Environmental Isotope Studies on Groundwater Problems in The Thar Desert, India

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SUMMARY. Environmental isotope studies carried out in the arid regions of Rajasthan show that recharge to shallow groundwater is possible as a result of direct infiltration of precipitation or through river channels during episodic floods. This is observed in Barmer and Jalore Districts in the southern part, where comparatively higher rainfall occurs. Present day recharge is absent or negligible in the northwestern region. Deep fresh groundwater is available in many parts in the region, which are mostly palaeowaters. Over exploitation of these old waters in some areas is indicated by mixing with shallow groundwaters. The expected head water connection of an old buried river cannel, in the northwestern part of Jaisalmer, with higher Himalayan sources seems remote. The groundwater along this course is old and flowing as indicated by the tritium and carbon-14 values.

1. INTRODUCTION

The Thar desert extends from the western side of the Aravalli Mountain ranges in India up to the limit of Indus Valley in Pakistan.It covers sixty percent of the area of Rajasthan state (Fig.1), in the northwestern part of the country. Having about 38% of the state's population, this is one of the most populated desert regions of the world. With constant increase in human as well as livestock population, the common problems faced by desert regions like scarcity of water, land degradation, deteriorating pasture lands etc. have become acute in this region.

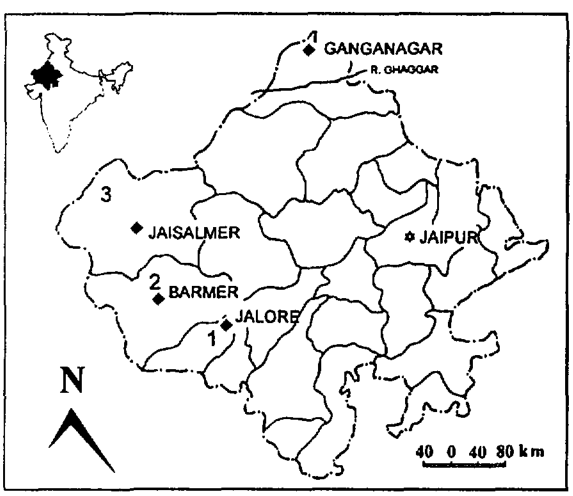

Figure 1: Map of Rajasthan showing study areas.

The land is characterised by sand dunes with interdunal plains in the north, west and south and alluvium in the central and eastern parts. Streams are very few, ephemeral in nature and confined mostly to the rocky part of the desert, the prominent being the Luni river in the south-west region. Precipitation being low (below 150 mm) and erratic in most of the parts, the main source of water in the area is groundwater. Efforts are being made by the State Ground Water Department to study known groundwater resources and explore potential ones in the region.

Isotope techniques have been successfully used by many investigators to solve problems in arid regions, many a times with advantage over conventional techniques (1). A few studies carried out by the authors, in which environmental isotopes ^{2}H, ^{18}O, ^{3}H, ^{13}C, and ^{14}C were used along with available chemical and hydrogeological data to obtain valuable information on groundwater condition, are given below.

2. RECHARGE STUDIES, BARMER

Barmer District lies in the south-western part of the state. Figure 2 shows the study area and sample locations together with some geological information. The area receives a mean annual

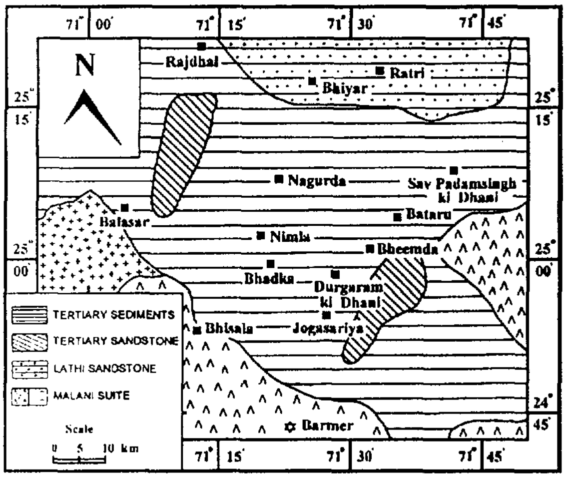

Figure 2: Study area, Barmer.

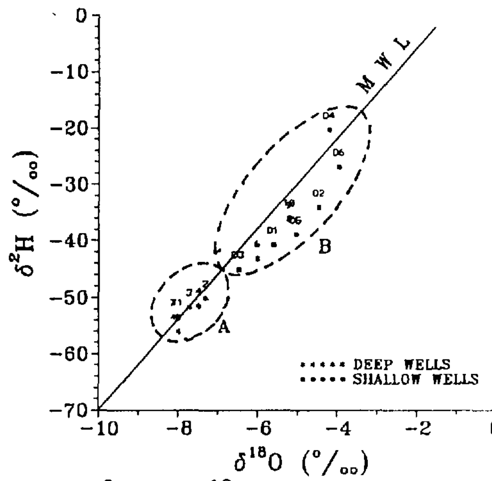

Figure 3: δ^2H Vs. δ^{18}O, Barmer samples.

rainfall of ~280 mm. The Tertiary aquifer having fresh water is the most important one in the area. Lathi formation of Jurassic age is present in the northern side and Malani suite of igneous rocks are present on other sides. Two lenticular outcrops of Tertiary sandstone, which are generally dry, are also found in the central part. In the middle portion comprising Nagurda, Bheemda and Nimla, shallow aquifers are under phreatic condition while the deeper aquifers are under confined or semi-confined condition. Table 1 lists the samples collected from the study area together with the analyses data. Shallow well samples are generally brackish and of Na-Cl type. The deep well samples which are brackish are also of Na-Cl type. The deep fresh groundwaters are of Na-HCO_3 type.

Figure 3 shows the δ^2H versus δ^{18}O plot for the samples. Fresh deep groundwater samples are comparatively depleted in stable isotope values and form the group A along the MWL. A brackish water sample from Bhadka also falls in this group. Except the sample from Rajdhal, which is from the northern dunal part, other samples are from the central portion of the study area. The shallow and deep well samples from Durgaram ki Dhani as well as other shallow well samples which are brackish form the group B. Samples from the Lathi sandstone aquifer also are included in this group. These samples show evaporation effect in their stable isotope content. They contain measurable concentrations of tritium indicating some component of recent recharge. The higher electrical conductivity

Table 1: Isotope and other relevant data of groundwater samples from Barmer study area.

Sample #	Place	Depth (m)	EC (μS/cm)	δ^2H (‰)	δ^{18}O (‰)	^{3}H (TU)	^{14}C (pMC)	^{14}C age (BP)
Deep Wells								
2	Bheemada	280	1830	-50.1	-7.30	<0.5	22	9700
3	Jogasariya	285	2450	-51.7	-7.70	1.4	25	7800
4	Bhadka	200	4500	-51.5	-7.47	0.7	-	-
5	Nimla	220	1560	-56.1	-7.98	1.0	50	4300
6	Durgaram ki Dhani	100	3850	-43.2	-6.00	0.9	-	-
7	Rajdhal	125	1380	-53.4	-8.10	1.7	-	-
9	Bhiyar	100	3000	-36.3	-5.20	4.5	-	-
10	Ratri	100	1820	-35.9	-5.19	-	-	-
11	Nagurda	95	1710	-53.4	-8.00	-	-	-
Shallow Wells								
D1	Bheemda	-	6700	-40.8	-5.60	6.0	-	-
D2	Bataru	-	5600	-34.1	-4.45	3.0	-	-
D3	Durgaram ki Dhani	-	4450	-45.1	-6.48	3.0	-	-
D4	Balasar	-	630	-20.3	-4.19	21.0	-	-
D5	Sav P.Singh ki Dhani	70	3200	-38.9	-5.03	2.9	-	-
D6	Bhisala	40	4400	-26.9	-3.95	-	-	-

shown by the shallow well samples could be due to leaching of salts from the soil matrix or due to concentration of salts by evaporation. The shallow and deep well samples from Durgaram ki Dhani are seen as mixtures of deep and shallow groundwaters. Their tritium values also support this. A shallow sample from Balasar, which is fresh, has tritium content of 21 TU, which is high compared to present day precipitation value of about 10 TU. This well probably taps water from the weathered igneous rocks and is about two to three decades old.

The deep fresh waters are depleted in stable isotope values and have negligible tritium. Their ^{14}C concentration ranges from 50 to 22 pMC with model ages (2) 4300 to 9700 BP. These groundwaters appear to have recharged during cooler and pluvial phases in the Holocene (3). If recharge zone for these groundwaters is assumed to be the Malani formations, a groundwater velocity of 6 to 10 m/a may be estimated.

3. RECHARGE STUDIES, JALORE

Jalore District is situated adjacent to Barmer in the south-west part of Rajasthan. An environmental isotope investigation (4) was undertaken to study the groundwater recharge mechanism in the study area (Fig. 4). The region receives a mean annual rainfall of ~380 mm and is drained by Sukri river, a tributary of the Luni river system, which is ephemeral in nature. The younger alluvium, which is present mostly along the river course, is unconsolidated to semi-consolidated, coarse to fine sand and gravel. Older alluvium of sub-recent to the Pleistocene age, formed by semi-consolidated to consolidated, medium to coarse sand with clay lenses, caliche and rock fragments, is observed away from the river course. Sand and shale fragments are encountered at deeper horizons. Study of subsurface geology (5) indicates the presence of a fault in the NE-SW direction, along which the Sukri river also is flowing. A number of samples from shallow (<2m) and deep wells were collected for environmental isotope analyses. The results are given in Table 2. From chemical analysis, it is observed that shallow and deep groundwaters from near the river course are generally fresh and of Na-HCO_3 type. Shallow and deep groundwaters away from the river course are brackish and of Na-Cl type. Figure 5 shows the δ^2H versus $\delta^{18}O$ plot for the samples. It is observed that most of the samples are depleted in stable isotope values compared to the rainwater samples collected from the area.

From their isotopic composition, the samples may be grouped into three sets. Shallow groundwaters along the river course are isotopically enriched and fall in group C. They show typical evaporation trend and have high tritium contents (5 to 20 TU). Shallow groundwaters which are away from the river course and located in the western and south-western part of the study area have comparatively depleted stable isotope values and form the group B. These samples have tritium concentrations ranging from 1.4 to 4.8 TU. Group A contains shallow well samples which are the most depleted in stable isotope values. It

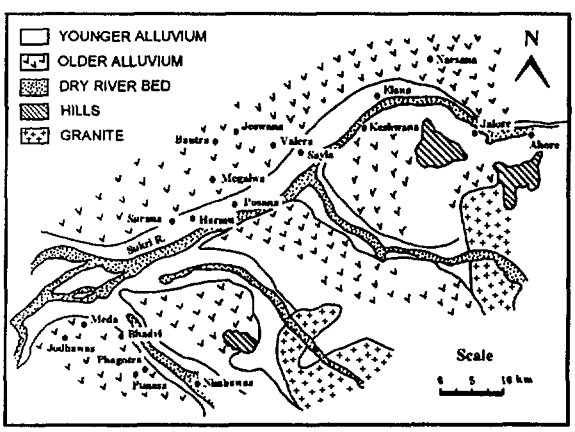

Figure 4: Locations of samples, Jalore.

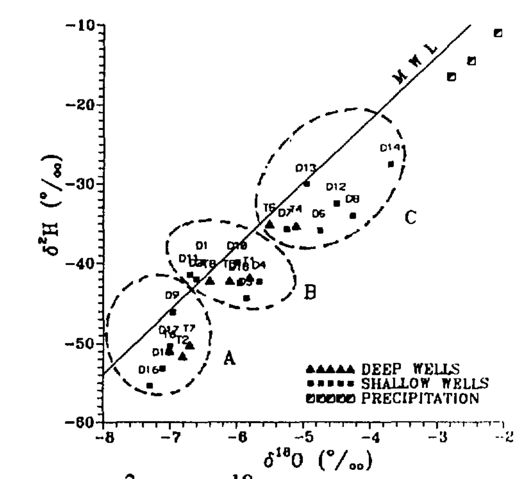

Figure 5: δ^2H Vs. $\delta^{18}O$, Jalore samples.

Table 2: Isotope and other relevant data os samples from Jalore study area.

Sample #	Place	Depth (m)	EC (μS/cm)	δ^2H (‰)	$\delta^{18}O$ (‰)	^3H (TU)	^{14}C (pMC)	Chloride (mg/L)
Deep Wells								
T1	Bautra	290	1215	-41.8	-5.80	0.8	-	168
T2	Megalwa	205	3800	-51.6	-6.80	0.6	-	801
T3	Punasa	300	1500	-42.2	-6.10	2.4	-	256
T4	Jodhawas	305	5350	-35.3	-5.10	0.5	12	1360
T5	Meda	280	5400	-35.1	-5.50	1.6	-	1333
T6	Posana	182	3800	-50.9	-7.00	0.9	-	781
T7	Phagotra	150	-	-50.2	-6.70	-	-	-
T8	Sayla	174	1320	-42.2	-6.40	3.0	71	229
Shallow Wells								
D1	Boutra	50	1230	-39.8	-6.50	1.9	-	162
D2	Megalwa	12	3950	-42.0	-6.60	3.0	-	946
D3	Punasa	46	1350	-44.4	-5.85	4.0	-	162
D4	Phagotra	40	3550	-42.3	-5.65	1.4	-	728
D5	Narsana	-	3400	-35.9	-4.75	5.2	-	751
D6	Jalore	21	1080	-12.5	-	12.0	-	121
D7	Elana	15	5300	-35.7	-5.25	6.4	-	1475
D8	Jeevana	-	4400	-34.0	-4.25	2.4	-	1028
D9	Harmu	12	2910	-46.1	-6.95	1.4	-	362
D10	Surana	-	1230	-39.9	-5.98	17.5	-	149
D11	Bhadri	-	4000	-41.4	-6.70	4.8	-	879
D12	Nimbawas	41	960	-32.5	-4.50	12.1	-	106
D13	Keshwana	14	3000	-30.1	-4.95	11.2	-	624
D14	Bhadrajun	12	1230	-27.5	-3.70	19.5	-	149
D15	Valera	43	-	-53.2	-7.10	-	-	-
D16	Sayla	15	-	-55.4	-7.30	-	-	-
D17	Pasana	-	-	-50.4	-7.00	-	-	-
D18	Ahore	27	1380	-42.5	-5.95	2.0	-	199

is observed that samples with depleted ^{18}O values have low tritium contents and vice versa. It is also seen that old waters with low tritium values have high chloride contents (800 to 1000 ppm), whereas recent waters with high tritium values have low chloride content. This indicates that the groundwaters near the river course are fresh waters with enriched stable isotopic composition and high tritium values showing presence of modem recharge. The groundwaters away from the river course are brackish, have depleted stable isotope and low tritium contents and thus seem to represent older waters.

From δ^2H-$\delta^{18}O$ plot, the deep wells samples also seem to fall into the three groups seen above. The most depleted samples are from intermediate depths (T2, T6 & T7), are brackish and have negligible tritium content, indicating absence of any recent recharge. The second group (T1, T3 & T8) are slightly enriched compared to the first group, are fresh and from near the river course and show measurable tritium contents. These wells appear to receive some recharge from the shallow groundwaters. Well T8 taps both intermediate as well as shallow aquifer and this is well reflected in the stable isotope, tritium and carbon 14 values. The Stable isotope contents of shallow wells D1&D3 as well as deep wells T1&T3 are similar indicating interconnection between them. This is also supported by the fact that the shallow groundwater table and the deep well piezometric levels are similar. Wells T4 &T5, which are from the south west comer of the study area, are characterised by the most enriched stable isotope values, fall in group C. They are brackish and have no measurable tritium content. Well T4, from Jodawas, is artesian flowing type with ^{14}C content of 12 pMC.

It is concluded from the study that the shallow aquifer receives recharge through river channels during episodic floods caused by intense rain events (amount effect ?). Some parts of the shallow aquifer also receive recharge from the deeper confined aquifer by upwelling through subsurface fault zones in the area. The deep aquifers are thought to be recharged during the cool pluvial periods in the Holocene.

4. ISOTOPE STUDIES ALONG A BURIED RIVER COURSE, JAISALMER

Interpretation of satellite imagery of the of the western parts of Jaisalmer District, revealed the buried course of a river in the NE-SW direction. In spite of the highly arid condition of the region, comparatively fresh groundwater is available along the course at 30 to 70 m depth. The aquifer consists of medium to fine sand with very little clay. A few dugwells in the study area do not dry up even in summer and tube wells do not show reduction in water table, even after extensive utilisation for human as well as livestock consumption. This course is seen to have link with the dry bed of Ghaggar river in the northeast, while in the southwest it is met with or even cut across the surviving courses of Hakra or Nara rivers in Pakistan. The above course is thought to belong to the legendary River Sarawati of Himalayan origin, mentioned in many early literary works and known to have existed before 3000 BP (6,7). This mighty river, originally flowing in a south-westerly direction, is supposed to have changed its course several times ending up in the present course of the river Ghaggar. The river built up a wide alluvial plain with considerable thickness. It is thought that the courses of the river in the area are still maintaining their head water connection with the Himalayan sources and could form potential sources of groundwater for exploitation.

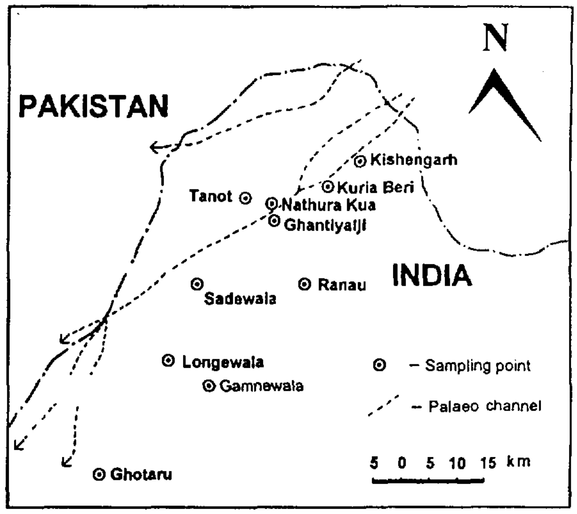

Figure 6: Locations of samples, Jaisalmer area.

To confirm the above scenario, an environmental isotope study was initiated. Figure 6 shows the study area with sample locations and Table 3 gives the results of analyses and other details for the samples.

From the results it is seen that both shallow and deep groundwaters are enriched in stable isotope values compared to that of present day Himalayan rivers ($\delta^{18}O$: -11 to -10 ‰) indicating that their head water connection with higher Himalayan sources is remote.

Table 3: Isotope and other relevant data of samples from Jaisalmer study area.

Type of well	Place	Depth* (m)	EC (µS/cm)	δ^2H (‰)	$\delta^{18}O$ (‰)	^3H (TU (± 0.5)	^{14}C (pMC)	$\delta^{13}C$ (‰PDB))
TW	Kishengarh	-	3460	-41.7	-5.6	0.2	47.3	-5.7
DW	Kuriaberi	39	2100	-42.6	-5.7	0.5	69.3	-
DW	Nathurakua	35	3040	-38.4	-6.3	0.3	58.3	-
TW	Ghantiyali	-	3660	-45.6	-6.6	0.5	32.2	-4.0
DW	Ghantiyali	38	2820	-41.2	-6.0	0.6	54.9	-
TW	Ranau	74-147(62)	1890	-45.3	-6.2	0.6	49.5	-7.4
DW	Ranau	55	2060	-46.1	-6.0	1.3	-	-
TW	Loungewala	-	2740	-44.0	-6.2	0.3	10.9	-5.6
DW	Loungewala	45	9370	-39.9	-5.9	1.0	-	-
TW	Gamnewala	87-147(65)	4060	-30.0	-6.1	0.6	-	-
TW	Ghotaru	91-157(40)	2270	-48.7	-6.9	0.2	21.1	-7.3
DW	Ghotaru	42	3650	-41.1	-6.4	1.1	62.7	-
TW	Asutar	73-95(68)	2560	-47.0	-6.3	0.4	35.8	-7.5
-	Rain (Jaisalmer)	-	-	-22.0	-4.3	7.0	-	-

DW/TW = Dug well/Tubewell; *= screen position for TW with static water level in brackets.

Shallow groundwaters generally have negligible tritium content and low ^{14}C values (54 to 70 pMC) indicating that they are old waters. However, dug well samples from Ranau and Gotaru show measurable tritium contents indicating small components of modern recharge.

Tube well samples also show negligible tritium and low ^{14}C values (10 to 49 pMC) indicating that they are old waters. Higher carbon-14 values at Ranau, Gotaru and Asutar could be due to mixing with some younger waters as seen from their lower chloride levels. Possibility of recharge from eastern side at these areas is indicated by existing dry stream channels. There is a trend of increase in the apparent ^{14}C age for groundwaters from Kishengarh to Loungewale along the suspected course of the river channel. From their relative ages, a groundwater velocity of about 5 m/a may be inferred.

5. CONCLUSIONS

The above studies indicate that in the southern part of the Thar desert, where precipitation received is higher compared to the north-western region, shallow aquifers could receive recent recharge. The mechanism could be direct infiltration after intense episodic rain events followed by floods or through river channels. In the north-western part, present day recharge is rare or negligible. In many parts of the desert deep fresh groundwater is available, which were recharged in the past (as indicated by the low carbon-14 values), when the climatic condition prevalent were more favorable than present. Reconstruction of the past climate in the region from palaeoclimatological and palaeontological studies (8,9), indicate that cooler and pluvial conditions in the Holocene were present in this region during which recharge to these aquifers could have taken place. However, the absence of modern recharge and evidence of over exploitation observed in the above studies stress the need for the proper management of such scarce groundwater resources. Isotope techniques can play a very important role in such efforts.

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