dam	Pali	102.5	1,885
Baretha	Bharatpur	141.0	4,165
Jaisamand	Udaipur	81.5	5,275

Based on the study, they have developed a trophic classification for the water of Rajasthan as given in Table 36. Thus, according to their classification, Meja dam, Bhilwara; Oda, Sirohi; Jaisamand, Alwar; Mansarovar, Sawai Madhopur and

Jaisamand, Udaipur are eutrophic. Gulabsagar, Jodhpur and and Sambhar lake, Sambhar with average clarity values of 41.25 cm and 38.0 cm respectively are already hypereutrophic. The study also confirms the eutrophic status of Pichola Lake and Fatehsagar, Udaipur.

Table - 36. Trophic classification for water bodies of Rajasthan based on the average clarity (after Sharma & Durve, 1990)

	Trophic Status	Average clarity (cm)
1.	Hyper-eutrophic waters	less than 50
2.	Eutrophic waters	50 - 100
3.	Moderately eutrophic waters	101 - 200
4.	Mild eutrophic waters	201 - 300
5.	Semi-oligotrophic waters	301 - 500
6.	Oligotrophic waters	more than 500

It needs to be pointed out here that eutrophication is a relative term and not absolute. Different workers have used different parameters to classify the trophic status of the water body. Often it is found that a water body can be classified as eutrophic on the basis of one parameter and it can be hypereutrophic or even oligotrophic based on other parameters. Although most of the workers in India follow some classification system or the other there is still no exact classification to follow in the case of a contradiction observed in trophic status following two different parameters or different classification systems. This aspects needs to be studied and a standard trophic status classification system for different regions of Rajasthan needs to be developed.

It should also be remembered that most of the trophic classification systems developed and which are being followed in India are for the temperate climate. Although the eutrophic water bodies are basically similar in temperate and tropical/subtropical regions there are differences between the eutrophication of these two limnological setting related primarily to the magnitude and timing (Ryding & Rast, 1989). As noted by Thornton (1987), "not all the symptoms of eutrophication normally observed in temperate zone lakes and reservoirs necessarily occur in tropical/subtropical systems. It is not that the eutrophication process is influenced by different factors in tropical systems, but rather that the eutrophication symptoms in these systems may not be indicative of the same water quality and/or trophic conditions as in temperate zone water bodies". Table 37 presents the boundary values for the various trophic state indicators for tropical regions. A comparison of temperate and tropical boundary values for several trophic indicators brings out the fact that boundary values for these indicators especially in case of phosphorus and nitrogen which are often considered as the limiting nutrients for eutrophication vary considerably. For example, as can be seen in Table 37, the 20-30 μgP/l phosphorus concentration often used as the mesotrophic-eutrophic boundary value in temperate zone lakes and reservoirs may be low when applied to tropical systems.

Table - 37. Mean boundary values between mesotrophic and eutrophic conditions (after Ryding and Rast, 1989)

Trophic Indicator		Temperate lakes	Tropical lakes
1.	mean primary productivity (gC/sq. m/ day)	1.0	2-3
2.	Chlorophyl a (μg/l)	10-15	10-15
3.	Total phosphorus (μg P/l)	30	50-60
4.	Total nitrogen (μg N/l)	50-100	20-100
5.	Nutrient limitation often by	phosphorus	nitrogen
6.	Dominant algal types	diatoms	blue green algae

It has already been mentioned that there are certain hydrological differences between lakes and reservoirs. Because of this differences reservoirs can exhibit physical, chemical and biological gradients not normally found in natural lakes. These gradients can differ in both time and space in given situations. Consequently, both need different sampling strategies (Ryding & Rast, 1989). Since most of the so called lakes of Rajasthan are actually manmade reservoirs it is advised that sampling strategies developed for reservoirs be used rather than the ones developed for lakes. This is especially important with respect to eutrophication modelling efforts, for calculating annual nutrient loads and for developing effective in-lake sampling programmes. These differences should be taken into account when engaging in these activities as pointed out and discussed by Ryding and Rast (1989).

8.0 Concluding observations

Going by the definition of a lake given by Zumberge and Ayers (1964) which still remains the most acceptable definition, there are almost no natural lakes in Rajasthan. The natural water bodies which are there like Nakki and Jalore are mostly ponds. Most of the water bodies of the State are manmade reservoirs either small, medium or big. It has been observed that the nomenclature used for these water bodies is mostly based on traditions and as such is technically erroneous. Some definition of lake and pond needs to be developed specifically for Rajasthan. A proper classification system needs to be developed to classify these water bodies into lakes, tanks, reservoirs and ponds. However, in the absence of complete morphometric data about all the water bodies along with the information about their origin, shoreline characteristics etc. it is difficult to classify them at present even with the existing definitions of lakes and ponds.

Although different lakes face different problems depending upon their environmental setting, the major problems generally observed in most of the lakes, if not all, are water pollution and eutrophication, sedimentation and high evaporation rates. Many of the water bodies of Jodhpur region have been reported to be destroyed forever due to dumping of excess domestic waste. Many of the water bodies are reported to be eutrophic and hypereutrophic.

Many studies have been reported on the lentic fresh water bodies of Rajasthan especially in those areas where the academic institutions are located. Udaipur lakes are by far the best studied lakes of all the water bodies. Most of the studies reported are understandably biased towards biological and limnological aspects. Even in these aspects many of them end up with relating the physico-chemical characteristics of the lakes with the fauna and flora of the lakes. Although temperature is expected to play a significant role in determining the biological processes there are hardly any attempts to study the overall energy exchange in lakes while studying its ecology. The role of various hydrological parameters in overall ecological behaviour has not been studied.

As far as the data are concerned, the morphometric data for a lake shows a lot of variation in different works. There is no uniformity in the units used. Quite a few errors in estimation of different values are also observed. Since the water quality parameters vary with the time and depth there is an obvious variation in the values reported by different authors. All these observation make it necessary that a guideline be prepared for the standardizing the estimation procedures, the units of various parameters to be used and the sampling strategies. It should also be remembered that there are certain hydrological differences between lakes and reservoirs because of which there are differences in their physical, biological and chemical behaviour also. So, the sampling strategies developed for lakes should not be used for reservoirs. However, since most of the so called lakes of Rajasthan are actually reservoirs, sampling procedures developed for reservoirs should be followed.

Although a considerable work has been done on water quality parameters research on other hydrological aspects is almost negligible. Most of the lakes are reported to be threatened by sedimentation and subsequent reduction in capacity but there are hardly any reports of sedimentation surveys or studies. Not a single complete water balance study is reported. Even the attempts of evaluating water balance components such as evaporation, runoff etc. are scarce. The saline lakes and the other closed water bodies like Pushkar Lake etc are expected to have interaction with the groundwaters of the surrounding catchment but there are no efforts to study them. Studies relating to thermal behaviour are also meagre.

Eutrophication studies have been conducted for many lakes. However it should be remembered that various workers use different parameters to decide the trophic status of lakes. Often it is found that a water body can be classified differently for its trophic status on the basis of two different parameters or different systems of trophic status classifications. Thus, there is a need to develop a standard system of trophic status classification for different regions of Rajasthan to avoid confusion. Moreover, it should be noted that the magnitude and timing of eutrophication in temperate and tropical/subtropical regions vary. As such, the classification systems developed for temperate regions should not be directly applied without making the required modifications.

Lastly, lakes are very valuable resources and more so in the water scarce arid region of Rajasthan. To properly manage a lake, to understand its ecological behaviour in totality either as a separate ecosystem or even as a subsystem of the greater ecosystem i.e. the biosphere, a complete knowledge about all the processes of lakes is needed. It is for this reason that the hydrological studies of lake carry significance. Since such studies are almost to find a beginning in Rajasthan it is suggested to make such a beginning without much delay. This is essential to save these water bodies from further deterioration and subsequently, to increase their life.

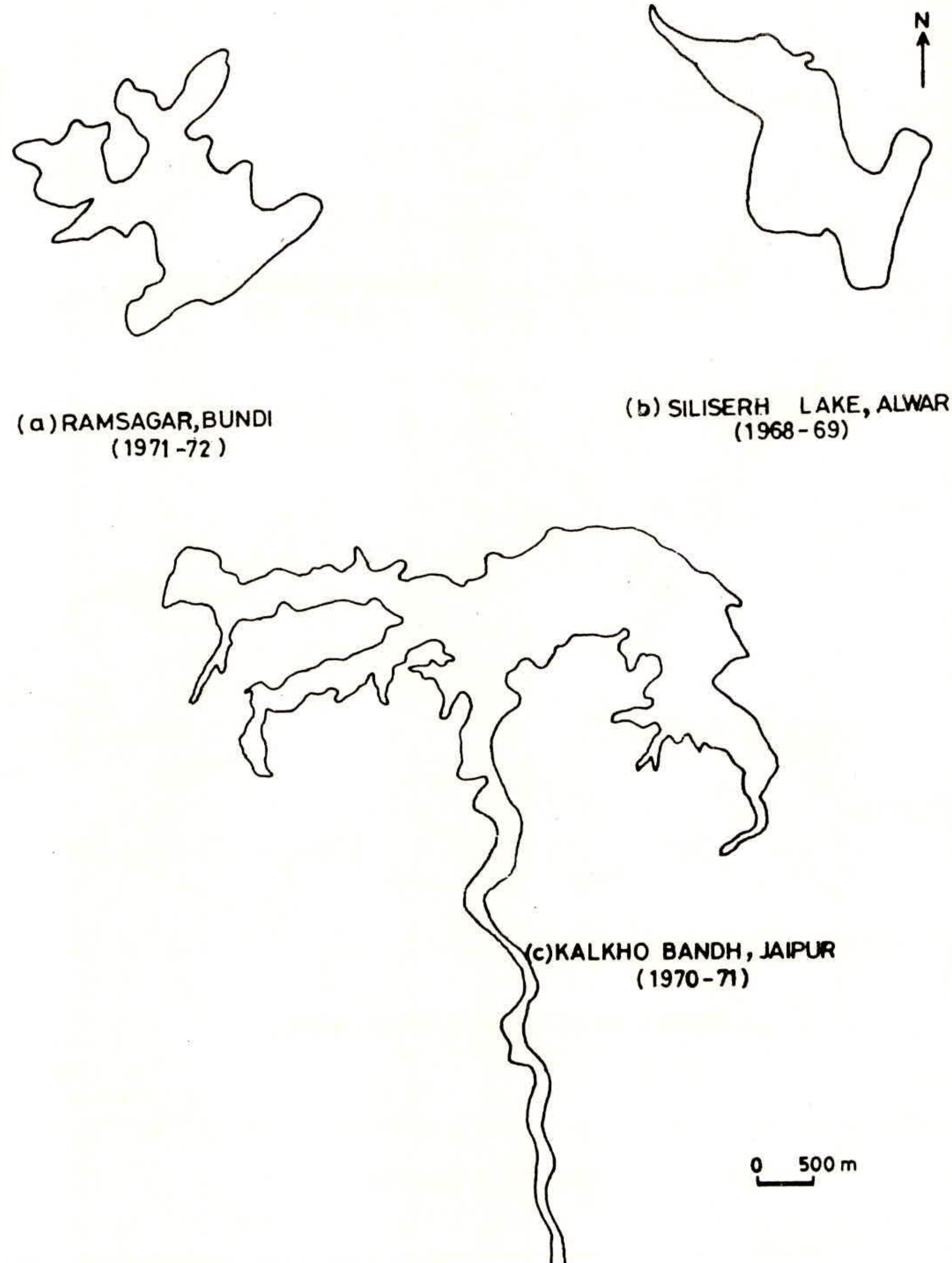


FIG. 17 BASIN MAPS OF SOME MAJOR MANMADE LAKES OF RAJASTHAN

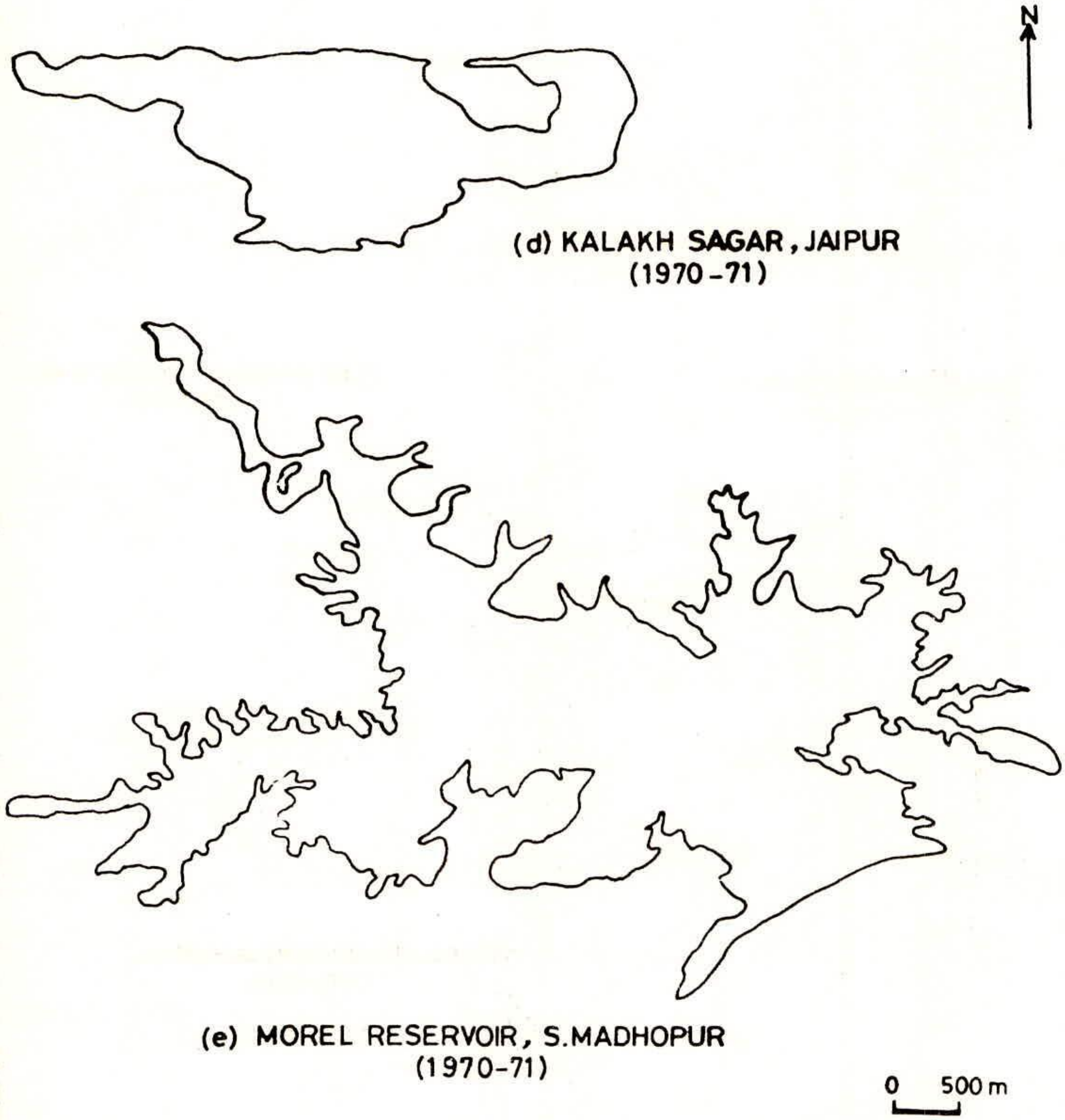

N
(d) KALAKH SAGAR, JAIPUR
(1970-71)
(e) MOREL RESERVOIR, S.MADHOPUR
(1970-71)
0 500 m

FIG. 17.... (CONTD.)

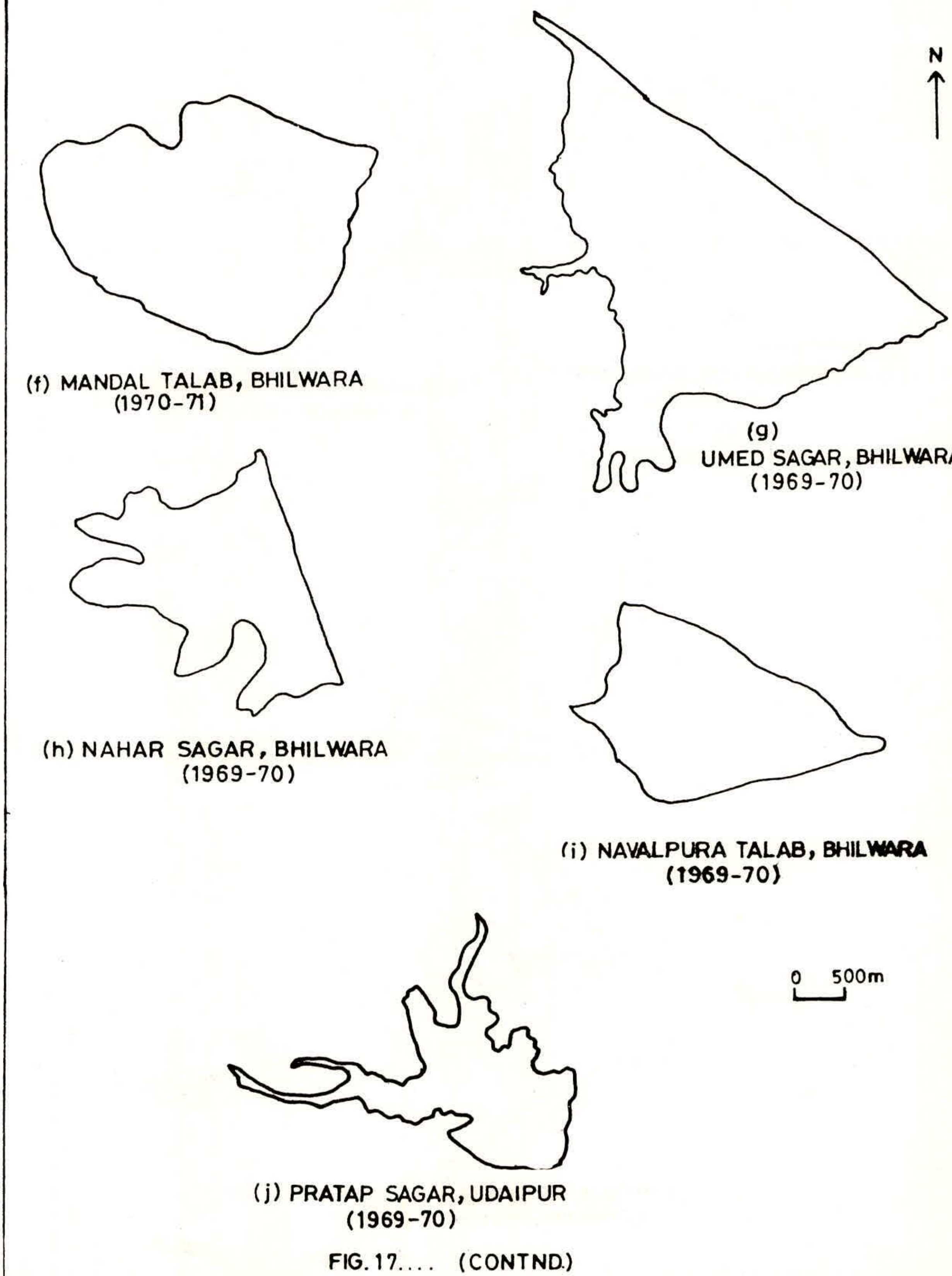


FIG. 17.... (CONTND.)

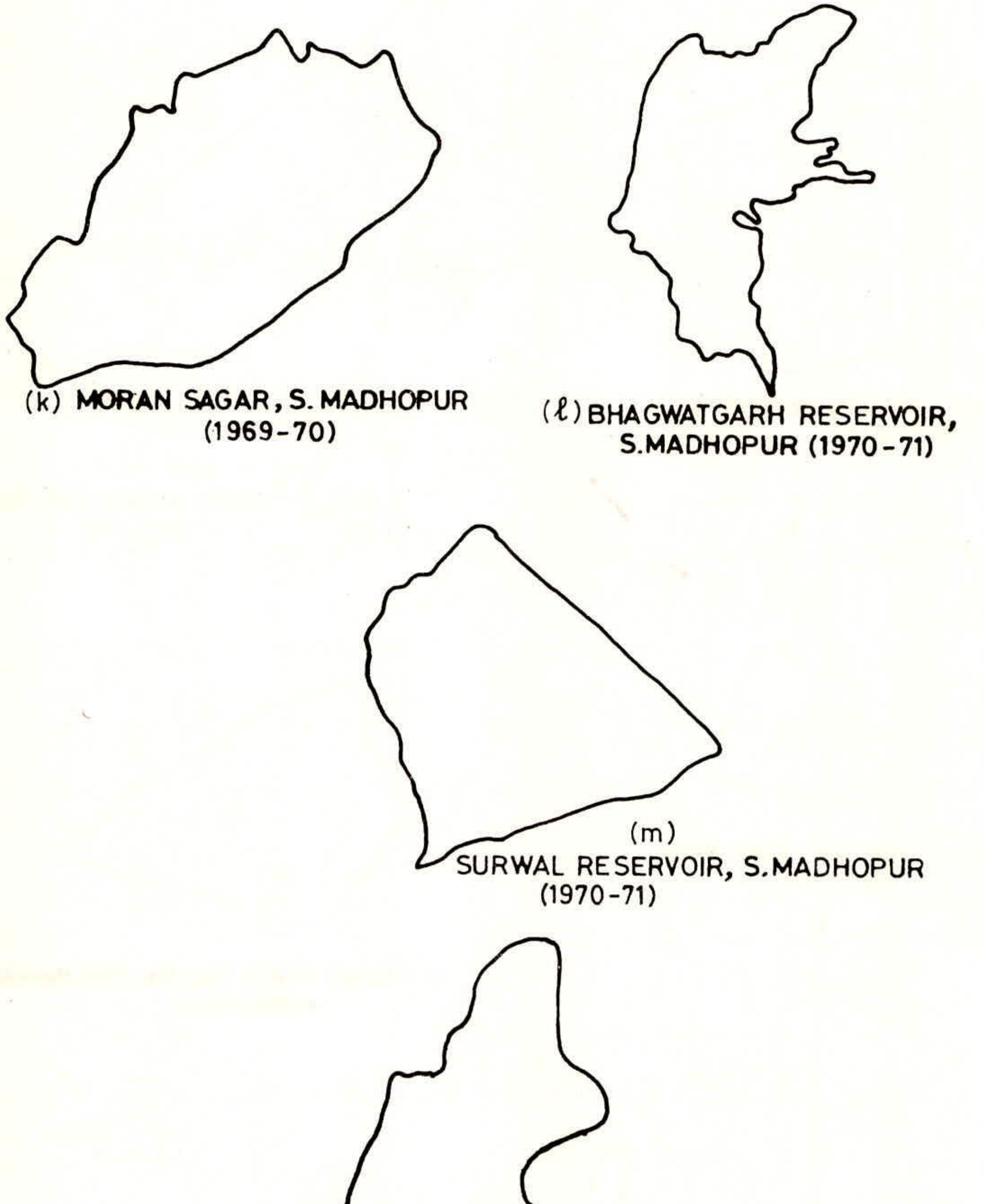


FIG.17... (CONTND)

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ANNEXURE - I

INVENTORY OF SOME FRESHWATER BODIES OF RAJASTHAN

Name of waterbody	Latitude (North)	Longitude (East)	Surface Area (Sq.km)	Gross Capacity (Mcuft)	River Basin
UDAIPUR DISTRICT					
Amar saagar	24°07'	73°38'	0.80[f]	--	--
Nagmala	24°13'	73°22"	0.55[f]	--	--
Jhadol	24°24'	73°29'	0.78[f]	145.00	--
Sangram sagar	25°31'	74°03'	0.25[h]	--	--
Bagolia	24°48'	73°57'	1.33[k]	835.00	Berach
Madar Talab	24°42'	73°37'	0.65[k]	--	--
Badi Tank	24°38'	73°36'	0.88[k]	410.00	Berach
Rang sagar	24°34'	73°40'	0.14	--	--
Pichola	24°34'	73°41'	3.20[k]	--	--
Rajsamand	25°04'	73°48'	6.73[i]	3786.00	Banas 1
Babar Talab	24°04'	73°58'	--	--	--
Pratap Sagar	24°12'	73°50'	3.32[f]	--	--
MataJi ka Khera	24°59'	74°06'	--	421.06	--
Sansera	24°57'	74°05'	--	172.00	--
Daya	24°20'	73°49'	--	438.00	--
Jaisamand	24°14'	74°02'	--	20000.00	Som
Somkagdar	24°02'	73°37'	--	1284.00	Som
Fatehsagar	24°35'	73°42'	2.30[k]	427.00	Berach
Swaroopsagar	24°33'	73°40'	--	483.00	Berach
Udaisagar	24°33'	73°47'	--	1100.00	Berach
Vallabh Nagar	24°30'	73°39'	--	1076.00	Berach
Jakham	24°10'	74°35'	--	5015.00	Jakhram
Sridam	24°23'	73°11'	--	1107.00	Sri
Hasan Bandh	24°12'	73°53'			
AJMER DISTRICT					
Lasaria	26°30'	75°13'	--	406.00	Dai
Narainsagar	25°56'	74°34'	1.55[h]	704.85	Khari
Ramsagar	26°16'	74°51'	0.40[h]	508.70	Dai
Madansarovar	26°09'	75°02'	1.73[h]	--	--
Bijaisagar	26°07'	75°02'	1.15[h]	--	--
Alagsagar	26°22'	75°06'	0.18[h]	--	--
Jasusagar	26°12'	74°58'	--	--	--
Gundola Talab	26°34'	74°53'	1.78[h]	--	--
Ana Sagar	26°28'	74°38'	1.85[h]	--	--
Pushkar Lake	26°29'	74°33'	0.08[h]	--	--
Foy Sagar	26°27'	74°34'	0.93[h]	--	--
Madhan Sagar	26°50'	74°40'	0.40[h]	--	--

Name of waterbody	Latitude (North)	Longitude (East)	Surface Area (Sq.km)	Gross Capacity (Mcft)	River Basin
JAIPUR DISTRICT					
Chapranara	26°31'	75°15'	5.02[j]	1236.30	Sabi
Chhitoli	27°32'	76°58'	--	861.00	Mashi
Kalakhsagar	26°59'	75°27'	3.80[j]	581.00	Mashi
Ramgarh	27°03'	76°04'	5.75[d]	2083.60	Banganga
Sainthalsagar	27°02	76°15'	--	454.32	Banganga
Garaulisagar	26°50'	76°38'	0.95[h]	--	--
Guman sagar	26°47'	76°38	0.28[h]	--	--
Morel Re'voir	26°27'	76°18'	12.58[j]	2707.80	Morel
Geolala Talab	26°52'	76°19'	2.8[j]	--	--
Hingoniasagar	26°47'	75°27'	1.08[j]	265.84	Morel
Gangasagar	26°42'	75°12'	1.85[h]	--	--
Nauliyam Talab	26°42'	75°12'	1.18[h]	--	--
Karnnelsagar	26°40'	75°12'	0.85[h]	--	--
Tordisagar	26°13'	75°24'	--	--	--
Kalkhobandh	26°55'	76°35'	6.03[j]	580.30	Banganga
SAWAI MADHOPUR					
Bhishansamand	26°49'	76°51'	--	408.00	Gambhir
Dheel	26°12'	76°08'	--	891.00	Dheel
Juggar	26°17'	77°05'	--	991.00	Gambhir
Kalisil	26°16'	76°49'	--	1472.00	Kalisil
Mansrover	25°56'	76°27'	--	461.30	Chambal
Moransagar	26°40'	76°33'	5.53[h]	456.50	Morel
Surwal	26°05'	76°20'	4.30[j]	508.10	BanasII
Bhagatgarh Reservoir	26°07'	76°16'	3.00[j]	--	--
Hoda hell Ka tal	26°42'	76°44'	0.40[h]	--	--
Gandalsagar	26°37'	76°41'	1.13[h]	--	--
Padam Talab	26°02'	76°28'	0.23[j]	--	--
Rajbagh Talab	26°02'	76°27'	0.3[j]	--	--
Jaisagar	26°23'	76°23'	1.38[j]	--	--
Ramsagar	26°19'	76°23'	1.45[j]	--	--
Bhumendrasagar	26°19'	76°48'	0.72[h]	--	--
Fatehsagar	26°42'	76°46'	1.20[h]	--	--
Galaisagar	26°02'	76°01'	0.38[j]	210.00	BanasII

Name of waterbody	Latitude (North)	Longitude (East)	Surface Area (Sq.km)	Gross Capacity (Mcft)	River Basin
TONK DISTRICT					
Chandsen	$26^{\circ}21'$	$75^{\circ}28'$	--	518.36	Sahodra
Galwa	$25^{\circ}54'$	$76^{\circ}01'$	--	1721.00	BanasII
Galmania	$25^{\circ}52'$	$76^{\circ}11'$	--	442.0	--
Mashi	$26^{\circ}25'$	$75^{\circ}46'$	--	1700.0	--
MotiSagar	$25^{\circ}56'$	$75^{\circ}42'$	6.1[j]	455.0	--
Tordisagar	$26^{\circ}12'$	$75^{\circ}24'$	--	1664.64	--
DaulatSagar	$26^{\circ}17'$	$75^{\circ}50'$	1.43[k]	--	--
DhibruSagar	--	--	1.15	--	--
GamelaSagar	--	--	0.70	--	--
SultanSagar	$26^{\circ}23'$	$75^{\circ}32'$	1.28[k]	--	--
VijaySagar	$26^{\circ}22'$	$75^{\circ}34'$	1.53[k]	--	--
HariPuraBandh	$26^{\circ}21'$	$75^{\circ}33'$	1.25[k]	--	--
BhairoSagar	$26^{\circ}21$	$75^{\circ}27'$	1.23[j]	--	--
Dwarkapura Reservoir	$26^{\circ}27'$	$75^{\circ}25'$	--	--	--
Dharam Ka Talab	$26^{\circ}22'$	$75^{\circ}12'$	0.25[h]	--	--
Ramji Ka Talab	$25^{\circ}58'$	$75^{\circ}18'$	0.73[k]	--	--
Pannar Sagar	$25^{\circ}47'$	$75^{\circ}26'$	1.53[k]	--	--
Ram Sagar	--	--	0.93[h]	--	--
JALORE DISTRICT					
Bandi Sendri	$25^{\circ}08'$	$72^{\circ}32'$	--	443.85	
Bandi Bankli	$25^{\circ}42'$	$72^{\circ}53'$	--	1200.00	Sukli
Chitalwana	$24^{\circ}56'$	$71^{\circ}39'$	--	432.13	Luni III
Jalore Lake	$25^{\circ}00'$	$71^{\circ}00'$	--	--	--
JODHPUR DISTRICT					
Jaswant Sagar	$26^{\circ}15'$	$73^{\circ}45'$	--	1865.29	Luni I
Surpura	$26^{\circ}27'$	$73^{\circ}05'$	--	764.47	Jajari
Kailana Takhat Sagar	$26^{\circ}18'$	$72^{\circ}58'$	0.43[b]	--	--

Name of waterbody	Latitude (North)	Longitude (East)	Surface Area (Sq.km)	Gross Capacity (Mcft)	River Basin
PALI DISTRICT					
Bagol	25°21'	73°38'	--	920.0	Luni I
Hemawas	25°44'	73°23'	--	2209.0	Bandi-hemnoi
Kharda	25°52	73°15	--	664.0	Guhiya
Raipur Luni	26°02'	74°01'	--	443.25	Guhiya
Sardar Samand	25°50'	73°29'	7.35[i]	3115.64	Guhiya
Chaupra Raj Sagar	26°03'	73°25'	0.98[j]	288.04	--
Kambh Sagar	24°52'	73°08'	0.25[d]	--	--
ChattarSagar	26°07'	74°02'	1.65[h]	--	--
Buntelar Talab	26°04'	74°02'	0.78[h]	--	--
Jawai Dam	25°06'	73°09'	--	7337.5	Jawai
SIROHI DISTRICT					
Ora Tank	25°03'	72°49'	4.13[a]	800.0	Khasi
Angore	24°48'	72°52'	--	475.0	Khasi
West Banar	24°05'	72°54'	--	1380.0	West Banas
Alwar Talab	24°36'	72°42'	--	--	--
Nakki Talab	24°36'	72°43'	0.25[a]	--	--
Kodra	24°34'	72°42'	--	--	--
Sarupsagar	24°53'	73°03'	0.85[d]	--	--
KOTA DISTRICT					
Gopalpura	25°10'	76°44'	--	1153.0	Parbati
Ummedsagar	25°12'	76°45'	1.50[f]	657.00	Parbati
Aklerasagar	25°07'	76°39'	--	--	--
Dhikwani Talab	25°07'	77°02'	--	--	--
Bilas Talab	25°05'	77°07'	--	--	--
Abhera Talab	25°12'	75°47'	0.35[c]	--	--
Kishoresagar	25°12'	75°51'	0.78[c]	--	--
Sursagar	25°09'	75°53'	0.9[c]	--	--
Kala Talab	25°12'	75°55'	--	--	--
Sawan Bhado	24°50'	76°07'	--	1059.42	Kalisindh
Vilas	25°03'	76°50'	--	949.43	Parwati
Alnia	25°58'	75°53'	--	1344.28	Alnia

Name of waterbody	Latitude (North)	Longitude (East)	Surface Area (Sq.km)	Gross Capacity (Mcft)	River Basin
BUNDI DISTRICT					
Bundi Ka Gothra	25°42'	75°57'	--	700.0	Mij
Dugari	25°40'	75°48'	--	679.0	Mij
Gudha Dam	25°29'	75°27'	--	3375.0	Mij
Vardha	25°15'	75°43'	--	1023.0	Mij
Phul Sagar	25°22'	75°37'	0.68[h]	--	--
Jet Sagar	--	--	0.5[h]	--	--
Ram Sagar	25°37'	75°30'	--	--	--
Toda Ka Gothra	25°40'	75°37'	--	--	--
Kanak Sagar	25°40'	75°50'	--	--	--
JHALAWAR DISTRICT					
Chhapi	24°21'	76°29'	--	2775.0	Parwan
BhimSagar	24°33'	76°21'	--	2703.0	Kalisindh
KadelaTalab	24°30'	76°24'	--	--	--
Khanchila Talab	24°30'	76°23'	--	--	--
BANSWARA DISTRICT					
Harela Talab	--	--	0.48[l]	--	--
Parrarja Talab	--	--	0.78[l]	--	--
Patlu Talab	--	--	1.23[l]	--	--
Mahi Bajaj Sagar	23°38'	74°33'	--	--	--
BHILWARA DISTRICT					
Arwar	25°48'	74°47'	--	1693.00	Khari
Meja	25°23'	74°33'	1.08[j]	490.00	Kothari
Khari	25°42'	74°17'	--	1376.00	Khari
Mandal	25°27'	74°34'	5.48[j]	490.00	Kothari
NaharSagar	25°44'	74°56'	3.00[h]	818.00	Khari
Sareri	25°42'	74°34'	--	1970.00	Khari
UmmedSagar	25°32'	74°54'	7.25[h]	628.00	Khari
JetPura	25°14'	75°12'	--	594.00	Banas -II
GandhiSagar	25°21'	74°39'	0.25[j]--	--	
KandolaTalab	25°18'	74°31'	0.58[j]	--	
Navalpura					--
Talab	25°24'	74°23'	3.05[h]	145.00	--
Ranjeet Sagar	25°16'	74°28'	1.88[h]	--	--
Merla Talab	25°42'	74°22'	0.78[h]	--	--
Gopal Sagar	25°35'	74°07'	0.55[h]	--	--

Name of waterbody	Latitude (North)	Longitude (East)	Surface Area (Sq.km)	Gross Capacity (Mcft)	River Basin
CHITTORGARH DISTRICT					
Badagaon	$24^{\circ}42'$	$74^{\circ}55'$	--	1112.0	Bearch
Bhupal Sagar	$24^{\circ}57'$	$74^{\circ}11'$	--	655.0	Bearch
Orai Dam	$25^{\circ}02'$	$74^{\circ}41'$	--	1246.0	Bearch
Wagon	$24^{\circ}28'$	$74^{\circ}27'$	--	1434.0	Bearch
Rashmi Talab	$25^{\circ}03'$	$74^{\circ}21'$	0.98[k]	--	--
Naya Talab	$25^{\circ}08'$	$74^{\circ}39'$	--	--	--
Harpala Talab	--	--	0.48[k]	--	--
DUNGARPUR DISTRICT					
Edward Samander	$23^{\circ}47'$	$73^{\circ}40'$	0.98[d]	--	--
Lodisar	$23^{\circ}40'$	$73^{\circ}55'$	--	422.0	Moran
Bamnia Talab	$23^{\circ}50'$	$73^{\circ}52'$	--	--	--
Bara Talab	$23^{\circ}52'$	$73^{\circ}52'$	--	--	--
Ran Sagar	$23^{\circ}52'$	$73^{\circ}53$	--	--	--
Luxman Sagar	$23^{\circ}46'$	$73^{\circ}55'$	0.53[d]	--	--
Sangela Talab	$23^{\circ}46'$	$74^{\circ}05'$	0.3[d]	--	--
Jimotar Talab	$23^{\circ}51'$	$74^{\circ}12'$	0.53[d]	--	--
Biplan Talab	$23^{\circ}37'$	$73^{\circ}44'$	0.44[d]	--	--
Gaibsagar	$23^{\circ}45'$	$73^{\circ}53'$	--	--	--
ALWAR DISTRICT					
Siliserh	$27^{\circ}03'$	$76^{\circ}31'$	2.26[e]	492.00	
Jaisamand	$27^{\circ}30'$	$76^{\circ}32'$	--	952.00	
Jaisagar	$27^{\circ}10'$	$76^{\circ}16'$		382.00	
Dewatramsagar	$27^{\circ}12'$	$76^{\circ}13'$	--	--	
Kaduli lake	$27^{\circ}37'$	$76^{\circ}36'$	0.90[f]		

a - Toposheet survey year 1959-60
b - Toposheet survey year 1960-61
c - Toposheet survey year 1964-65
d - Toposheet survey year 1967-68
e - Toposheet survey year 1967-69
f - Toposheet survey year 1968-69
g - Toposheet survey year 1968-72
h - Toposheet survey year 1969-70
i - Toposheet survey year 1969-72
j - Toposheet survey year 1970-71
k - Toposheet survey year 1971-72
l - Toposheet survey year 1965-66
-- - information not available

ANNEXURE - II

M. A., M. PHIL. M. SC. AND PH. D. THESES (UNPUBLISHED) ON SURFACE WATERS OF UDAIPUR

1. Babel, K., (1992), "Water Resources of Udaipur Basin", Ph.D. Thesis, Sukhadia University, Udaipur, (Dr. N.L. Gupta, Deptt. of Geology).
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5. Gautam, M., (1987), "Irrigation in Udaipur Basin", Ph.D. Thesis, Sukhadia University, Udaipur (Dr. N.L. Gupta, Deptt. of Geography).
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13. Paliwal, P.P., (1984), "An Ecological Study of Fateh Sagar Lake (Udaipur) With Special Reference to Macrophytic Vegetation", Ph.D. Thesis, Sukhadia University, Udaipur (Dr. L.N. Vyas, Deptt. of Botany).

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Note : Name of the Guide/ Major Advisor is indicated in paranthesis.

Courtsey: L.L.Sharma, Department of Limnology and Fisheries, C.T.A.E., Udaipur

ANNEXURE - III

RESEARCH PROJECTS ON SURFACE WATERS OF UDAIPUR

1. "Hydrobiological and Icthyological Studies on the Lake Fatehsagar, Rajasthan", (1973-78), Sponsored by ICAR, New Delhi, PI : Dr. V.S. Durve, Department of Fisheries Science, R.C.A. Udaipur
2. "Ecology and Conservation of Lakes In and Around Udaipur, Rajasthan", (1983-86), Sponsored by Department of Environment, New Delhi under MAB programme, PI : Dr. L.N. Vyas, Department of Botany; College of Science, Sukhadia University, Udaipur.
3. "Location and Siting of Industrial Activity : A Case Study of Udaipur City and Its Environs", (1985-90), Sponsored by Department of Environment, New Delhi, PI : Dr. R.M. Lodha, Department of Geography, CSSH, Sukhadia University, Udaipur.
4. "Biomonitoring and Hazard Evaluation of Water Pollution In and Around Udaipur", (1987-89), Sponsored by Department of Environment, Government of Rajasthan, Jaipur, PI : Dr. Madhu Sudan Sharma, Department of Zoology, College of Science, Sukhadia University, Udaipur.
5. "Sedimentation Studies of Fatehsagar and Pichhola Lakes, Udaipur", (1988-91), Sponsored by Department of Environment, New Delhi, PI : Dr. R.C. Purohit, Department of SWC Engineering CTAE, Udaipur.
6. "Impact of Urban Settlement on Certain Lentic and Lotic Water Bodies of Bedach River System in Girwa and Mavli Tehsils of Udaipur : A Limnological Study", (1987-91), Sponsored by Department of Science and Technology, Government of Rajasthan, Jaipur, PI : Dr. L.L. Sharma, Department of

Fisheries Science RCA, Udaipur.

7. "Pichhola Fatehsagar Lake Complex Wetland Conservation Awareness Programme", (1991), Sponsored by Department of Environment, Government of Rajasthan, Jaipur, PI : Head, Department of Fisheries Science, RCA, Udaipur.

PI : Project Investigator

Courtsey: L.L. Sharma, Department of Limnology and Fisheries, C.T.A.E., Udaipur

DIRECTOR	:	S. M. SETH
STUDY GROUP	:	S. D. KHOBRAGADE
ASSISTING STAFF	:	DIGAMBAR SINGH