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SURFACE WATER AND GROUNDWATER INTERACTION IN MARALA – KHANKI AREA, PUNJAB

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ABSTRACT

Isotope hydrological investigations were carried out in Marala-Khanki Area of Punjab for elucidating various aspects of surface water and groundwater interaction. Groundwater samples were collected on seasonal basis (low and high river discharge periods) while surface water (Chenab River) samples were collected more frequently (weekly or monthly basis). Isotopic data suggested that there is no significant contribution of surface water to groundwater recharge in Marala-Khanki Area and rain is the prevailing source of groundwater recharge. The data further revealed that isotopic values of the river Chenab at Khanki are higher than those at Marala especially in low flow condition meaning that there is a significant contribution of baseflow in this river section. Stable isotopes were successfully used to quantify the baseflow contribution in the selected section of the Chenab River.

SURFACE WATER AND GROUNDWATWER INTERACTION IN MARALA-KHANKI AREA, PUNJAB

1. INTRODUCTION

Water in rivers/streams has two main components: surface and near-surface quick flow in response to rain or snowmelt, and baseflow, which is water that enters from persistent, slowly varying sources and maintains streamflow between water-input events [1]. Their respective contributions differ in each system and depend on physical settings of the drainage basin as well as on climatic parameters. Baseflow generally comes from shallow unconfined aquifers containing water less than 50 years old in depths between 10 and 100 m and enters the river through the riverbanks and the bottom of river beds [2,3]. Baseflow is an important component of the water in rivers/streams. Quality of river water is deteriorated due to discharge of poor quality groundwater from saline zones, industrial effluents and urban contamination. This implies that shallow groundwater needs to be studied as a part of the catchment and improved understanding of the role of the baseflow in overall catchment vulnerability is a key need towards water resources management tools and best management practices on large scale [4].

Pakistan is an arid to semi-arid country and suffers from general shortage of water. The quest for rapid social and economic growth gives great boost to the development of water resources. Most of the rainfall occurs in monsoon and due to inadequate storage facilities, significant quantity of precious water is lost through drainage in to sea. At high discharge level, the river water is recharged in to groundwater, while during dry seasons when flow reduces significantly, shallow groundwater discharges in to the rivers in high water table areas. In order to manage the water resources, information on interaction between the rivers and groundwater is needed. Isotopes provide useful tools for such investigations.

Under an IAEA Coordinated Research Project, study was carried out in a selected area of Punjab (Marala - Khanki Area) to investigate various aspects of surface water and groundwater relationship.

2. STUDY AREA

Area around the river Chenab between Marala and Khanki Headworks was selected for the present study. This area is a part of Indus Basin. The dominant geologic unit in the area is alluvium [5]. The unconsolidated alluvial deposits are of Pleistocene to Recent in age and are overlying the Precambrian basement rocks. These were deposited in a subsiding trough by the ancestral and present tributaries of the river Indus. The alluvial fill is more or less homogeneous in nature, and has little continuity vertically or laterally, indicating diverse depositional environments from time to time caused by the constant change in the river courses.

The alluvial sediments mainly consist of grey, a greysish brown, fine to medium sand and silt. Minor amounts of gravel and clay and clay are also present. Kankars, a calcium carbonate material of secondary origin are associated with fine-grained strata. Clay is generally found in lenses and its origin has not been ascertained but presumably it is repeatedly reworked loess. Of the alluvial complex, sand forms the areas of fairly transmissive aquifer material in which groundwater occurs under water table conditions [6].

The climate is subtropical continental influenced by large fluctuations in temperature with hot summers and cool winters. The average annual rainfall is about 1000mm in the northern part. The monsoon rains mostly occur from mid July to mid September.

3. SAMPLE COLLECTION

Samples of Chenab River were collected at Marala and Khanki on fortnightly / monthly basis. In order to account for the temporal and seasonal variations in isotopic composition of groundwater, shallow and deep groundwater samples were collected from selected sections on both sides of the river twice in monsoon period when the river was in very high flow (August 2005 and July 2009) and twice when the river had very low flow (January 2006 and February 2009). The groundwater sampling points included hand pumps, motorized pumps and tube wells. Hand pumps and motorized pumps represent shallow groundwater while tube wells represent deep groundwater. Location of sampling stations is shown in Fig. 1. Samples were also collected from selected stations for CFC analyses.

4. ANALYSIS

Surface water and groundwater samples were analyzed for environmental isotopes (^{2}H, ^{3}H, ^{18}O) and chlorofluorocarbons (CFCs). Methods used for sample analyses are given below.

4.1 Stable Isotope Analysis

Water samples were analyzed for stable isotopes (^{2}H, ^{18}O) by gas source mass spectrometers, which do not accept water and other organic or inorganic substances for analyses. The sample was first transformed into gas form and then introduced into the mass spectrometer. The stable isotopes concentrations are expressed in terms of relative concentrations as the difference between the measured ratios of the sample and standard. These concentrations are expressed using the delta (δ) notation and defined as [7]:

$$\delta_x = \left[\frac{R_x}{R_{std}} - 1\right].1000 \quad (1)$$

Where R_x represents isotope ratio of a sample ($^2H/^1H$, $^{18}O/^{16}O$, $^{34}S/^{32}S$ etc.) and R_{std} is the corresponding ratio in a standard.

(a) Oxygen isotope (^{18}O)

For determining the oxygen isotopic composition of water samples, CO_2 equilibration method was used [8]. This method involves equilibration of CO_2 with sample water and subsequent mass spectrometric determination of "R" - the ratio of $^{12}C^{16}O^{18}O/^{12}C^{16}O_2$ obtained by necessary corrections from the masses 46 and 44 in CO_2, which have isotopically equilibrated with water sample. This is compared with R_{std} - the isotopic ratio in CO_2 equilibrated with internal standard (IS) at identical temperature and $\delta^{18}O_{IS}$ (per mill deviation from internal standard) is determined. Finally the results are quoted against internationally known standard VSMOW (Vienna Standard Mean Ocean Water) by converting $\delta^{18}O_{IS}$ to $\delta^{18}O_{VSMOW}$. Measurement uncertainty of $\delta^{18}O$ is $\pm 0.1‰$.

(b) Hydrogen isotope (^2H)

For analysis of hydrogen isotope ratio ($^2H/^1H$) analysis, water samples were first reduced to hydrogen gas using zinc reduction method [8]. Quantitative reduction of water to hydrogen gas was achieved by treating water sample with zinc shots of 0.5 – 2.0 mm size under vacuum of the order of 10^{-4} torr according to the equation:

$$H_2O + Zn \longrightarrow ZnO + H_2 \quad (2)$$

The hydrogen produced was measured on a mass spectrometer against internal standard and converted to delta values against International Standard (δ^2H_{VSMOW}). Measurement uncertainty of δ^2H is $\pm 1.0‰$.

4.2 Tritium Analysis (^3H)

Tritium content of water samples was determined by liquid scintillation counting after electrolytic enrichment [9]. The enrichment was carried out by using cells with stainless steel anodes and phosphated mild steel cathodes. Starting with 250 ml of initial volume, about 17 folds enrichment is done for subsequent counting by liquid scintillation spectrometer. The standard error of measurement is about ±1 TU.

4.3 Chlorofluorocarbons (CFCs) Analysis

Dissolved CFCs were released by purging high purity nitrogen gas through the samples and the released CFCs were adsorbed in a column. Concentrations of the CFCs (CFC-11, CFC-12 and CFC-113) were measured by gas chromatography using electron capture detector [10]. A special low level CFC device provided by IAEA under a TC Project was used for this purpose.

5. RESULTS AND DISCUSSION

Isotopic data of the study areas is given in Table 1 – 4 and discussed in the following sections.

5.1 Isotopic Data of Rain

Hussain et al [11] have studied the isotopic index of rainfall at a station located very close to the present study area during 1984 - 1988. The weighted mean values of $\delta^{18}O$ and δ^2H of rainfall over the period of four years were found to be -4.5‰ and -22‰ respectively. Local Meteoric Water Line (LMWL) was also determined which is given by the equation: $\delta^2H = 8\delta^{18}O + 14$. LMWL has same slope as that of GMWL but different deuterium excess. The higher deuterium excess is due to the contribution of Mediterranean moisture in winter rainfall. $\delta^{18}O$ values of rains occurring at nearby mountains (average elevation = 600 m w.r.t. rain sampling station) in the northeast of the selected area was estimated by taking altitude effect (using average value of -0.25‰ per 100m for $\delta^{18}O$ gradient) into consideration and found to be -6.0‰.

5.2 Isotopic Data of Surface Water

Isotopic values of the river Chenab at Marala (2002-06) vary from -13.2‰ to -7.7‰ with the average value of -9.5‰ for $\delta^{18}O$ and -88‰ to -35‰ with the average value of -57‰ for δ^2H. At Khanki, $\delta^{18}O$ and δ^2H values of the river (2002-2008) vary from -11.9‰ to -5.7‰ (average value = -8.2‰) and -78‰ to -31‰ (average value = -52‰) respectively. These ranges and average values clearly show that $\delta^{18}O$ and δ^2H are higher at Khanki (downstream station) as compared to those at Marala (upstream station).

5.3 Isotopic Data of Groundwater

Isotopic values of groundwater show large spatial variations but no significant temporal or seasonal variations (Table 1 - 4). $\delta^{18}O$ and δ^2H values of shallow and deep groundwater samples lie in the range of -11.4 to -3.3‰ and -75 to -24‰ respectively (1st sampling), -10.1 to -2.5‰ and -71 to -23‰ respectively (2nd sampling), -9.3 to -3.1‰ and -64 to -22‰ respectively (3rd sampling), and -11.1 to -2.5‰ and -72 to -20‰ respectively (4th sampling). Tritium concentrations vary from 1 to 18 TU.

5.4 Surface Water and Groundwater Interaction

Stable isotopic values of groundwater have been plotted in Fig. 2 to 5 which reveal the similar trend during all the samplings. Most of the groundwater samples are enriched in $\delta^{18}O$ and $\delta^{2}H$ as compared to the river water and are plotted below the LMWL showing significant evaporation [12]. Locations of these points in the figures indicate that most of the samples do not show significant recharge from the river. $\delta^{18}O$ values of groundwater along the right bank (Side B) are generally higher and vary over a narrow range of -3 to -6.5‰. These samples plot near the rain index. This trend is not altered in the monsoon season when the river has very high discharge. This fact proves that this area receives recharge mainly from the rain and there is no significant contribution of river water towards groundwater recharge. Data points pertaining to groundwater samples collected from the stations along the left bank of the river (Side A) show large variations in $\delta^{18}O$ and the values range from -10.2 to -2.5‰. Some samples from this side indicate contribution of the river. The samples taken from the Side-A piezometers (P1 & P2) are relatively depleted in $\delta^{18}O$ and $\delta^{2}H$ revealing major contribution from the river water even when the river is in low flow. However, in case of Side-B peizometers (P3 & P4), the situation is different. P-3 located at a distance of 0.5km only from the river has oxygen-18 value -7‰. P-4 located 1km from the river has oxygen-18 value of -4.5‰ (almost same in both seasons) which is quite different from the river. This implies that river influence even at such a short distance is not significant on Side B.

As discussed earlier (Section 5.2), stable isotope values of the river Chenab at Khanki (downstream station) are higher than those at Marala (upstream station) which suggests that there is a contribution of groundwater (baseflow) in this river section [13]. In order to study the seasonality of the baseflow contribution, river data at each station was divided into two groups based on the river discharge. First group included the data of those months when the river has high discharge (monsoon season) and the second group included the data of the low flow period. Summary of the data is shown below.

Station	Period	Average $\delta^{18}O$ (‰)	Average $\delta^{2}H$ (‰)
Marala	High flow	-10.1	-61
	Low flow	-9.4	-56
Khanki	High flow	-9.8	-60
	Low flow	-7.7	-50

It can be seen that the river has depleted values during high flow and the values are close at both stations which means that baseflow contribution is not significant during this period. Isotopic composition of the river at Marala is almost similar during high flow and low flow periods. However, situation is much different at downstream station (Khanki) where oxygen-18 and hydrogen-2 concentrations show an increase of 2‰ and 10‰ respectively during low flow period. During this period, isotopic values also show considerable increase at Khanki as compared to those at Marala. These changes in the isotopic composition of the river suggest that baseflow contribution in Marala – Khanki section of the river Chenab is significant during the low flow period.

5.5 Tritium and CFC Dating of Groundwater

Data of the river Chenab indicate that the average value of tritium of the river at Marala is 11.7 TU. Current value of rain (Islamabad) is about 10 to 15 TU. Tritium concentrations of groundwater range from 0.6 to 18.8 TU. Three samples having no tritium (0 to 1 TU) indicate longer residence time. They were recharged before the start of nuclear bomb test period i.e. 1953. Samples with tritium in the range of 4 to 8 TU indicate residence time of few years to 30 years. Many groundwater samples show tritium concentration close to the rain index. This implies that they are young waters and movement of water at these locations is quite quick. CFC concentrations of groundwater samples and the determined

CFC based ages are given in Table 5. Ages determined by different CFCs [14] for a given sample are generally in good agreement with each other.

5.6 Baseflow Quantification

Two component mixing model was applied to quantify the baseflow contribution using average isotopic data of groundwater and surface water in different periods.

$$\delta^{18}O\ (\text{mixture}) = x.\ \delta^{18}O(A) + (1\text{-}x).\ \delta^{18}O(B) \qquad (3)$$

where A (river water released from u/s station) & B (baseflow) are the two components of river discharge received at the d/s station.

Calculated baseflow percentage (%) in the river (Marala-Khanki Section) is given below. Results show that baseflow % calculated by the two isotopes is close. It can also be noted that baseflow contribution is more when the river has low flow.

Isotope	Period	Baseflow Contribution (%)
^{18}O	High flow	8
	Low flow	32
^{2}H	High flow	11
	Low flow	39

7. CONCLUSIONS

Isotopic values of groundwater are generally enriched as compared to river water but they are close to the values of the rain on nearby mountains. Hence, rain is the major source of groundwater recharge. Groundwater at some locations on the left bank shows contribution from the river. Tritium and CFCs suggest groundwater residence time ranging from >50yrs to recent. Enrichment of $\delta^{18}O$ and $\delta^{2}H$ in river water at Khanki as compared to Marala is due to contribution of isotopically enriched baseflow Average baseflow contribution in this river section during low flow periods calculated by stable isotopes is about 36%.

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Table 1. Isotopic data of groundwater in Marala-Khanki area ((August 2005)

Sample #	Source	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)
1	Hand pump	-9.96	-64.87
2	Hand pump	-4.97	-35.13
3	Hand pump	-5.91	-39.8
4	Tube well	-9.54	-62.78
5	Hand pump	-3.33	-23.56
6	Hand pump	-5.95	-45.58
7	Hand pump	-5.21	-37.15
8	Tube well	-5.24	-36.67
9	Hand pump	-5.01	-39.08
10	Tube well	-5.1	-40.91
11	Hand pump	-5.91	-42.12
12	Tube well	-7.57	-49.48
13	Tube well	-4.06	-33.37
14	Hand pump	-3.72	-34.42
15	Tube well	-3.48	-34.65
17	River	-11.37	-74.6
18	River	-11.22	-74.03
21	River	-11.12	-71.94
23	Hand pump	-4.58	-32.74
24	Tube well	-5.43	-39.83
25	Tube well	-5.48	-40.18
26	Tube well	-4.65	-32.32
27	Hand pump	-4.83	-32.3
28	Tube well	-6.17	-37.33
29	Hand pump	-7.26	-43.59
30	Tube well	-6.72	-46.23
31	Hand pump	-5.97	-34.23
32	Tube well	-8.51	-59.9
33	Hand pump	-4.32	-34.21
34	Tube well	-4.25	-35.72
35	River	-10.65	-70.25
36	Tube well	-5.66	-37.55
37	Hand pump	-9.43	-65.72
38	Hand pump	-8.23	-61.94
39	Hand pump	-7.53	-62.27
40	Hand pump	-4.73	-37.36

Table 2. Isotopic data of groundwater in Marala-Khanki area (January 2006)

Sample #	Source	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	Tritium (TU)
5	Hand pump	-3.82	-26.8	
7	Hand pump	-3.92	-26.9	6.5
11	Hand pump	-5.51	-51.52	
12	Tube well	-8.02	-55.49	
14	Hand pump	-6.09	-47.13	5.1
16	Hand pump	-2.48	-23.43	7.9
23	Hand pump	-4.43	-38.86	6.9
26	Tube well	-5.04	-39.47	
27	Hand pump	-4.46	-37.43	
28	Tube well	-5.94	-46.47	8.9
29	Hand pump	-5.54	-41.02	1.2
30	Tube well	-6.2	-38.9	0.8
31	Hand pump	-5.14	-39.49	5.6
41	Tube well	-5.94	-43.86	5.8
42	Hand pump	-5.63	-40.19	4.9
43	Tube well	-5.88	-45.76	6.2
44	Tube well	-5.65	-40.85	6.2
45	Hand pump	-5	-42.75	6.1
46	Hand pump	-4.79	-33.23	7.4
47	Hand pump	-6.1	-42.03	3.6
48	Tube well	-6.03	-44.07	5.2
49	Hand pump	-6.13	-42.07	14.1
50	Tube well	-9.22	-65.5	
51	Hand pump	-9.02	-61.38	
52	Hand pump	-10.12	-65.03	1.6
53	Hand pump	-9.93	-71.39	
54	Hand pump	-3.79	-37.86	8.7
55	Hand pump	-7.03	-44.02	11.9
56	Hand pump	-7.28	-47.9	11.2
57	Hand pump	-4.52	-34.26	
58	Hand pump	-8.18	-47.87	11.8
59	Hand pump	-5.87	-48.06	
60	Hand pump	-4.5	-34.35	
61	Hand pump	-2.91	-24.34	
62	Hand pump	-4.18	-29.18	11.7
63	Hand pump	-5.58	-39.55	
64	Hand pump	-3.58	-30.88	6.2
65	Hand pump	-5.24	-33.74	13.7
P-1	Hand pump	-9.18	-64.9	14.2
P-2	Hand pump	-8.32	-56.44	11.6
P-3	Hand pump	-7.07	-50.93	18.8
P-4	Hand pump	-4.54	-35.84	12.9

Table 3. Isotopic data of groundwater in Marala-Khanki area (February 2009)

Sample #	Source	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	Tritium (TU)
5	Hand pump	-3.92	-28.8	
7	Hand pump	-3.72	-25.9	6.5
11	Hand pump	-5.25	-46.52	
12	Tube well	-7.8	-54.9	
14	Hand pump	-6.9	-49.13	5.1
16	Hand pump	-3.08	-22.43	7.9
23	Hand pump	-4.4	-37.86	6.9
26	Tube well	-5.4	-40	
27	Hand pump	-4.6	-37.9	
28	Tube well	-6.2	-38.9	8.9
29	Hand pump	-5.4	-42.02	0.4
30	Tube well	-6	-36.9	-0.5
31	Hand pump	-5.4	-38.49	5.6
41	Tube well	-5.74	-40.86	5.8
42	Hand pump	-5.73	-43.19	4.9
43	Tube well	-5.68	-42.76	6.2
44	Tube well	-5.8	-43.85	6.2
45	Hand pump	-5	-42.75	6.1
46	Hand pump	-4.49	-31.23	7.4
47	Hand pump	-5.7	-40.03	3.6
48	Tube well	-6.43	-47.07	5.2
49	Hand pump	-6.3	-42.7	14.1
50	Tube well	-8.72	-58.5	
51	Hand pump	-8.24	-59.38	
53	Hand pump	-9.3	-64.3	
54	Hand pump	-3.59	-34.86	8.7
55	Hand pump	-7	-45.02	11.9
58	Hand pump	-7.88	-44.7	11.8
59	Hand pump	-5.7	-43.06	
60	Hand pump	-4.5	-33.5	
62	Hand pump	-4.8	-27.18	11.7
63	Hand pump	-5.5	-38.55	
64	Hand pump	-3.78	-32.88	6.2
65	Hand pump	-4.54	-34.84	13.7
P-1	Hand pump	-8.1	-58.9	14.2
P-2	Hand pump	-8.2	-56.44	11.6
P-3	Hand pump	-6.7	-46.93	18.8
P-4	Hand pump	-4.84	-35.1	12.9

Table 4. Isotopic data of groundwater in Marala-Khanki area (July 2009)

Sample #	Source	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	Tritium (TU)
5	Hand pump	-4.1	-25.4	
7	Hand pump	-4.2	-27.7	
11	Hand pump	-7.7	-44.2	
12	Tube well			
14	Hand pump	-4.9	-43.02	
16	Hand pump	-2.5	-20.33	
23	Hand pump	-4.04	-27.28	7.9
26	Tube well	-4.51	-43.76	
27	Hand pump	-4.2	-29.27	9.6
28	Hand pump	-6.27	-40.85	
29	Hand pump	-7.58	-47.32	
31	Hand pump	-6.34	-44.29	
41	Tube well	-6.19	-46.5	
42	Hand pump	-6.43	-43.22	
46	Hand pump	-6.2	-37.63	
46A	Tube well	-5.3	-37.8	
47	Hand pump	-6.19	-41.4	
49	Hand pump	-6.4	-40.26	
51	Hand pump	-9.5	-62.6	
53	Hand pump	-9.1	-55	
54	Hand pump	-4.5	-27.9	
55	Hand pump	-8.5	-53.58	9.4
55A	Tube well			5.4
56	Hand pump	-7.13	-47.35	4.7
57	Hand pump	-4.12	-39.81	
58	Hand pump	-7.84	-50.73	
58A	Tube well	-7.91	-42.3	
60	Hand pump	-5.28	-36.38	
61	Hand pump	-4.72	-34.88	10.7
61A	Tube well	-4.59	-32.88	
62	Hand pump	-5.57	-34.45	
63	Hand pump	-7.75	-55.57	
64	Hand pump	-3.96	-28.1	15.9

Table 5. CFC data of groundwater in Marala - Khanki area

Sample No.	Concentration (pmol/kg)			Recharge Year		
	CFC-12	CFC-11	CFC-113	CFC-12	CFC-11	CFC-113
1	1.57	1.64	0.08	1980	1973	1976
3	X	X	0.33			1987
4	0.96	1.39	0.13	1974	1971	1979
6	0.72	1.1	0.08	1971	1970	1976
9	4.58	3.54	0.19		1981	1983
10	1.00	0.71	0.05	1974	1967	1973
11	X	X	0.25			1985
12	X	X	0.09			1977
13	0.66	0.72	0.09	1970	1967	1976
22	2.29	5.9	0.33	1988		1987
23	1.4	0.44	0.02	1978	1964	1965
24	1.06	0.25	0.03	1974	1961	1966
26	1.28	0.56	0.02	1977	1965	
28	1.13	0.92	0.05	1975	1969	1973
30	0.68	1.03	0.1	1970	1969	1977
31	1.7	2.74	0.26	1982	1977	1985
35	1.92	3.47	0.35	1984	1981	1988
36	0.71	0.37	0.05	1971	1963	1973
P-2	X	X	0.45			1990
P-3	2.44	5.84	X	1989	1992	

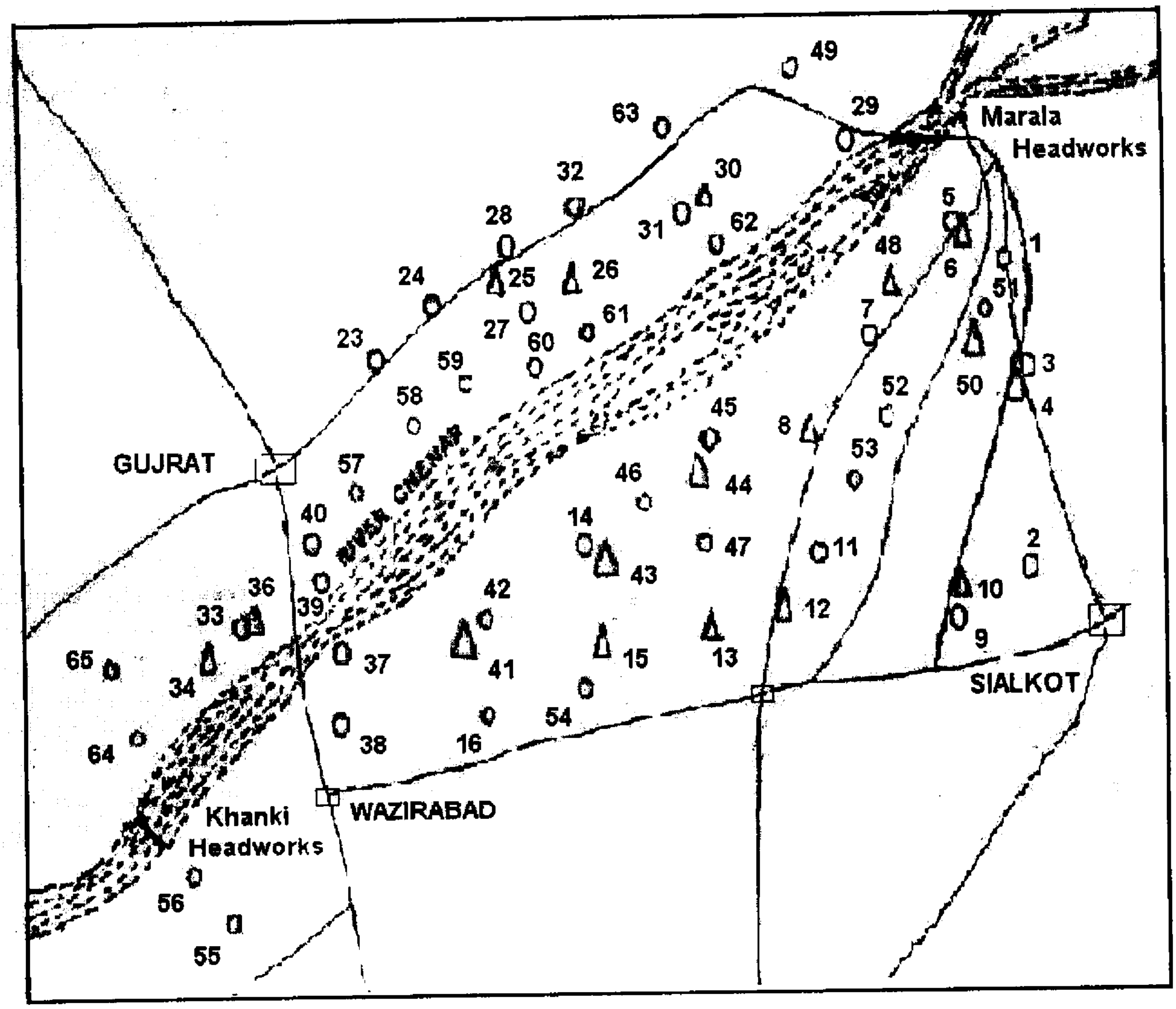

Fig. 1. Location of sampling points (groundwater) in Marala –Khanki Area
(o = Handpump, Δ= Tubewell , □ = City)

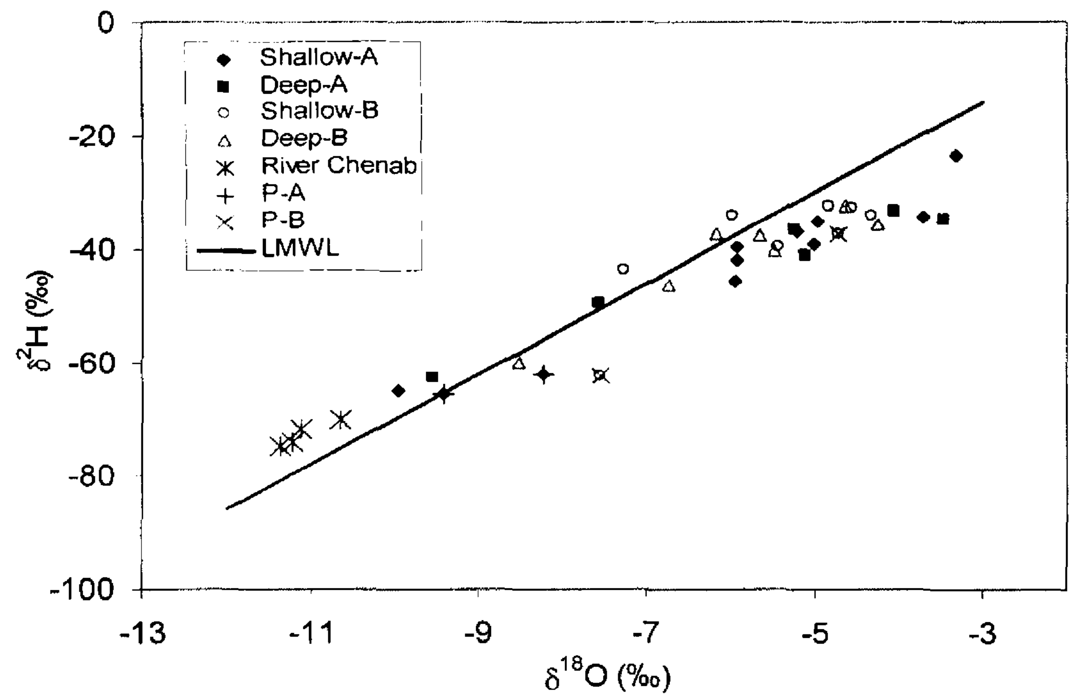

Fig. 2. Isotopic data of groundwater in Marala-Khanki Area (Aug. 2005)

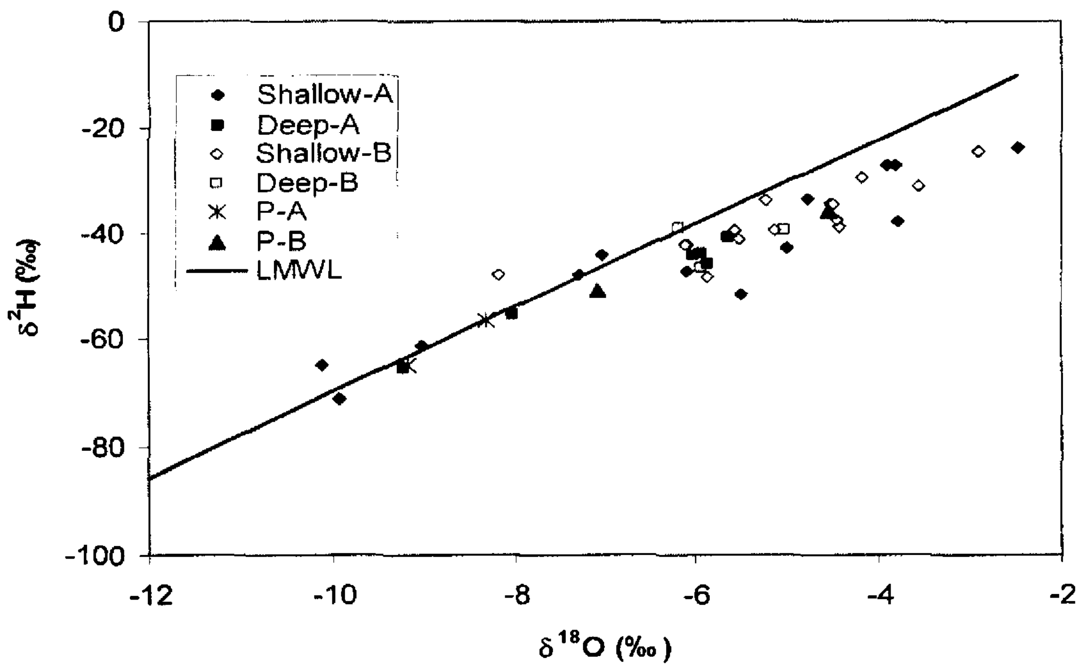

Fig.3. Isotopic data of groundwater in Marala-Khanki area (Jan. 2006)

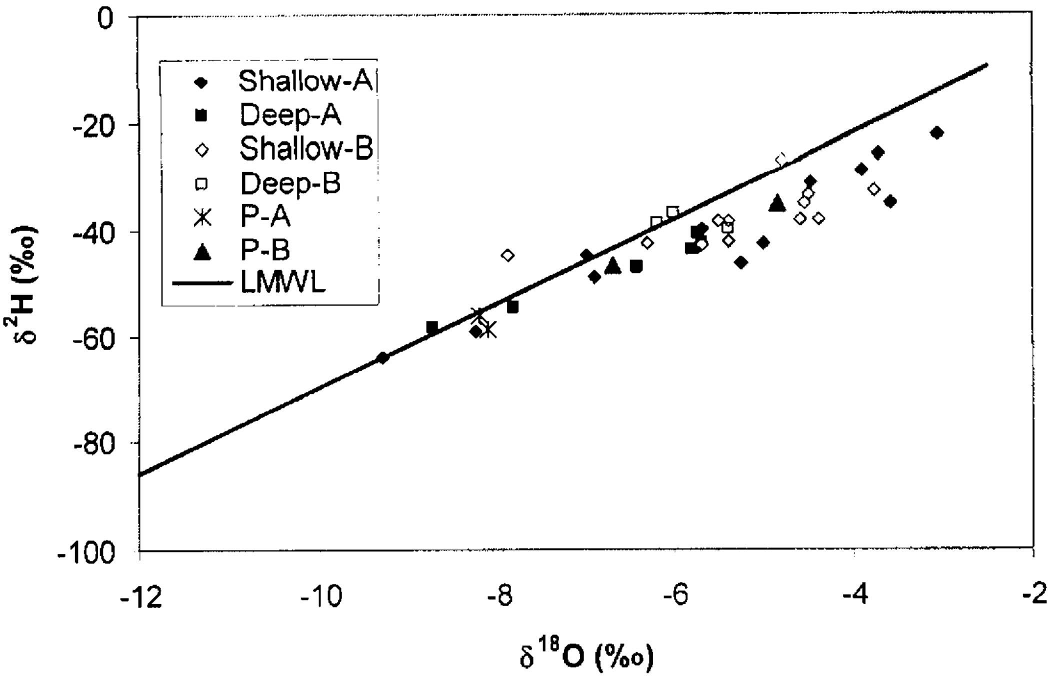

Fig. 4. Isotopic data of groundwater in Marala-Khanki area (Feb. 2009)

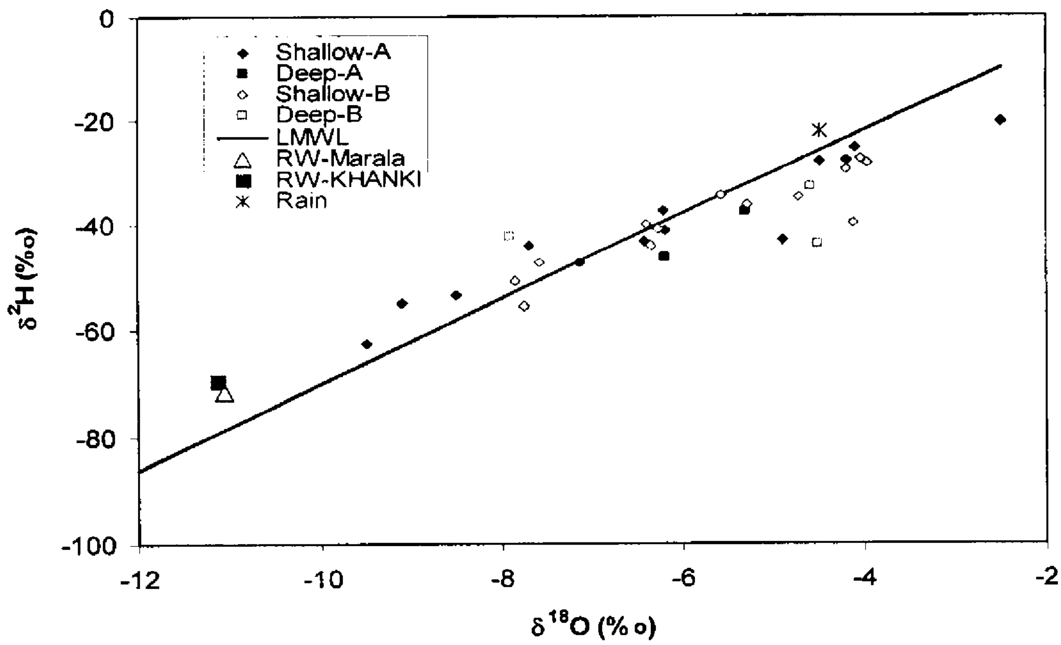

Fig. 5. Isotopic data of groundwater in Marala-Khanki area (July 2009)