ISOTOPIC INVESTIGATIONS OF GROUNDWATER COMPONENT IN THE LAKE PICHHOLA, UDAIPUR

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ABSTRACT

Within the past few decades, isotope tracers have provided new insight into the age, origin and pathways of water movement in the field of hydrological sciences. The advantage to opt for stable isotope investigations over the conventional technique are due to its requirement of small quantity of sample for its analysis (few ml), rapid measurements with very high precision (error $1\sigma < 1\%$), and qualitatively simple to interpret the data. For example, a good conceptual visualization for the subsurface flow system can be framed from the stable isotope data for one or two periods of sampling. A detailed and generalized analysis can even be used to probe and address the origin of water vapor, precipitation pattern and the surface-sub-surface hydrological system. Its versatility can therefore be used in addressing micro-scale localized as well as macro-scale generalized hydrological systems. As a case for the micro-scale local hydrological system, in the present paper, stable isotope of oxygen analysis for one time sampling has been used in investigating the sub-surface inflow and outflow components to the Lake Pichhola in the city of Udaipur of Rajsthan.

The lake Pichhola is the major attraction to the tourists of Udaipur and it serves as the major source of drinking water for the city. In the last decade water levels in the lake have gone down considerably due to various reasons. One of the possible causes for decrease in water levels is the subsurface outflow from the lake.

With an objective to investigate the subsurface component to the lake water, groundwater samples, were collected from different parts of the lake watershed in the pre-monsoon of the year 2005. The samples were analyzed for $\delta^{18}O$ (stable isotope of oxygen) and electrical conductivity to represent its average water quality. In the analysis, annual average isotopic composition of groundwater at recharge zone has been considered as the annual average isotopic composition of precipitation. The analysis was carried out over a recharge altitude range from 650 to 1000m above msl. From the analysis, depletion in $\delta^{18}O$ in the precipitation was estimated to be 0.36‰ per 100m rise in altitude which is well within the normal range observed globally i.e., 0.1‰ to 0.4‰ per 100m. From this relation, $\delta^{18}O$ of precipitation at the lake level was estimated as -3.3‰. $\delta^{18}O$ in groundwater exhibit pre-dominantly the altitude effect in the upper reaches of the lake while, in the lake surroundings and in the lower reaches, it is the evaporation enrichment effect which is more dominant. On the basis of the enriched isotope data, the sub-surface outflow from the lake was mapped. The high subsurface outflow appears to be one of the reasons for reduction in the lake level. A remedial measure to reduce the sub-surface outflows may be possible by identifying groundwater that taps the water with $\delta^{18}O$ depleted than -1 ‰ indicating the recharge source other than the lake. The water quality data corroborates the isotope data pattern of the groundwater.

INTRODUCTION

Rainfall is the basic supply source for all kinds of water resources. In the arid/semi-arid region, due to low rainfall conditions, most of the area remains unusable with the dry and desert like features and barren mountains and other wildernesses. Water is the most challenging natural resource to sustain life in such an environment. Presence of lake is the boon to sustain life and environment in such regions. In fact, many cities have been built up on the banks of lakes. These lakes also provide means of economy such as fisheries, transport, health resorting, tourism etc. These surface water bodies also play a significant role in shaping the hydrological, ecological and environmental balance of the region by developing flora and fauna and habitation of aquatic biota. Udaipur City in Rajasthan is one such city, built on the bank of the Lake Pichhola.

Udaipur popularly known as *city of lakes* was the princely state of Mewar of pre-independence India. Its history dates back to Ahar (also known as Girwa) civilization. There are number of lakes in and around Udaipur of these, the Lake Pichhola, is the biggest of all. The lake Pichhola was created by a Banjara chief in 14^{th} century. The present day Udaipur was established by Rana Udai Singh in 1560 A. D at the bank of the lake.

GEOLOGY

Geologically, the Udaipur city is situated in the valley surrounded by two high ridges of Iniamagara-Sajjangarh in the west and Dabari in the east and the Arrawali Super group. The basement rocks known as Mewar Gneiss Complex crop out between Neemach Mata and Bari Lake and around Titari and Udai Sagar areas. The surrounding rocks are carbonate dolomite with algal stomatolite phosphatic and non phosphatic type. These are exploited commercially by fertilizer industries in near by towns such as at Jhamarkotra, Maton etc.

CLIMATE

The area falls under semi-arid climatic regime. There are three distinct seasons, viz. winter (October to mid February) summer (mid February to June) and monsoon (mid june to September). Maximum temperature is around 43^0 C in May-June while minimum can be as low as 3^0 C. The normal annual rainfall is 635 mm. About 80% of the total rainfall occurs during the monsoon months of June-September. Distribution of annual rainfall is uneven and shows large temporal and spatial variations. Air is generally dry except for the monsoon period when the humidity is around 70%. Summer months are the driest of the year when the humidity goes to about 20-25%. Winds are generally light with some strengthening in the latter half of summer and the monsoon. Dust-storms and thunderstorms occur sometimes in the hot months of summer. No specific information on the soils of the catchments is available. Major crops in the catchment are maize and wheat and the forest is mixed deciduous tropical type.

LAKE ENVIRONMENT

The lake Pichhola is the major source of drinking water for the city of Udaipur. Till recently, of the total water supply to Udaipur city, about 85% used to be met from the Lake Pichhola alone. The lake is fed mainly by rain water. River Sisarama that forms the major inflow stream to the lake receives its discharge from two of its tributaries viz., Kotra Nadi and Amjok Nadi. The salient physical parameters of the lake are given in the Table 1.

Table 1. Salient features of Lake Pichhola, Udaipur

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

The lake ecosystem once used to support a wide variety of fauna is now unable to meet the water demand. The lake is suffering from regular drying. The comparison of water filled area as seen from the toposheet surveyed in 1964 with that with the remote sensing imagery of 2000 shows a significant shrinkage of the lake surface area. A long term decline in the lake level/shoreline indicates that the inflows are not balanced with the out flows. Over the past one decade, the lake water level is reducing continuously, alarming the growing scarcity of water resources in the region. In-fact the declining water availability in the lake has necessitated the arrangement of an alternate water supply from Lake Jaisamand, which is located at about 40 kms from Udaipur. In general, the condition of the lake is precarious and calls for an urgent remedial action. For this purpose, the present investigation on Lake Pichhola has been undertaken to scientifically investigate the reasons for the changes that are occurring in the regime system including groundwater inflows and outflows.

Anthropogenic Factors Affecting the Lake Water Level

Inflow components of a lake are usually through direct precipitation input on the lake surface area, run-off inflows and subsurface inflows while dissipation is mainly through evaporation, transpiration, surface abstraction and sub-surface outflows. Human intervention through various constructions and land-use changes in and around the lake area can affect both the inflow and out flow components. Frequently in the mountainous regions falling in the upper reaches of the lake, to full-fill the water needs, obstructions are constructed in the upper reaches to break the surface run-off. A large fraction of water gets lost through evaporation due to these structures stop. Similarly, in the lake outflows, in addition to the regulated lake water supply by the local society there can be large quantum of lake water abstraction through ground water pumpage. The continuous abstraction of ground water in the surrounding of the lake lowers the local water table. This in turn develops a hydraulic gradient and mobilizes lake water into the aquifers from the sites where lake is interconnected with the groundwater. The extension of the lake influenced groundwater recharge area can be large enough and can be a significant component in the total outflow from the lake. Therefore, lake planning should include mapping of the effective catchment's area in the upper reaches of the lake where any construction can change the inflow to the lake and demarcation of the zone on the surrounding area and the lower reaches of the lake within which groundwater is recharged through lake.

STABLE ISOTOPES IN HYDRODYNAMIC INVESTIGATIONS

Stable isotopes of water (oxygen-18 and deuterium) are considered to be ideal tracers in deciphering the groundwater movements (Mathieu and Bariac, 1996). At global scales these are used in tracing the hydrological cycle (Merlivat and Jouzel 1979). At local scale, the stable isotope ratio of water is useful in the identification of altitude of precipitation due to systematic depletion in its ratio with the rise in the altitude (Donfiantini, 1996), in identification of recharge sources (Carrillo-Rivera et al., 1992), in the investigation of evaporation losses from surface water bodies (Welhan and Fritz, 1977) and soil moisture (Allisson, 1982), in pollution movement (Aravena et al., 1996), in the lake water balance (Dincer, 1968) etc. In the present study, the stable oxygen ($\delta^{18}O$) of groundwater is used in deciphering the altitude of its recharge area and in mapping of the groundwater interlinked with the subsurface discharge from the lake.

SAMPLING AND ANALYSIS

The sampling sites were selected for the purpose to characterize the altitude effect in the study region and to map the area contributing inflows to the lake and the area receiving sub-surface discharge from the lake. The altitude effect was possible to identify in the present study due to rapid rise in the topographic altitude by nearly 400m from the lake to the watershed periphery which is less than 10km distance from the lake. To map the inflows to the lake, altitude effect was considered while for the outflows from the lake the evaporation effects were considered. For measurements, groundwater was considered to be suitable as it provides seasonal averaged information due to its slow movements. The samples were planned to collect in a short span so as to get a snap shot view of the isotopic characteristic of groundwater.

On all 14 groundwater samples from 12 sites were collected in a single day in the field work. The distribution of these sites in the study area is shown in the figure 1. All the samples were analyzed for oxygen-18 isotope ($\delta^{18}O$) on GV-Isoprime-Dual Inlet Isotope Ratio Mass Spectrometer at NIH, Roorkee. Results of ^{18}O are expressed in : $\delta^{18}O$ (‰) = (Rsample/Rstandard-1) x 1000 the standard being the Standard Mean Ocean Water (SMOW), which give a ratio of $^{18}O/^{16}O$ equal to $2.005x10^{-3}$. The EC of these samples were measured as a measure for the salinity in groundwater. The measurement errors were less than 1%. The EC of these samples were measured as a measure for the salinity in groundwater.

RESULTS AND DISCUSSION

The EC and $\delta^{18}O$ results of the samples along with their location details are given in the table- 2 and their distribution is shown in the figure 2.

Table 2. Isotope and water quality results for the groundwater in the study area

Sl No.	Site detail	Depth (ft)	$\delta^{18}O$ (‰)	EC (υS/cm)
1	Chandpole outer Jhara Ganesh Ji ki badi nr. Ata Chakki	150	1.24	2475
2	C/o sh. Ratanlalji Address--- do----	110	1.62	1792
3	C/o Himmat Singh Bhali, 5-A, Haridas ji ki Magri	200	-1.15	6250
4	Vill. Gorella, Nr. Bherunath Kirana Store	<200	-2.88	2600
5	Opp. Ratan ka house, Vill. Naya Gurha. Nr. Puliya(on the Rd.,at turning)	<200	-4.29	1071
6	Bujhra Vill., Opp., Mahtma Gandhi Library	300	-3.53	3110
7	Nr. Grm. Panchayat Off., In front of Govt. Madhyamic Sch., On the Rd. Sisarama Vil.	120	-3.51	3612
8	Nai Vil. , Nr Shri Narendra Mehta's house	120	-3.94	2660
9	Sitarama Nursery Militry Campus base, Khas Odi Gate	120	-3.50	
10	Gokul Chandarmaji Mndr. Ke pas, City Palace Rd.	200	0.99	1795
11	C/o Bhagwan Chabraji, 4-A JawaharNgr.	120	-0.09	1692
12	Chatrbhuj Hanumanji ka Mandr, Haridas ki Magri	75	-1.83	1440
13	C/o Ramesh Chand pargi, Vill. Pipliya	220	-4.84	390
14	In the field of Ramesh Chand Pargi, Piplya	130	-4.25	389

On the basis of $\delta^{18}O$ data and their distribution the groundwater can be segregated in four groups as

(a) Groundwater at high altitude region represented by $\delta^{18}O < -4.0$

(b) Groundwater in the foot-hill region represented by $\delta^{18}O$ in the range -3 to -4

(c) Groundwater in the region close to lake in the north-northwest side represented by $\delta^{18}O$ in the range -1 to -2 and

(d) Groundwater distributed in the north-east and east side of the lake with its $\delta^{18}O$ >-1.

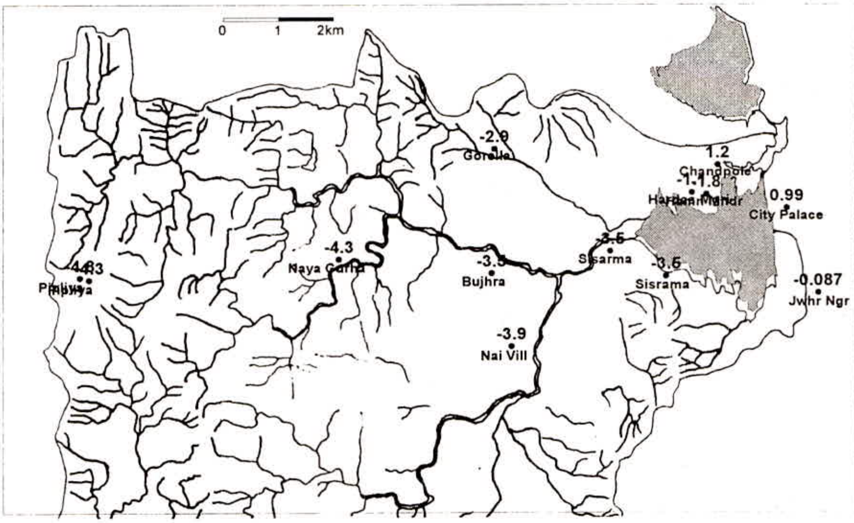


Fig 2. Sampling locations and the observed $\delta^{18}O$ in groundwater at these sites

ALTITUDE EFFECT AND SUB-SURFACE INFLOW TO THE LAKE PICHHOLA

To determine altitude effect, $\delta^{18}O$ in groundwater at Piplia, Naya Gurha and Bujhara were considered. Of these three, Piplia and Naya Gurha are located near the mountain peaks of altitude 900m and 1000m above msl and the average altitude of landscape from Bujhara to the nearest hill peak is about 650m above msl. Considering these as approximate recharge altitudes for groundwater at these sites, the altitude effect is determined by plotting these altitudes against the isotope index of the groundwater at these sites (fig 3). With the limited experimental data, the plot between $\delta^{18}O$ and altitude is a straight line with the mean gradient is 0.36‰ depletion in $\delta^{18}O$ per 100m rise in the altitude. Extrapolating back this line to the altitude of Pichhola Lake which is at 600m indicates isotope value -3.3‰ for the precipitation on the lake. The observation of altitude effect in the groundwater indicates that groundwater recharged at these sites is moving through separate aquifers with no or minimum intermixing between them at least up to Bujhara. However, in the south of Bujhara to up to the lake it appears that the groundwater is moving in the same aquifer as $\delta^{18}O$ in groundwater at Bujhara and at Sisarma exhibited the same ratio -3.5‰. In terms of direction of groundwater flow from west (Piplia) to East (Lake Pichhola) these results are shown graphically in the figure 4.

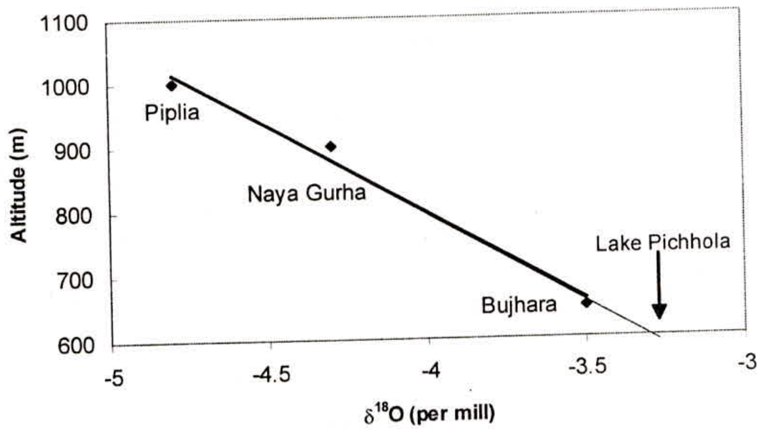


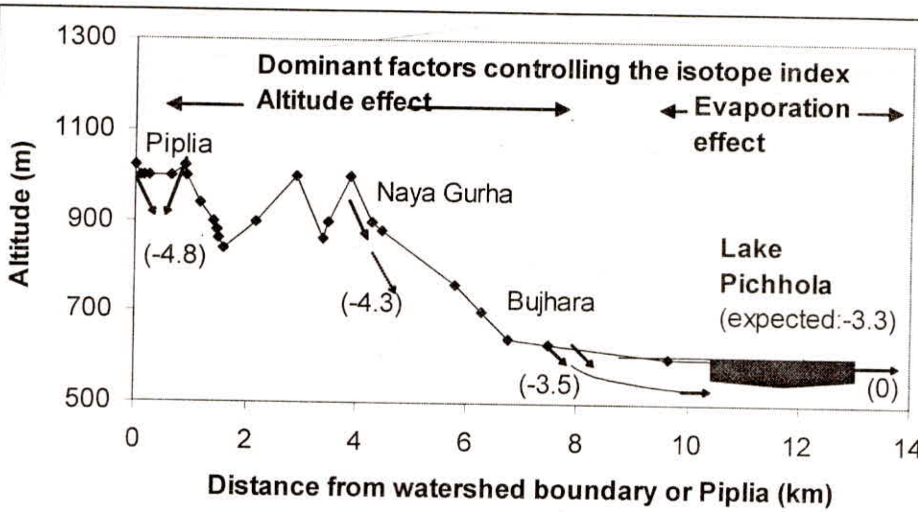
Fig 3: Altitude effect in the groundwater. The mean gradient is 0.36‰ depletion in $\delta^{18}O$ per 100m rise in the altitude. The estimated precipitation index at the Lake Pichhola is -3.3‰

The result indicates a sub-surface in-flow to the lake recharged mainly in the area between Bujhra to the Lake. Any structures at locations above the altitude of Bujhra will not have much effect in the inflow component to the lake but within this reach can shrink the inflows. Since the sub-surface inflow to the lake is taking place from a limited region from foot-hill to lake spanning a few kilometer length and width only a small base flow is expected through this region. Moreover, groundwater pumpage within this stretch further expected to reduces this base flow.

SUB-SURFACE DISCHARGE FROM THE LAKE

The analyses of groundwater sampled at City Palace located in the down stream of the lake and at Chand Pole which is located close to the interlinking drain exhibited values 0.99‰ and 1.2 ‰ respectively. These values are much enriched compared to -3.3‰ as seen in the groundwater in the south western region. Such high enrichment in the groundwater is possible, if it is subjected to high evaporation during the recharge process such as that from stagnated surface water body which in the present case is the lake and the interlinking drain. The isotope data therefore indicate lake water groundwater interconnection in the northern and eastern part of the lake which is getting tapped for the drinking needs of the city.

Considering the sub-surface outflow index of the lake as 0.99‰, the lake water contribution at the site indicated by the value -0.087 at Jawahar Nagar can be computed as;



(Data in the parenthesis indicate $\delta^{18}O$ values)

Fig 4 : Direction of groundwater flow between Piplia and Lake Pichhola

$0.99xV_L + (-3.5) \times (1-V_L) = -0.087$

where, V_L is the volume of the lake water fraction in the groundwater and $(1-V_L)$ is the fraction of the sub-surface water volume arising from recharge region other than the lake represented by the isotope index of -3.5.

Solving it for V_L it can be seen that at Jawahar Nagar about 75% of the groundwater component is recharged through the lake bed.

It is clear from the above calculation that the lake is losing its water due to its interconnection with the groundwater that is being tapped for the drinking needs of the city. This recharge may be induced type due to continuous abstraction for the city water supply.

The $\delta^{18}O$ (=+1.2) for groundwater sampled near link-drain is observed to be more enriched compared to the groundwater sampled near the lake Pichhola (~-1.1 to -1.8). This indicates a more static water condition in the north portion of the lake compared to the southern side of the lake. This as a corollary suggests higher groundwater pressure in the southern side of the lake compared to that in the north region.

WATER QUALITY

In the present study EC of the groundwater is taken as a measure of overall salinity. Above the salinity of the direct precipitation water, further increase in salinity in groundwater take place due to evaporation at the time of infiltration and due to interaction with soil matrix. On the contrary, isotope index in groundwater depends upon the isotopic index of recharging water and changes that is incorporated due to evaporation at the time of infiltration. Therefore, a cross plot between the isotope ratios in groundwater against the EC is expected to provide an index for increase in salinity due to interaction with soil matrix. This is shown for the present data in the figure 5.

The graph indicates two distinct lines, in one of these, the EC increases slowly with the associated evaporation (increase in $\delta^{18}O$) and may also be due to slow rate of weathering while, the other line having high slope probably indicates salinity increase mainly due to

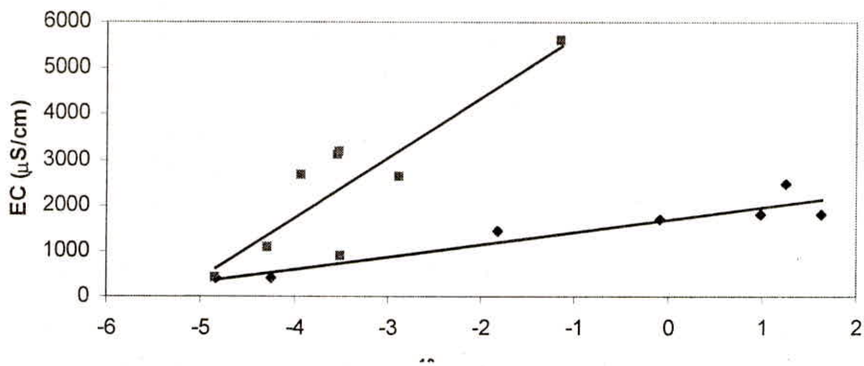


Fig 5: EC increase in groundwater with the enrichment in $\delta^{18}O$

increase in the dissolved salt content from the weathered matrix. The 1st line with the low slope are the samples that were collected from the high altitude region (>800m) and from the sites which as per the discussion in the previous section were concluded to receive the lake water as a base flow. The terrain in the high altitude region contains hard to weather material and therefore expected to also incorporate a low salinity in the infiltrating water. The lake receives major input from the precipitation (in addition to the groundwater as a base inflow to it) and therefore the lake and its seepage water that appears in the groundwater in the north and eastern parts of the lake is expected to be of low salinity. The other line with high slope indicates increase in salinity originating from interaction with the more abundant weathered material such as that from Bujhara, Nai, and Sisrama etc. The graph also indicate that the lake water is highly diluted in salinity compared to the groundwater component it is receiving; indicating that the groundwater inflow to the lake forms a very small component compared to the fresh water inflow to the lake from the direct precipitation.

CONCLUSION

The present study, indicate 0.36‰ depletion in the $\delta^{18}O$ of the recharge water per 100m increase in the altitude. The annual average $\delta^{18}O$ in the precipitation at Lake Pichhola is estimated to be ~-3.3‰. Groundwater recharged in the catchment's area from foothill to the lake contributes as a base flow component to the lake. Of the total input to the lake storage, precipitation is the dominant component and the base flow is minor contribution to it. The lake water is largely drawn out from surface and sub-surface abstraction. The sub-surface abstraction is due to groundwater-lake water inter action and that is being tapped by the surrounding localities for their regular needs. The southern portion of the lake appears to be more dynamic with respect to the groundwater exchange compared to that in the north. The surface water storage structure developed at high altitudes at Piplia and Naya Gurha have insignificant effect to the direct run-off or base flow to the lake but similar structures in the area between Bujrah to lake can cause increase surface evaporation and decrease surface run-off reaching to the lake.

One of the factors causing dryness of the lake is the groundwater draft linked with the recharge by the lake. This component can be reduced by mapping areas where groundwater is not directly recharged by the lake. Such areas if tapped for the local water supply can help in reducing the sub-surface losses. Similarly, from the monthly change in the isotopic ratios of the lake water and from the humidity data, the evaporation losses can be computed using the standard Rayleigh distillation equation. Work on this direction is presently in progress.

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