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INVENTORY OF DEUTERIUM IN SHALLOW AND DEEP GROUND WATERS OF NORTHERN INDIA: STUDY OF HYDROLOGICAL INTERCONNECTIONS

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RESUMO

As águas subterrâneas, na natureza, contém concentrações de deutério a nível de traços, que dependem da origem dessas águas e da sua história prévia. Neste trabalho estudou-se o movimento de corpos d'agua de diferentes localidades, a partir da determinação de seus teores de deutério natural. Analizaram-se 63 amostras de água. Essas amostras consistiram, principalmente, de água subterrânea extraida de poços rasos, profundos e artesianos e também de rios. As medições de deutério foram efetuadas com um espectrometro de massa Thompson CSF, model TSN-202, por redução da água em hidrogênio.

O balanço de deutério nas amostras coletadas mostrou que o teor de deutério nas águas subterrâneas, varia muito de um local para outro, dentro da região investigada. Isto tem conduzido a varias deduções sobre a origem, mistura e interconexão de águas subterrâneas, nessa região. Para um máximo benefício, os dados de deutério foram interpretados em conjunção com uma compilação de dados hidrogeologicos já existentes, referentes à área estudada.

INTRODUCTION

Deuterium ($HD^{16}O$) and oxygen-18 ($H_2^{18}O$) constitute an efficient tool for studying origin of water bodies or for identifying different water bodies and their interconnection. A description of the use of these environmental isotopes in hydrological problems has been made by Pyane(1971). Detailed discussions on the subject are contained in International Atomic Energy Agency guide book(IAEA,1968).

Because of its occurrence in very low concentrations, the deuterium compositions of a water sample is expressed in units, ie. as difference in per mille of the ratio D/H in the sample with respect to the same ratio in the standard mean ocean water(SMOW) defined by Craig,1961,

$$\delta D = \frac{(D/H)\ Sample - (D/H)\ Standard}{(D/H)\ Standard} \times 1000$$

During the natural processes occurring in the hydrological cycle causing changes of the state of water through condensation or evaporation, isotopic exchange of H,D and ^{16}O,^{18}O in liquid and vapor phases occurs(Craig et al.,1963). One of the main factors for fractionation during condensation is the temperature at the time of condensation. Fractionation factors are reported to be much higher for deuterium than for oxygen-18. Consequently, variations in stable isotope composition of precipitation with lattitude and altitude are observed(Friedman,1964;Moser and Stichler,1970). In a given location, seasonal variations in the stable isotope composition of precipitation are also common. Thus, ground water bodies would have a stable isotope composition similar to that of precipitation recharging them, depending on the area and time of recharge.

The stable isotope composition of ground water is commonly close to that of the precipitation which infiltrates as recharge. If part or all of the recharge is from a surface water body(lake or pond) instead of infiltration of precipitation,the deuterium or oxygen-18 are ordinarily enriched(ie. they have a positive or less negative deviation from the standard SMOW)because of the preferential evaporaration of the light(H,^{16}O) isotopes.Thus it is possible to differentiate between directly infiltrated precipitation and infiltration from surface water bodies that have been subjected to evaporation.Analysis of precipitation which have not evaporated show a good linear relationship between deuterium and oxygen-18 contents(Dansgard, 1964).

It has been shown by many workers today that the Nir mass spectrometer (Nier,1947) as modified by Mckinney et al.(1950), is capable of determining δ values routinely with great deal of accuracy. Deuterium and oxygen-18 occur in natual waters in concentrations of about 300 ppm and 2000 ppm respectively. The varying proportions of these isotopes in terrestial waters can be measured with precisions of better than ±2‰ for deuterium and ±0.2‰ for oxygen-18 by commercial mass spectrometers.

The mass spectrometers designed for highly precise isotopic ratio measurements are equipped with two collectors, which collect simultaneously the two isotopic ionic species the ratio of which is to be determined. The double collector is not suitable for determining hydrogen isotope ratios, because the two ionic species to be measured H_2^+ and HD^+ have too large a relative mass difference, and therefore the two ions will be too far from each other. In this case, two independent Faraday cages are used to collect the ions of masses 2 and 3.

The present paper deals with the inventory of deuterium content in shallow and deep ground waters of northern India.

AREA OF INVESTIGATIONS

The area of investigation lies in the foothills region of the Himalayas in Dehradun,Saharanpur and Naini Tal districts of state of Uttar Pradesh. The area (Fig.1) constitutes the "Tarai-Bhabar" belt, the Doon Valley and Upper Gangetic Plain.

Topography

Topographically, the area can be divided into three distinct zones, namely, the sloping submontane tract just south of the foothills zone of the Himalayas, the comparatively flat region covered by "Tarai" alluvium and the intermontane Doon Valley located in the Himalayan ranges. The submontane exhibits a general fall towards south varying from 10 to 17 meters per kilometer for a short stretch from the foothills region. The slope gradually decreases and becomes almost flat at the southern boundary of the "Tarai" belt.South of this belt, the Gangetic alluvium forms the extensive plains. The intermontane valley is located between high sub-Himalayan ranges and the foothills zone of the Siwalik mountains.

Drainage

The area presents innumerable drainage lines. The unique feature of the region is the debouching of major rivers like the Ganges,Yamuna,Ramganga into the plains from the lower Himalayas, some of them having their origin in the snowy peaks of the central Himalayas. These rivers have perenial flow. The Ganges,Yamuna feed significant number of canal systems.

Rainfall

The rainfall is not uniform in its areal distribution. The difference in rainfall is considerable. The submontane tracts experience the heaviest precipitation. The normal annual rainfall in general varies from 100 to 215 cm in the region. The amount of rainfall decreases in general from east to west. Run-off forms about 38 per cent of the rainfall in the plains of "Tarai" region and about 17 per cent of rainfall in the submontane tracts and intermontane valley in the area.

Sub-Suface Geology

The "Tarai" formations consist of clays,sandy clays,sand and occassional gravels. The northern limit of the belt is the spring line separating the "Bhabar" formation.The southern limit of the belt is not clearly defined and is generally taken as the zone where flowing conditions cease to exist in the tube wells. In this belt clayey beds predominate over sand beds. The granular beds occur mostly as lenses and also interfinger with the clastic and non-clastic beds(Fig.2, Pandey et al.,1968).

The "Bhabar" formations form the integrated alluvial fan deposits constituting unconsolidated sand-boulder and clay-boulder beds. Sometimes the size of the boulder runs in feet. The northern boundary of the belt is its contact with the Siwalik hill range and the southern limit is generally the spring line which also defines the northern limit of the "Tarai" sediments.

The lower Siwaliks are made up of hard and massive sandstones,clays and shale beds. These form the outer ranges in the Naini Tal Himalayas and occassionally exhibit local foldings and high dips.Near western corner of Doon Valley, the low hill ranges are constituted of these formations on a limited areal extent.

The Doon Valley alluvial fill is made up of clays, sandy clays and gravel associated with boulders, cobbles and pebbles of limestone,shale,phyllite and quart ite which conceals the underlying Siwalik mountain formations.

The tectonic studies of the lower Himalayan range point out the existence of number of thursts in the region,some of them culminating in the foothills region and also into the alluvium. The Ganges and Yamuna rivers follow major structural weak zones (probable faults) in their courses through the lower Himalayan ranges. The Siwalik hills between the Ganges and Yamuna rivers are folded and form anticline at Mohand(Pandey et al.,1968).

Occurrence of Ground Water

The occurrence of ground water in the present area consisting of three distinct ground water belts viz."Tarai","Bhabar" and intermontane valley is discussed in detail as following:

The lower Siwaliks in the area normally dip towards north and do not contribute much to the ground water in the sub-montane tract. The middle and upper Siwaliks in many places have southernly dips and act as feeders to the "Bhabar" aquifers when they are obviously connected hydrologically with the latter. Ground water occurs under confined and also water table conditions in these formations.

The sands and gravel associated with "Tarai" formations are the principal aquifers and are characteristically under conditions of high artesian pressure. The clays and clayey sands of these formations also absorb large quantities of water but exhibit low transmission capacity. Through sub-surface correlations it is believed that these formations are generally in continuity with "Bhabar" formations and thus receive ground water by downward infiltation and lateral flow from "Bhabar" belt. The dug well zone represents the unconfined ground water where the water table is within 5 meters.

Due to the absortive and permeable nature,"Bhabar" formations allow precipitation water to percolate to the water table.In view of this, the ground water storage capacity is large in this belt. Ground water occurs under water table conditions. The water table is generally very deep. Fluctuations of water table is also normally of high magnitude. Seasonal fluctuations in deep water table is enormous.

The sand and gravel beds associated with Doon alluvial fill are also good repositories of ground water due to their porous and permeable nature.Water table conditions prevail in this area except where the formations are shallow and are underlain by the confined beds of the Siwalik mountains. The water table in the Doon Valley and "Bhabar" varies from 6 m to 144 m below ground level.The terrain being that of foothills region, the depth of water table depends largely on the slope of the country.

Occurrence of ground water under perched conditions in the "Bhabar" belt and the Doon Valley was reported in the past. During percussion drilling perched water conditions were found at various sites in Naini Tal, Dehradun and Saharanpur districts(Pandey,1968).

The local terms "Tarai" and "Bhabar" hitherto applied to the marshy and waterless tracts respectively of the foothills region of the Himalayas are based largely in the geographical sense. It is difficult to define "Tarai" formations strictly in a geological sense of terminology except for its individuality as a zone of recently formed Gangetic alluvium. The "Bhabar" belt in contrast is geologically defined as the integrated alluvial fan deposits along the foothills and are constituted of consolidated sand-boulder and clay-boulder beds.

OBJECTIVE OF INVESTIGATIONS

The investigations were aimed at studying,the recharge mechanism in the region, surface and ground water relations and stratification of ground waters at various depths. It is thought that at some areas, the aquifers are interconnected. One of the purpose of the present isotope study was to check this hypothesis and determine the origin of ground water in various aquifers. It has been possible to compile detailed geohydrological information of the area so as to use the isotope data in conjunction with it for maximum benefit.

The artesian aquifer conditions in Pant Nagar Agricultural Farms situated in "Tarai" region is interesting. The isotope study would confirm whether or not the multilayered aquifers present in the area are connected among themselves and whether or not the "Bhabar" belts are in hydrological continuity with them.

SAMPLING OF WATER

To study the movement of local ground waters, samples of water were collected from various localities in the area of investigations. In all 63 samples of water were collected from the area during the summer of June 1975,ie. before the onset of monsoon.Samples taken included from shallow dug wells,hand pumps, deeper private and state tube wells in their running condition,flowing wells and shower of the seasonal monsoon. Private tube wells penetrate the strata upto 100 feet while the state tube wells penetrate upto 300 feet.

Samples were taken from carefully selected places of interest which were located at the boundaries of Doon Valley,Siwalik Hills,"Tarai" and "Bhabar" belts and northern part of Ganga-Yamuna basin. The artesian and multilayered aquifer conditions around farms of Pant Nagar were matter of special interest.Pant Nagar lies in "Tarai" belt and is situated south of the "Bhabar" formations . The artesian wells which had been drilled by Exploratory Tube Well Organisation in the past are penetrating different and multilayered aquifers. From this area alone,7 artesian and 4 shallow water samples were collected.The drilled-depths of the artesian wells is shown against the sampled well in Table-1.

The location of each sampled site in the entire region of investigation is shown in Fig.3.There are few sites from which both shallow and deep waters were sampled. These samples include 10,28;31,32;43,44;45,46;48,49 and location of only one sample, either deep or shallow,has been shown in Fig.3. In this figure the completed circle represents the location of the sample in the map,the number below the circle represents the sample number and the value above the circle represents the δ value of deuterium.

The water in the shallow dug wells in the region was not stagnant.It is assumed that evaporation effects may not be significant.

ANALYSIS OF DEUTERIUM

Deuterium analysis in water samples was carried out on the hydrogen gas obtained by quantitative reduction of water. Thomson CSF mass spectrometer model TSN 202 was used for the measurement of deuterium. For reduction of water into hydrgen, use was made of the sample preparation line provided in the inlet system of the mass spectrometer.

The working standard used was SMOW-1972 as supplied by International Atomic Energy Agency. The standard was introduced into the mass spectrometer at regular intervals. In order to eliminate memory effects, each sample was analysed three or four times till its D/H ratio was very different from that analysed immediately before. Memory effects were largely avoided by heating the sample preparation line to about 100° C. The uncertainty in measurement of δ D was less than 2 ‰ and was comparable with that of other methods. Few samples were repeated randomly for cross checking of results and they yielded the same value.

The deuterium contents of the samples expressed as per mille deviation from SMOW are shown in Table-1 and Figure 3. The Table also shows the reduced level (R.L.) of the sampling point, the depth of the ground water and temperature of the water at the time of sampling.

DISCUSSION OF RESULTS

For the sake of ease of interpretation of the observed variation of deuterium contents, the wells/waters sampled have been grouped in the following categories:

1- Shallow dug wells away from rivers and canals. These wells are 40-50 feet deep and have been further sub-grouped as following;

   i) wells with high R.L. of water (400 to 734 m)
   ii) wells with medium R.L. of water (300 to 332 m)
   iii) wells with low R.L. of water (228 to 294 m)

2- Shallow dug wells existing near rivers/canals

3- Wells which are in close proximity to each other

4- Deep wells (private and state tube wells which draw water from 100 feet and 300 feet deep aquifers respectively)

5- Waters sampled from same vicinity but from different depths

6- Artesian wells (depths are indicated in Table-1)

7- Samples from rivers Ganges and Yamuna

8- Rain water at Saharanpur

The shallow and deep water nomenclature has been done for convenience in grouping the deuterium data and does not necessarily reflect the most appropriate subdivision of the aquifer units on the basis of hydrogeological characteristics.

The δ D values of waters classified as above are shown in various columns of Figure 4. A marked variation of δ D values has been observed in the area of investigation. The results are discussed as following:

1- Deuterium contents of waters at various R.L.s are shown in columns-d,e,f. The deuterium contents of most of the dug wells vary within -35‰ to -50‰. The values show less and less scattering as R.L. of water goes on decreasing. Waters of high R.L. show a maximum variation from -66.7‰ to -20.0‰.

Group of samples which are in close proximity of each other, column-h,i, viz. (31),(33);(61),(62), have evidently not shown variation in deuterium composition. In contrast to this, the group of samples viz. (6),(9);(7),(8);(25),(44);(26),(29);(34),(35);(39),(40);(46),(47);and (50),(51), which are in close proximity to each other have shown varying deuterium composition. This pattern of variation of deuterium contents perhaps is resulting from relative variation of permeability within the aquifer and evaporative processes occurring on soil surface and agricultural lands of the region.

2- The δ D values of the wells (12,13,25,33,46),column-c, are quite negative than those of the others in their vicinity. Taking into account the location of these wells in the immediate vicinity of river/canals, a significant exchange of river/canal water and ground water is more probable explanation for the observed δ D values.

3- Of the shallow dug wells, water from sample no.(3)-water R.L. 330.48 m, sample no.(17)-water R.L. 332.80 m, sample no.(6)-water R.L. 416.65 m and sample no.(23)-water R.L. 734.71 m, have shown the same and most positive (-20‰) δ D values, which are difficult to explain. The first three wells are situated at the base of hills while the fourth is at quite elevated level in the mountain ranges.

4- Even though wells no. 20,21,22 are far placed, their δ D values are same. This is strong indication that same ground water stream or belt is underlying the region.

5- Wells(26,27,28,29,32,37,42,43,45,48),drawing water from deeper horizon have shown wide range of variation in deuterium contents(column-a). Whereas, in some places their D contents are depleted than those of shallow dug wells in their immediate vicinity(compare D contents of sample no. 27,38;32,31;45,46;48,49),in other places their D contents are richer than of immediate-vicinity shallow dug wells (compare D contents of sample no. 26,25/44;42,1;43,44). Only at two places the deeper waters showed D contents equal to those of immediate-vicinity shallow dug wells (compare D contents of sample no. 28,10;37,36).

Shallow and deep waters sample at the same spot viz.deep sample,no.(28), shallow sample,no.(10); deep sample no.(32),shallow sample no.(31);deep sample no.(43), shallow sample no.(44);private tube well water,sample no.(45), hand pump water,sample no. (46);private tube well water,sample no.(48),shallow sample no.(49); show,(column-g), that but for the shallow waters,sample no (10) and (44), all shallow waters are enriched compared to the deeper waters.

The foregoing patterns of variation of deuterium contents of deep and shallow waters show that there is apparent stratification of ground waters at many places. In some places there is interconnection between shallow and deep waters,as indicated by their **equal** deuterium contents,whereas in many points such interconnection does not exist. These conditions are largely due to presence of thick confining clay bands which are characteristically abundant in the region.

Gangetic plain is agriculturally fertile region where ground water is extensively used for irrigation.The enriched deuterium contents in shallow waters could also be due to evaporation of irrigation water which gets continuosly cycled.

6- All the artesian wells sampled in the farms of Pant Nagar(column-i), have shown same deuterium values, which are much depleted than any ground water sampled in the area of investigation. The δ D value of hand pump water sampled at Lalkua,about 12 Km away in the north in the southern boundary of "Bhabar" belt (see Figures 1,3 and 4),clearly shows that there is no difference at all between ground water of this area and the water stored under pressure in the "Tarai" belts. This proves that the "Bhabar" and "Tarai" belts are hydraulically well connected and the precipitation of of higher altitudes/submontane "Bhabar" area serves as feed for "Tarai" aquifers.

The fact that all the artesian wells which penetrate different depths, have shown same deuterium content proves that the multilayered aquifers,which are believed to be existing (Fig.2) in the region,are hydraulically in continuity with each other and for all practical purpose the deep aquifer behaves as one unit.

The enriched D contents of the shallow hand pump waters(sample no. 60, 61,62), right in the vicinity of artesian wells either indicate a perched water body or evaporation of the ground water being used for irrigation.

7- The two rivers, the Ganges and Yamuna, sampled at Haridwar and Dak Pathar barrage (see Fig.3) respectively, show marked variation in their deuterium contents(column-b). The Ganges while traversing upto Haridwar also receives the adjoining ground water as seepage which has positive D values, whereas, Yamuna at Dak Pathar contains mostly the depleted precipitation from higher and surrounding mountains.

8- The rain sample taken in between the initial monsoon showers at Saharanpur (sample no. 63), shows the most depleted -115.9‰ D value and serves as index of variation of isotopic composition in fresh rain, older shallow and deep waters.

CONCLUSIONS

The regional variation of deuterium in ground waters of northern India is interestingly significant. The distinct differences in deuterium contents of shallow and deep aquifers establishes that transfer of appreciable amount of ground water from shallow to deep aquifers is not occurring at many places. These are probably the places where extensive clay bands are separating upper and deep aquifers.

At many places interconnection of ground waters, laterally or vertically, has been established by indication of same δ D values.

It is confirmed that the "Tarai" and "Bhabar" formations are hydraulically well connected and further, the multilayered aquifers which are believed to be existing in "Tarai" region are hydraulically in continuity with each other and for all practical purposes the deep aquifer behaves as one unit.

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Table 1- Deuterium contents in ground waters of "Tarai-Bhabar" belt, Doon Valley and Upper Gangetic Plain in northern Uttar Pradesh, India

S.No. a	Sampling point b	Reduced level, m c	Water level below ground, m d	Temperature, °C e	D ‰ f
1.	Imlikhera	275.15	11.30	25.5	-43.7
2.	Aurangabad	300.10	11.83	25.5	-40.5
3.	Harnaul (at the base of hills)	337.35	6.87	24.5	-20.0
4.	Dholkhand	446.28	4.80	21.5	-37.3
5.	Mohand V-2	472.81	9.34	25.0	-37.9
6.	Sahajahanpur (at foothills)	419.45	2.80	-	-21.3
7.	Sakhumbhari (Bhura Devi temple)	422.61	7.36	26.0	-29.0
8.	Bhaguwala	356.70	48.6	26.0	-48.1
9.	Fatehpur	323.87	16.25	31.0	-31.5
10.	Muzzafarabad	313.97	7.01	26.0	-52.0
11.	Chutmulpur	296.30	6.78	-	-
12.	Daulatpur (Near Ganga Canal)	274.10	7.46	25.0	-40.5
13.	Jwalapur (Near Canal)	285.59	17.51	21.5	-44.3
14.	Ferupur	262.30	6.6	25.0	-31.5
15.	Pathri	257.35	4.5	25.0	-44.3
16.	Haridwar	251.70	9.91	22.5	-53.9
17.	Raiwala VIII-2	353.18	20.38	24.5	-20.0
18.	Rishikesh	340.19	8.1	26.0	-41.1
19.	Harrawala	599.63	17.24	-	-39.8
20.	Jajhra	548.55	16.73	24.0	-44.9
21.	Sahaspur	489.13	12.14	24.0	-41.7
22.	Herbertpur	443.37	10.62	22.0	-41.7
23.	Dat	750.97	16.26	22.5	-20.0
24.	Dak Pathar (Barrage water)	-	-	-	-70.5
25.	Roorkee (2 Km. east of canal)	260.93	4.54	-	-64.1

I.P.E.N.

a	b	b	d	e	f
26.	Private Tube Well (Matlabpur village)	270.00	-	25.0	-32.8
27.	State Tube Well NO. 43 (Kamalpur village)	290.00	-	-	-54.5
28.	State Tube Well NO. 53 (Muzzaffarabad)	314.04	-	-	-30.2
29.0	State Tube Well NO. 50	-	-	-	-41.0
30.	Badshahibad	408.36	8.02	25.5	-43.7
31.	Mirzapur	331.16	37.0	25.5	-42.4
32.	State Tube Well No. 66 (200 m away from Mirzapur)	-	-	-	-68.0
33.	Raipur (150 m away from Eastern Yamuna Canal)	313.67	22.40	22.5	-44.3
34.	Behat III-2	302.24	9.39	23.0	-29.6
35.	Hatauli	300.00	10.70	24.5	-53.9
36.	Ghunna	285.81	3.38	26.0	-36.5
37.	Private Tube Well (Ghaunakhandi village)	-	-	24.0	-37.3
38.	Punwarka	286.64	3.29	23.5	-45.6
39.	Khatiakhurd	281.44	5.15	24.0	-48.1
40.	Chilkhana	289.00	7.41	24.5	-36.0
41.	Sarsawa	273.68	8.30	23.5	-34.7
42.	State Tube Well NO. 120 (Phuhana village)	-	-	-	-37.9
43.	State Tube Well NO. 62 (Iqbalpur village)	-	-	25.5	-37.3
44.	Hand Pump(Iqbalpur)	-	-	25.0	-44.3
45.	Private Tube Well (Jabreda)	-	-	25.0	-67.3
46.	Hand Pump (Jabreda)	263.89	2.22	25.5	-54.5
47.	Lakhnauta	260.89	8.43	26.0	-48.8
48.	Private Tube Well Deoband	-	-	24.5	-60.3
49.	Deoband	254.90	0.80	24.5	-41.5
50.	Majhra	609.05	1.10	-	-66.7
51.	Manav Kendra,Dehradun	-	-	-	-59.0

a	b	c	d	e	f
52.	Artesian Well NO. 2 (Pant Nagar)(960 feet)	-	-	-	-75.6
53.	- do - NO. 4	-	-	-	-77.5
54.	- do - NO.7(377 feet)	-	-	-	-74.3
55.	- do - NO.11(446 feet)	-	-	-	-73.1
56.	- do - NO.12(730 feet)	-	-	-	-71.8
57.	- do - NO.19	-	-	-	-73.1
58.	- do - NO.20	-	-	-	-73.1
59.	Hand Pump, Lalkua	258.09	-	-	-73.1
60.	Hand Pump, Kichcha	207.45	-	-	-66.7
61.	Hand Pump,Pant Nagar (Railway station)	-	-	-	-52.6
62.	Hand Pump,Pant Nagar (University campus)	-	-	-	-55.2
63.	Rain Water,Saharanpur (June,21, 1975)	-	-	-	-115.9

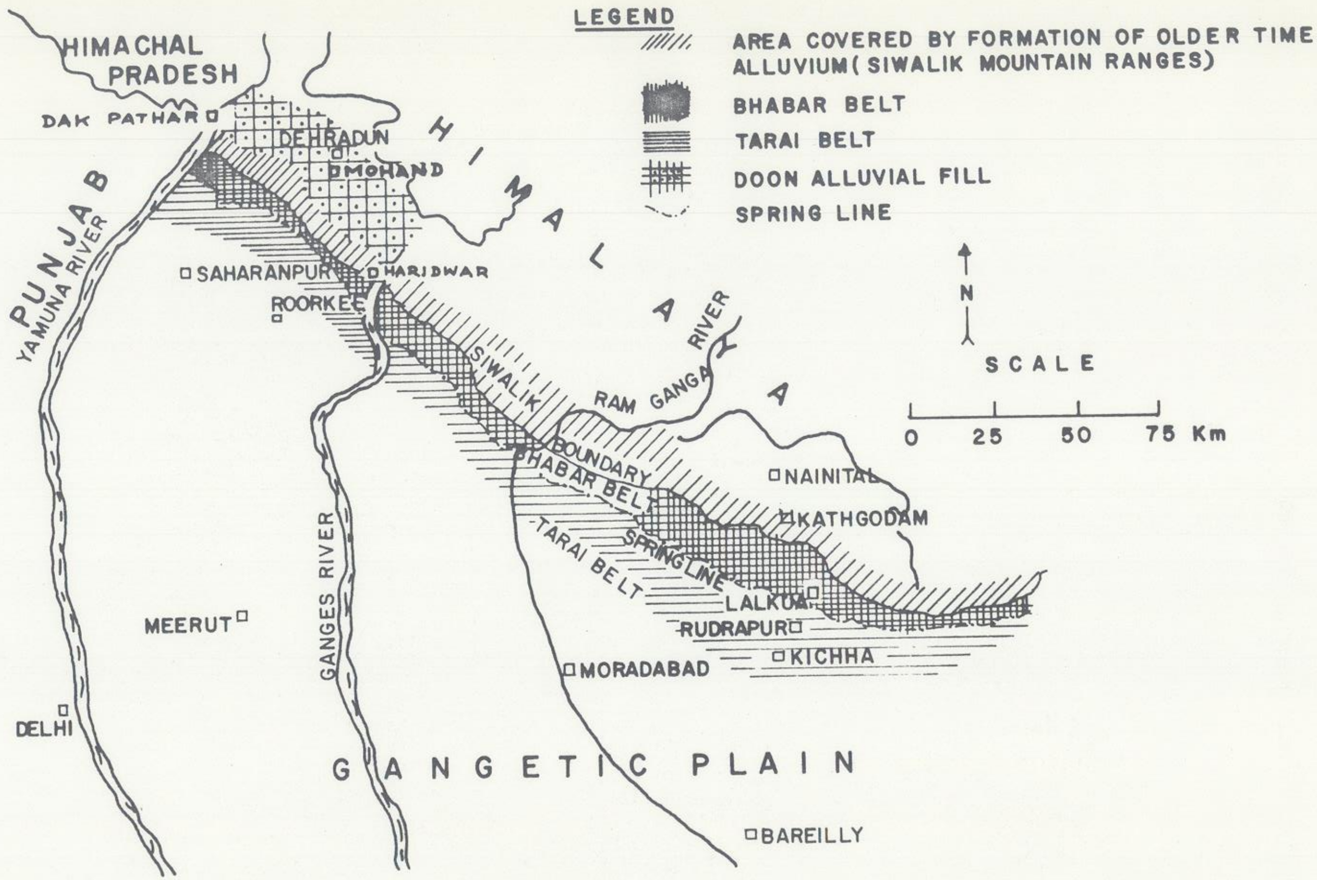


FIGURE 1 - Geological classification of the deuterium-inventory area

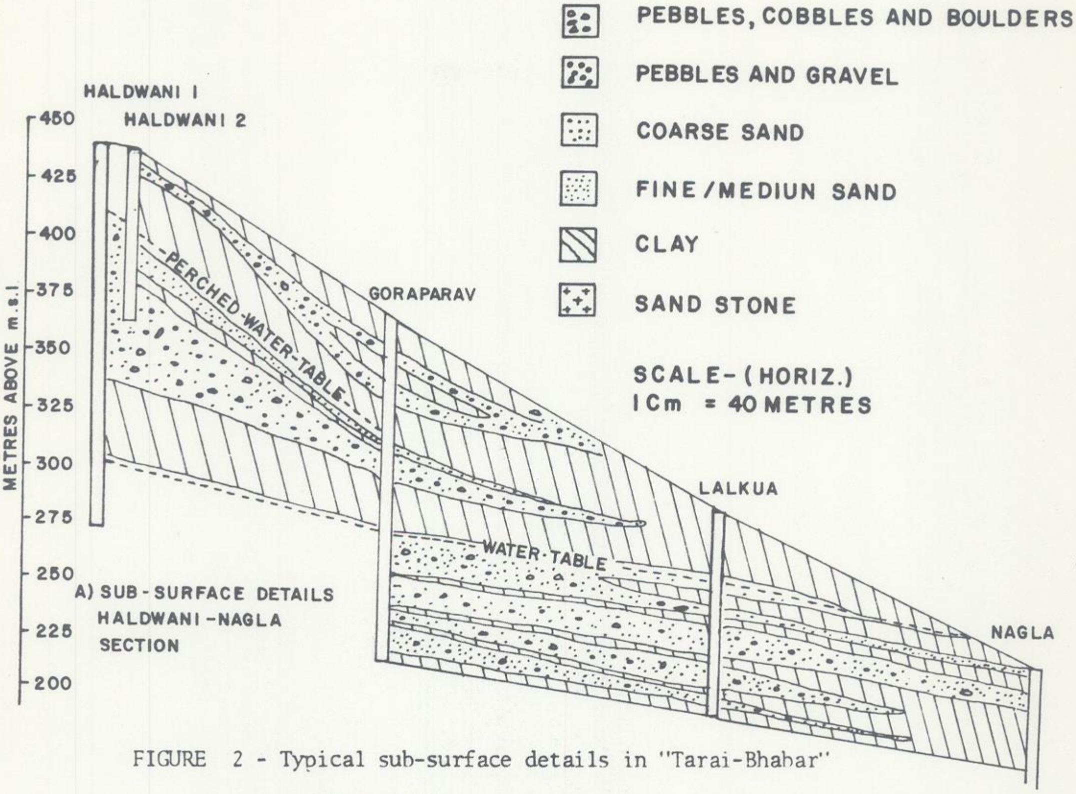
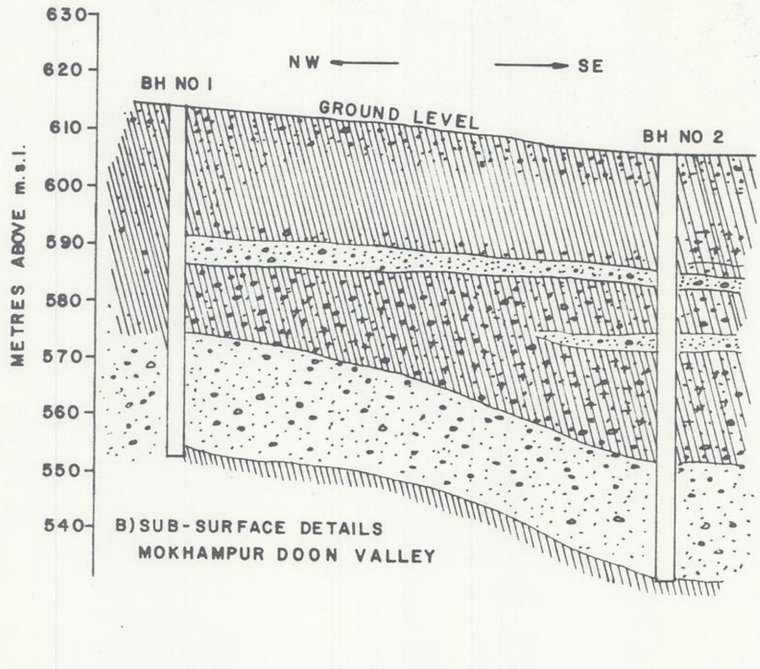


FIGURE 2 - Typical sub-surface details in "Tarai-Bhabar" and Doon Valley



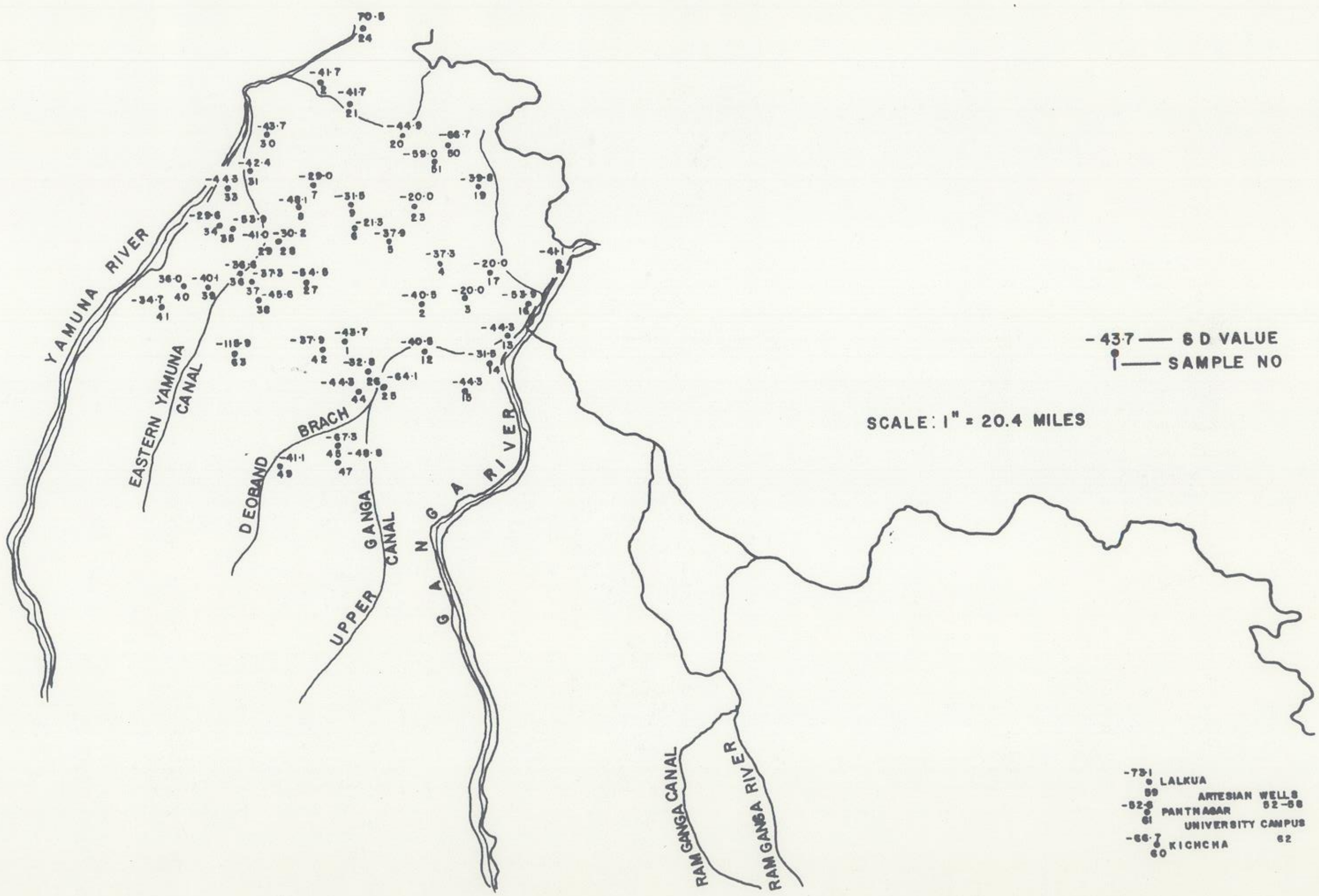


FIGURE 3 - Deuterium contents of ground waters in northern Uttar Pradesh, India

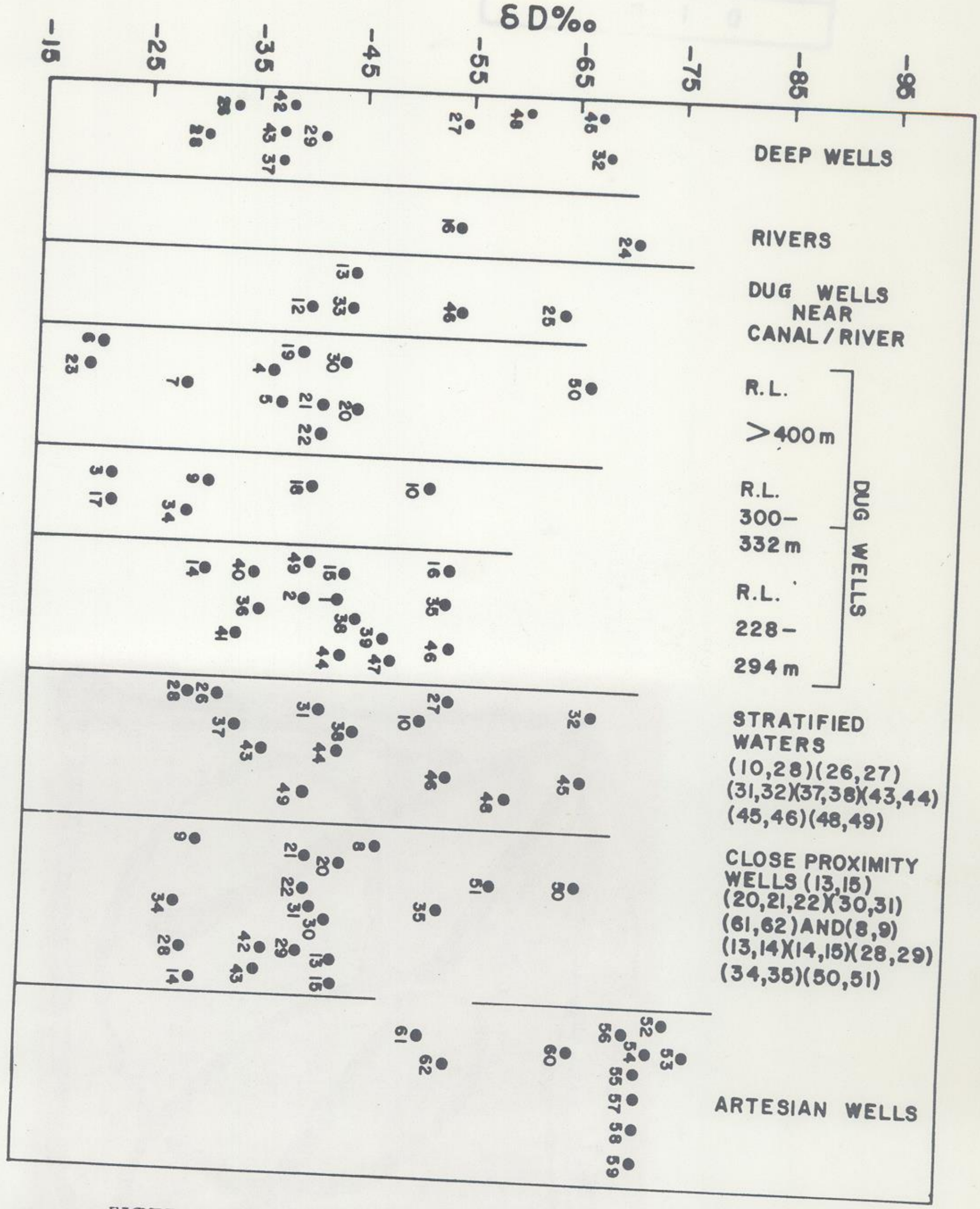


FIGURE 4 - Classification of observed δD values in the area