PINSTECH/RIAD-133

STUDY OF GROUNDWATER RECHARGE IN RECHNA DOAB USING ISOTOPE TECHNIQUES

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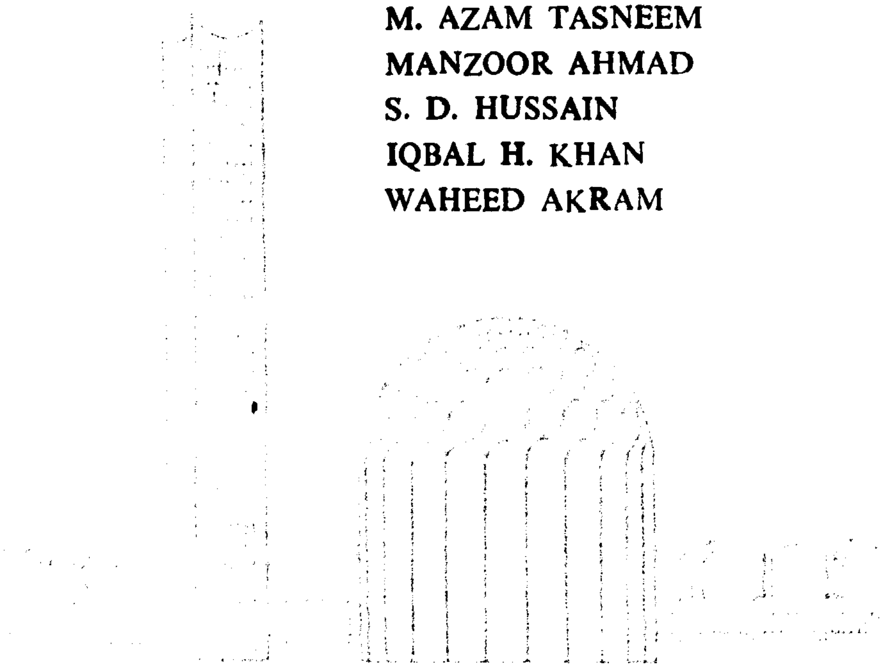

RADIATION AND ISOTOPE APPLICATIONS DIVISION
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ABSTRACT

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Isotopic studies were performed in the Rechna Doab area to understand the recharge mechanism, investigate the relative contributions from various sources such as rainfall, rivers and canal system and to estimate the turn-over times and replenishment rate of groundwater. The isotopic data suggest that the groundwater in the project area, can be divided into different zones each having its own characteristic isotopic composition. The enriched isotopic values show rain recharge and depleted isotopic values are associated with river/canal system while the intermediate isotopic values show a mixing of two or more sources of water. The major contribution, however, comes from canal system. The isotopic data suggest that there is no quick movement of groundwater in the area.

STUDY OF GROUNDWATER RECHARGE IN RECHNA DOAB USING ISOTOPE TECHNIQUES.

1. INTRODUCTION

The increasing world population led to extensive agriculture and expansion of industries, thereby, putting greater demand on water. In the last few decades, an increasing awareness has thus been shown on the importance of occurrence and distribution of water on the earth. A great importance is now being given to hydrology all over the world in the development and management of water resources.

The project area "Rechna Doab" which is a part of Indus Plain, plays an important role in the economy of Pakistan. For the last few decades, the agricultural economy of Pakistan is facing serious problems. Thousands of hectare of irrigated land has been lost either completely or partly to cultivation by waterlogging and salinity due to improper development and management of water resources. For the groundwater development and estimation of safe yield, it is important to study the potential sources of groundwater recharge and relationship between different hydraulic regimes.

Isotope hydrological investigations were initiated in Rechna Doab with the following main objectives:

a) To identify different recharge sources in the area and their relative contribution.

b) To establish a relationship between different hydraulic regimes in the area.

c) To estimate the turnover times of groundwater.

2. THE PROJECT AREA

2.1 GENERAL DESCRIPTION OF THE AREA

Rechna Doab comprising about 28,500 sq. Km is enclosed by the river Chenab on the north-west and river Ravi on the south-east with the piedmonts near the Jammu and Kashmir boundary in the north-east. Rechna Doab is about 403 km long in a southwest direction and has a maximum width of about 113 km. The location of the project area is shown in figure 1. The area is interfluvial and is southwesterly sloped. In the upper part of the Rechna, Doab the slope is about 380 cm/km to about 9 cm/km.

In Rechna Doab area, controlled irrigation system was started with the construction of Marala, Khanki, Qadirabad and Trimmu Head Works on the river Chenab. All the canals flowing through the study area have been taken out from the river Chenab. The main irrigation canals are the Upper & the Lower Chenab Canals (UCC & LCC) and BRBD. LCC (taken out from Khanki H/works) has four main branches namely: Jhang Branch (JB), Rakh branch and, lower & upper Gugera and Burala branches. Four link canals viz. Marala Ravi link (taken out from Marala H/works) and Qadirabad-Balloki link (taken out from Qadirabad H/Works) and two from Trimmu H/works (Haveli canal and Trimmu-Sindnai link canal) are also flowing through the area (figure-1A).

The river Jhelum is also contributing to the area through a link canal feeding river Chenab at Khanki H/works and itself joining river Chenab at Trimmu H/works - upstream of confluence point of rivers Chenab and Ravi.

2.2 CLIMATE

Climate of the area is sub-humid in the northeast to semi-arid in the southwest and is characterized by seasonal changes in temperature and precipitation. The precipitation has a marked seasonal fluctuation and also differs considerably across the area increasing from south to north. In the high relief area the precipitation may exceed 89 cm per year but in the southwest it decreases to about 20 cm per year near the confluence of the rivers Ravi and Chenab. About 70 percent of the average annual rainfall occurs in the period from June to September.

During summer (June to August) the day temperature is generally more than 40.5 °C while the maximum temperature during winter (December to February) is between 15.5 and 21.1 °C and minimum temperature between 3 to 7 °C. The mean summer temperature is about 32 °C; the hottest day may reach 49 °C while the minimum summer recording may be as low as 21 °C [Khan, 1978].

2.3 SURFACE AND SUBSURFACE GEOLOGY

The consolidated exposed rocks near Chiniot, Sangla and Shahkot represent the remnants of the buried ridge of metamorphic or igneous rocks forming the basement of the alluvial deposits in the Doab. These indurated rocks are known as Kirana Hills and are of Precambrian age. These rocks cover the central part of Rechna Doab making the longitudinal section across its width.

The unconsolidated alluvial deposits are of Pleistocene to Recent in age and are overlying the Precambrian basement rock. These were deposited in a subsiding trough by the ancestral and present tributaries to 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 constant change in the stream courses.

The alluvial sediments mainly consist of gray, grayish brown, fine to medium sand, silt and clay. Gravel or very coarse sand are uncommon, Kankers, a calcium carbonate material of secondary origin are associated with fine-grained strata. Clay is generally found in lenses. The origin of clay 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 ground water occurs under water table conditions [Khan, 1978].

3. FIELD WORK

After preparation of area maps, actual sampling stations were selected in the field and are shown in figure 1A. Sampling stations include already existing tubewells, hand pumps and canals in the project area. The distance between the sampling stations is from 15 to 20 km depending upon the availability of hand pumps and tubewells and other field conditions. In total 150 stations were selected for regular sampling. Five water samplings (March 88, Dec. 88, March 89, Sep. 89 & Jan. 90) were carried out. Physiochemical parameters like pH, electrolytic conductivity and temperature of the water samples were measured in-situ. Weekly sampling of canals at some selected points had also been arranged. Multiple depth piezometers were installed at different locations to study the vertical distribution of isotopes in groundwater.

4. LABORATORY WORK

Water samples were prepared for mass spectrometric analysis for determination of D/H and $^{18}O/^{16}O$ ratios. Tritium analysis for most of the samples was done on scintillation spectrometer after enrichment of samples. The electrolytic conductivity (EC) of deep and shallow zones was plotted to locate the saline zones in the area for installation of piezometers.

5. RESULTS AND DISCUSSION

5.1 SOURCES OF GROUNDWATER RECHARGE

Three possible sources of groundwater recharge in the area are:

a) rivers, canals and their distributaries(all unlined)
b) rains and
c) irrigation water from canal system and tube-wells.

5.1.1. ISOTOPIC DATA OF RIVER/CANAL SYSTEM

The canal system (canals and branches) have $\delta^{18}O$ & δD in the range of -11.75 to -6.25‰ and -80 to -38‰ respectively as shown in figure 2. All values of δD and $\delta^{18}O$ of the canals are well represented by the regression line:

$$\delta D = 8\ \delta^{18}O + 14$$

The seasonal variations of $\delta^{18}O$ for rivers Chenab, Ravi and Jhelum are shown in figures 3-5. Some special features are as follows:

5.1.1.1. RIVER CHENAB

The river Chenab was sampled at Marala and Trimmu H/works. $\delta^{18}O$ and δD of samples at Marala have range from -12 to -6.5%o and -76 to -32%o respectively. The weighted averages are:

$\delta^{18}O$ = -10.04%o
δD = -61%o
^{3}H = 30 TU (variation 24 to 58 TU)
d = 18%o (deuterium excess)

The weighted averages at Trimmu H/works are:

$\delta^{18}O$ = -9.36%o
δD = -59.4%o
d = 15.5%o

The enrichment in isotopic data and decrease in deuterium excess at Trimmu as compared to Marala is due to the contributions of river Jhelum at Khanki (downstream of Marala) which has weighted averages as [Hussain, et.al., 1990]:

$\delta^{18}O$ = -7.95%o
δD = -64%o
d = 15%o

5.1.1.2. RIVER RAVI

The river Ravi was sampled at Balloki H/Works and has weighted isotopic data as:

$\delta^{18}O$ = -8.30%o
δD = -52.4%o
d = 14%o

5.1.1.3. UPPER CHENAB CANAL (UCC)

Isotopic index of UCC which has been taken out from river Chenab at Marala H/works, would be on slightly heavier side as compared to that of river Chenab itself. Its estimated values for $\delta^{18}O$ and δD are -9.63 and -59%o respectively. The discharge of the canal is kept almost constant over the year and includes heavier isotopic values (with same discharge as that of lighter) during the months of Jan. to March. Whereas in the case of river Chenab, these heavier values are associated with smaller discharge rates as compared to that during the monsoon. Moreover, the most depleted values of the river during July to September are associated with higher discharge rates due to monsoon and snow melt at high mountains. As a result, the river index is slightly more depleted compared to the canal taken out from it.

5.1.1.4. LOWER CHENAB CANAL (LCC)

LCC has four main branches e.g. Jhang Branch, Rakh branch and upper and lower Gugera branches. These irrigate about 2/3 area of the Doab starting from right of Qadirabad - Balloki link up to Trimmu-Sindnai link canal. The canals flowing through out the year have similar isotopic variations. The range of $\delta^{18}O$ values is -11 to -5‰ with mean value of -8.6‰ The range of δD variations is -79.8 to -21.3‰ with a mean value of -53.5‰. The discharge of river Chenab shows a peak during July-September period. The most depleted values of $\delta^{18}O$ in these canals are also found almost during the same period indicating major contribution from snow-melt and rains at high mountains.

The isotopic index of LCC, $\delta^{18}O = -8.6‰$ is much higher than that of UCC ($\delta^{18}O = -9.63‰$) due to the reason that downstream of Marala H/Works and upstream of Khanki, the river Chenab is fed by the river Jhelum through a link canal. In the water of river Jhelum, the isotopic variations are damped due to storage effect at Mangla Lake. Furthermore, its water is characterized with slightly heavier isotopic contents due to altitude effect of catchment area and evaporation during the storage period.

5.1.2. ISOTOPIC DATA OF RAINS

The isotopic indices of rainfall are more depleted in north-east area due to high altitude and high intensity of rains than those of in the south-west areas due to relatively low altitudes and low intensity of rainfall.

As the isotopic data of rains of less intensity are significantly affected by evaporation and such rains are most probably insignificant in recharging the groundwater, only rains with intensity above 15 mm were considered while taking weighted average of one year rainfall at Faisalabad. The $\delta^{18}O$ is -4.0‰.

The weighted average values of $\delta^{18}O$ and δD of rainfall (selected events, more in next section) at Sargodha (100 km from Faisalabad) over the period of four years are -4.5‰ and -22‰ represented by [Hussain et. al, 1990].

$$\delta D = (8 \pm 0.4)\delta^{18}O + (14 \pm 2) \quad (\text{corr.coeff} = 0.97)$$

To determine isotopic index of rainfall at the piedmont area near Jammu and Kashmir boundary in the north-east of project area, six sampling points out of eight (shallow and deep wells) along Sialkot-Pasrur-Narowal cross-section line) were selected. These wells are located away from the canals in Bar upland and are beyond the reach of flood water of the rivers. Moreover, upper soil layers are silty and would resist the infiltration from local rains, so can only be recharged by adjoining piedmont front. The mean $\delta^{18}O$ and deuterium excess of these wells are -6.8‰ and 9.3‰ respectively. These values can safely be taken as isotopic index of rainfall at piedmont area. Two sampling points (both shallow wells) excluded, have mean $\delta^{18}O$ as -5.3‰ and d-excess of 8.5‰. This may represent the isotopic index of local rains as suggested by lower d-excess due to evaporation before infiltration in the soil.

6. ISOTOPIC VARIATIONS IN GROUNDWATER

6.1. SOME FEATURES OF δD-$\delta^{18}O$ DIAGRAMS

Evaluation of the isotopic variations with time, space and some features of δD-$\delta^{18}O$ diagrams as depicted in figures 6-8, are as under:

The range of $\delta^{18}O$ for the groundwater is -10 to -5‰ while for the rivers and rains it is -11.75 to -4‰. The isotopic range of shallow and deep water is very similar to that of the river system. However, their range of variations is smaller. This is essentially due to smoothing effect in the soil due to dispersion and mixing. Figure 2 further demonstrate that the range of river system extends more towards depleted values of $\delta^{18}O$ and δD.

The wide spread isotopic data along δD-$\delta^{18}O$ line suggest that the groundwater is a mixture of varying proportions of two or more sources each having its own characteristic isotopic composition.

The groundwater especially towards the heavier isotopic side (figures 6) shows evaporation effect. It may be due to one or more of the following causes:

a) Continuous Recycling of partially evaporated irrigation water (pumping and then infiltration).

b) Direct evaporation from the water table where it is close to ground surface.

c) Contribution of already evaporated rains through sandy soils.

Another important feature of δD-$\delta^{18}O$ is that the spread of "deuterium excess" of deep and especially shallow waters is more in lighter values (depleted) and tends to approach a value of 8 on the heavier side (figure 6). This low deuterium excess on heavier side could be due to mixing of partially evaporated irrigation waters or/and infiltration of local rains which have usually heavier isotopic values (low d-excess) than the groundwater recharged by river system.

The groundwater samples having isotopic values on the heavier side (figures 7 & 8) fall on the δD-$\delta^{18}O$ regression line with slopes of 6 & 7 in lower and upper Rechna doab respectively.

The isotopic data of river/canal system (figure 2) and that of rain specially at Sargodha (section 5.1.2) lie on the slope of about 8. In case of Sargodha rains, different situations depending upon the limitations on the amount of precipitation, were studied and different regression equations between δD and $\delta^{18}O$ were obtained [Hussain et. al. 1990]:

Precipitation: > 5 mm:

$\delta D = (8.05 \pm 0.48)\delta^{18}O + (13.48 \pm 6.01)$ $n=27, r=0.958$

Precipitation: > 10 mm:

$\delta D = (7.91 \pm 0.59)\delta^{18}O + (12.61 \pm 6.89)$ $n=19, r=0.956$

Precipitation: > 15 mm:

$\delta D = (7.96 \pm 0.67)\delta^{18}O + (12.42 \pm 7.15)$ $n=14, r=0.960$

Precipitation: excluding all positive $\delta^{18}O$ and δD values:

$\delta D = (7.50 \pm 0.54)\delta^{18}O + (9.43 \pm 7.68)$ $n=33, r=0.947$

Evaporation and isotopic exchange between droplets, water vapour and falling raindrops in a cloud are the dominant factors responsible for the fact that the best-fit lines for local precipitation often have slope less than 8 [Dansgaard, 1964]. Rains represent the cloud base composition only in humid climates and when it is abundant. When the air beneath the cloud base is unsaturated, the rain evaporates in part during its fall to ground, with a modification of both the drops and their environment. This is again a non-equilibrium fractionation which results in the increase of the heavy-isotope content of the residual drops and a decrease of value of the associated 'd'-parameter [Stewart, 1975].

Coming back to the groundwater in Rechna doab, at some sampling stations, groundwater samples exhibit evaporation effect and lie on a regression line of slope of 7 or even lower (figures 7 & 8). As this evaporation and consequently the enrichment in $\delta^{18}O$ (or δD) is not associated with the increase in salinity, the evaporation must have occurred before infiltration in the the soil. This is further demonstrated by the example of upper Chaj doab which is exclusively recharged by rains. For which the regression line between δD & $\delta^{18}O$ has slope close to 8, while the similar regression line of the corresponding groundwater has slope of 7 as in the equation [Hussain et. al. 1990]:

$\delta D = (7.08 \pm 0.52)\delta^{18}O + (5.03 \pm 1.97)$ $n=24, r=0.897$

Here too, the isotopic enrichment has no correlation with chloride.

6.2. SPATIAL AND TEMPORAL VARIATIONS OF ISOTOPIC DATA

Spatial distributions of $\delta^{18}O$ of shallow and deep groundwater and the contours of delta values are given in figures

10-12.

In general, the most heavier $\delta^{18}O$ values are found in the north-east of project area, and become gradually more and more depleted towards the confluence area (south-west) with the most depleted (-10 ‰) just upstream of Trimmu H/works where the river Jhelum (with relatively higher $\delta^{18}O$ index) joins the river Chenab. Similarly, most depleted values of $\delta^{18}O$ are found along length of river Chenab and become more and more heavier toward the river Ravi (width wise).

Another distinct feature of isotopic data is that the contours of deep aquifer are more regular and well-defined as compared to shallow ones (figure 11 and 12). This is due to the fact that a number of processes such as mixing of rain water with irrigation water and that of canals, pumping of shallow groundwater through a large numbers of hand pumps and then partial infiltration of the same, presence of drains with heavier isotopic contents etc., are simultaneously taking place in the upper part of the soil zone.

The variations of isotopic contents of groundwater with time are seen as a response to the seasonal variations in the isotopic values of input sources. Such variations can be seen in the groundwater near water channels and also in some of the shallow wells. Away from the canal system and also in deeper zone these variations cannot be seen because of smoothing effect.

7. THE GROUNDWATER RECHARGE FROM DIFFERENT INPUT SOURCES

The project area can be divided into different regions on the basis of isotopic data.

The active flood plains along the rivers Chenab and Ravi are generally recharged by the respective rivers. The canals and rainfall in these areas locally modify the isotopic contents of the river recharged plains (figures 1A & 10).

The Bar uplands in the north-east of project area up to Qadirabad - Balloki link canal, have isotopic contents (i.e $\delta^{18}O$) very similar to that of rainfall($\delta^{18}O$ = -6.8‰) over the piedmont area on the north-eastern boundary of the project area (figures 10-12). Here infiltration takes place along the boundary of the project area in the piedmont region. The upper silty layers in most of the region restrict the surface infiltration. This is further manifested by the fact that three canals (BRBD, UCC and Qadirabad-Balloki link canal) with mean $\delta^{18}O$ of -9.63‰ are flowing through this area for more than couple of decades, but there seems the least influence of this isotopically depleted water in the groundwater regime ($\delta^{18}O$ around -6.8‰). This is demonstrated by the histogram in figure 9 where the majority of samples are grouped around $\delta^{18}O$ values of -6.75 and -5.5‰ which are isotopic indices of rainfall at piedmont areas and local rains respectively.

However, there is an exception too. A small area bounded by dotted line (below Marala H/works) which has two groups: first one with $\delta^{18}O$ in the range of -5.9 to -5.0‰ (9 hand pumps and tubewells) characterized by average tritium content of 20 TU, seems to be recharged by local rains. This area has about 3 m thick layer of silt at the top below which there exist a sandy zone. The recharge may be taking place by infiltration through some sandy region extending up to the surface layer. The other group of three wells have $\delta^{18}O$ in the range of -8 to -7‰. It might have been recharged at least 30 to 50 years ago as one well has tritium content of 55 TU and other two close to 2 TU.

The frequency histogram of mean $\delta^{18}O$ values for shallow and deep waters (figure 13-15) depict a clear picture of recharge mechanism in the area. Two peaks at $\delta^{18}O$ values of -6.8‰ and -8.6‰ which represent isotopic indices of rainfall at piedmont area and UCC respectively, are major sources of recharge in the area.

The area near Trimmu H/works bounded by river Chenab and a dotted line has most depleted $\delta^{18}O$ values and is solely recharged by the river Chenab ($\delta^{18}O$ = -10‰).

8. TURN-OVER TIMES OF THE GROUNDWATER

There is a wide range of variations with time in the stable isotopes of input sources. However, with the exception of certain areas, no such variations have been observed in the groundwater indicating that there is no quick movement of groundwater in the area.

Three input sources of recharge: namely river Jhelum, river Chenab and rains at piedmont area have weighted tritium contents as 32 TU (range 23-47 TU), 30 TU (24-58 TU) and 20 TU (9-48 TU) respectively. The groundwater in the project area has tritium range of 0 to 57 TU. The spatial distribution of tritium in groundwater is given in figure 16. On the basis of tritium data, the area can be divided into four main categories:

a) Tritium contents 0-2 TU

The area having tritium contents of 0-2 TU were certainly recharged before 1950s when thermonuclear tests were made in the northern-hemisphere releasing a large quantity of tritium into the atmosphere. In Pakistan, it reached its peak value during 1964. Most of the samples have tritium in the range of 0-4 TU. Another small group with 20-24 TU indicates the recent recharge.

b) Tritium Contents 3-10 TU

Here too, the major recharge took place about 40 years ago but also have small contributions after the year 1964.

c) **Tritium Contents 11-35 TU**

Areas with tritium values between 11-35 TU were recharged very recently or have major recharge of the recent time.

d) **Tritium Contents 36-57 TU**

Groundwater with tritium contents more than 35 TU were recharged during 1963-64 period when this region received peak of tritium due to nuclear tests.

9. VERTICAL DISTRIBUTION OF ISOTOPES.

The multi-depth piezometers were installed at various sites in the area. The Isotopic data of piezometers penetrating up to depths of 23 m indicate that there is a spatial variation in ^2H and ^{18}O contents. This variation has a range of -10 to -6‰ in $\delta^{18}O$ and -65 to -40 ‰ in δD. This again proves the fact that the different areas in Rechna Doab are recharged by different sources. However, no significant isotopic variation with depth and time, at any piezometer site exists. Isotopic data especially the tritium contents delineate that downward movements are rather slow.

Wells penetrating up to about 190m depth in the Faisalabad city area, were sampled at different horizons by means of packers. There is no systematic decrease in stable isotope contents with depth. Such a decrease of stable isotopes would indicate that there is groundwater of glacial or pluvial times with colder climates. Such a climatic change took place about 10,000 years ago and is not conserved in the area under study.

Further, the mean isotopic values of deeper wells ($\delta^{18}O$ = -10‰ , δD = -62‰) are very much identical to those of present river waters and quite different from the rainfall data. This is enough evidence to show that in the deeper zone (190 m depth), infiltration from rivers is dominant source of recharge.

The tritium data with mean value of 1.3 TU suggest that the recharge to these wells, must have taken place prior to bomb test i.e. before 1952. This would mean that minimum time span during which no significant recharge has occurred is about 40 years and, their replenishment rate is rather slow.

10. CONCLUSIONS

1) The bar upland in the north-east of the project area up to Qadirabad-Balloki link canal is being recharged by the rainfall over the piedmont on the north-eastern boundary of the project area.

2) The data of the north-western part of the project area bounded by the river Chenab and dotted lines (figure 10) shows that the groundwater is being recharged

directly by the river itself.

3) The isotopic data in the rest of the project area show that the groundwater is a mixture of different input sources. However, the major contribution comes from the canal system. The groundwater towards heavier isotopic side shows evaporation effect. It may be due to one or more of the following reasons: a) Continuous recycling of partially evaporated irrigation water (pumping and then infiltration through soils), b) Direct evaporation from the water table where it is close to the ground surface, c) Contribution of already evaporated rains through soils.

4) Stable isotopes and tritium data suggest that (with the exception in certain areas), there is no quick movement of groundwater in the area.

5) The piezometric isotopic data indicate that the spatial isotopic variations do exist up to 25 m depth from the surface while the deeper zone (below 30 m) have no systematic isotopic variation with depth and space. So this region can be termed to have pre-irrigation groundwater. Also, infiltration from rivers seems to be the dominant source of recharge to the deep groundwater.

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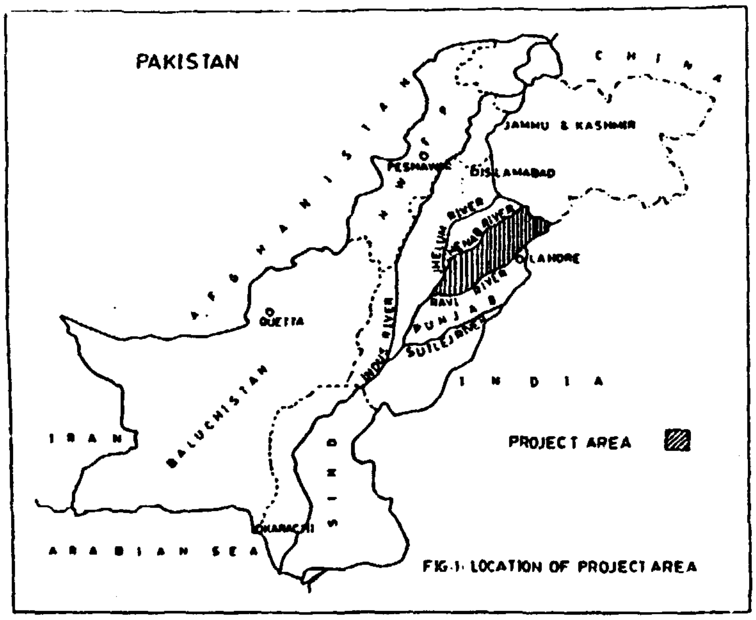


FIG-1: LOCATION OF PROJECT AREA

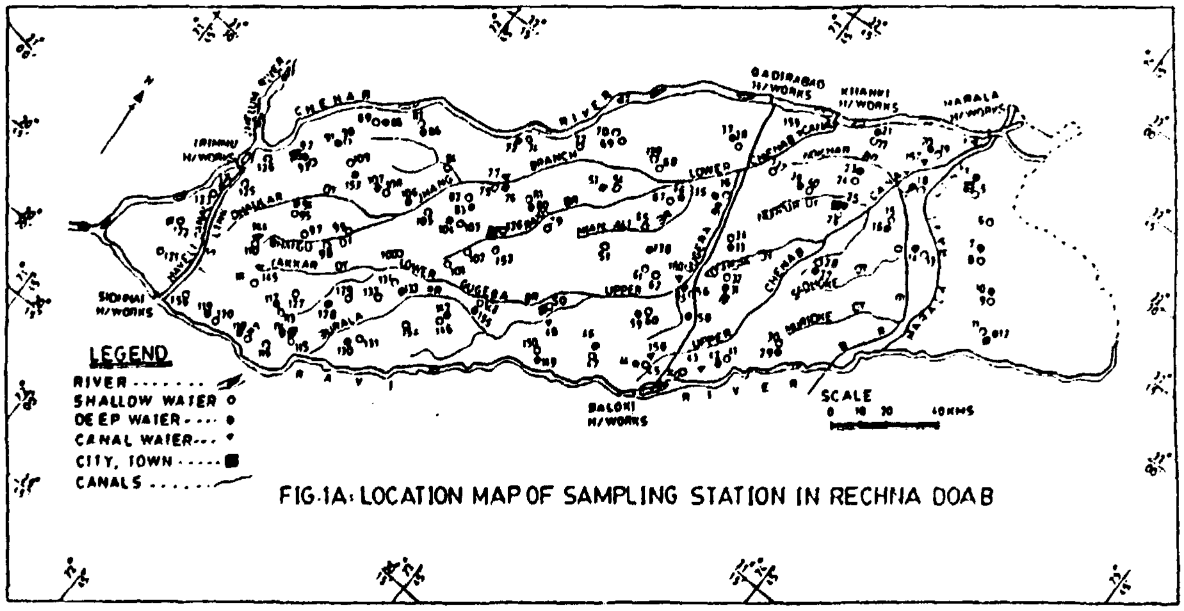


FIG-1A: LOCATION MAP OF SAMPLING STATION IN RECHNA DOAB

FIG.2: δO-18 VS δD OF RECHNA DOAB CANALS

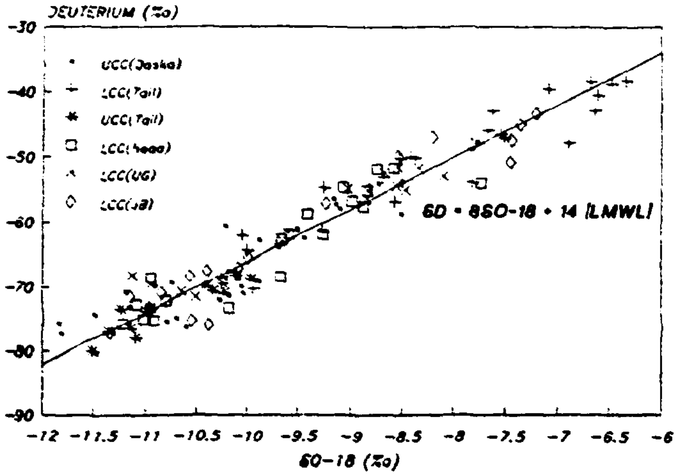


FIG. 3: VARIATION OF δO-18 OF RIVERS AND CANALS

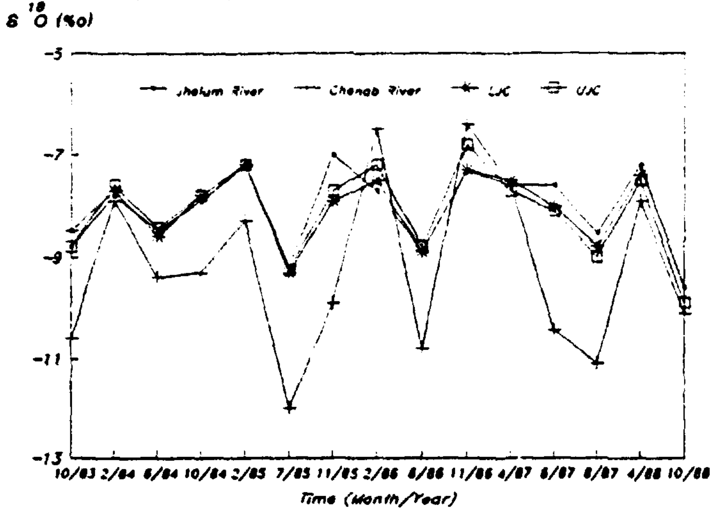


FIG. 4: VARIATION OF δO-18 OF RIVER CHENAB AT TRIMMU H/WORKS

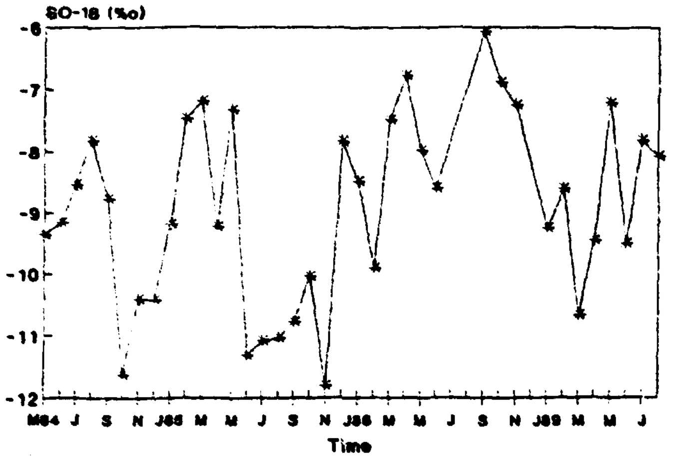


FIG. 5: VARIATION OF δO-18 OF RIVER RAVI AT BALLOKI H/WORKS

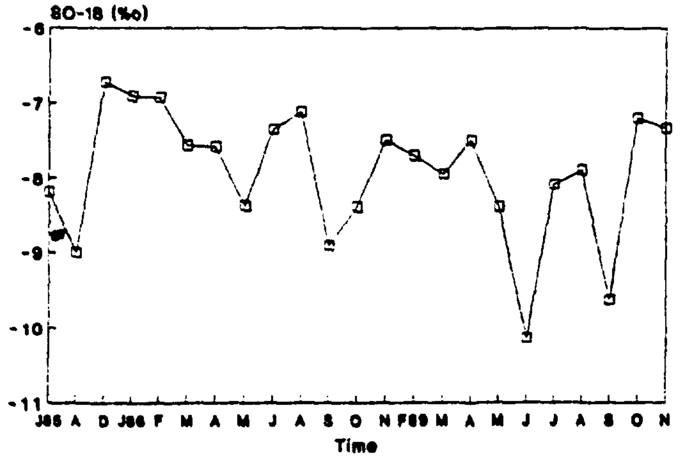


FIG. 6: δO-18 VS δD OF GROUNDWATER AND CANALS (MEAN VALUES)

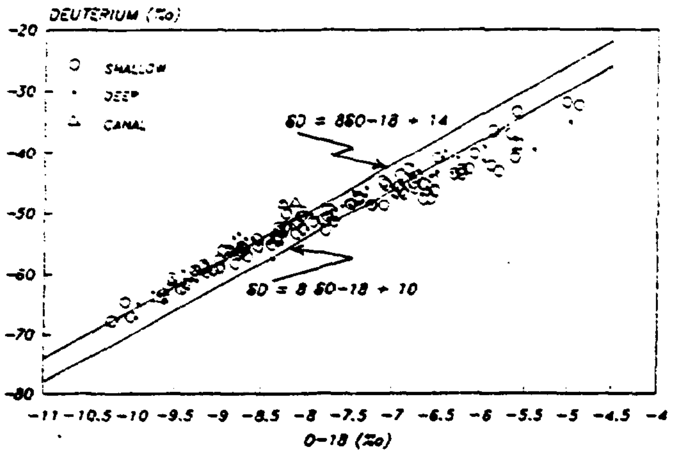


FIG. 7: O-18 VS DEUTERIUM OF LRD AREA Mean Values of shallow & deep waters.

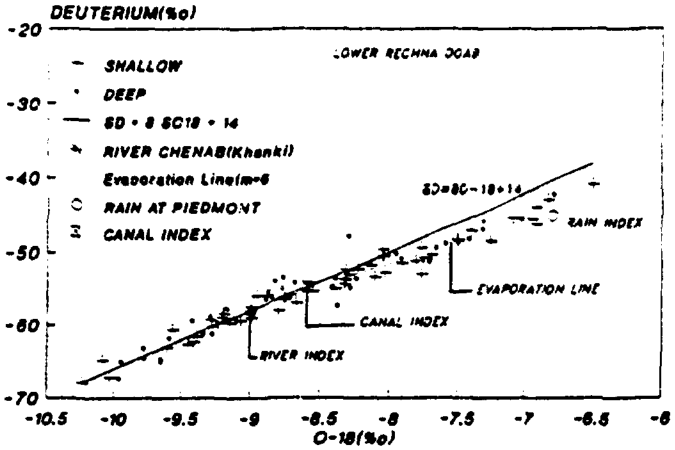


FIG.8: O-18 VS DEUTERIUM (URD AREA) Mean Values of shallow & deep waters.

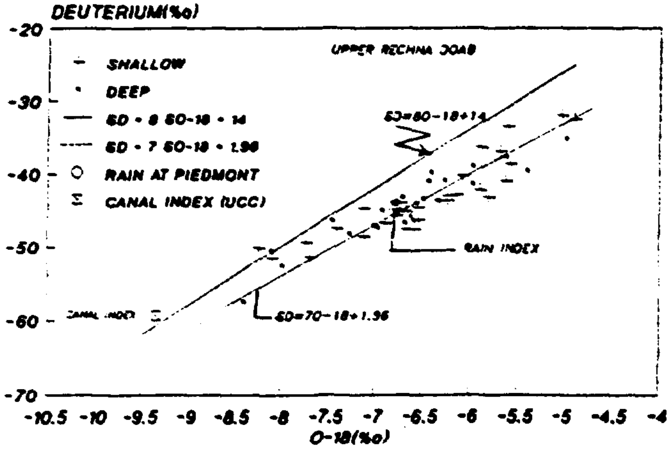
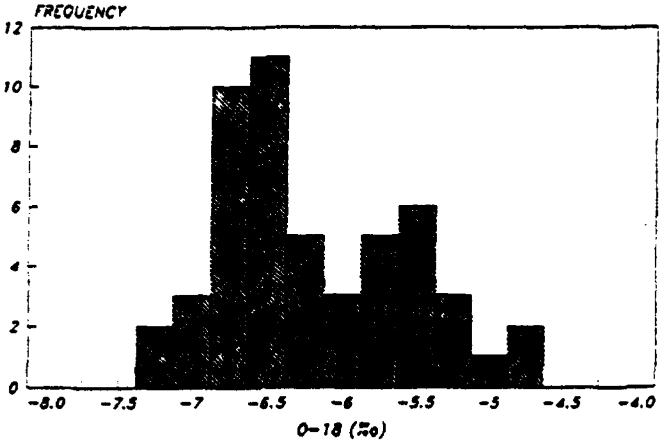


FIG. 9: FREQUENCY HISTOGRAM OF δO-18 OF GROUNDWATER (North-eastern part of Doab)



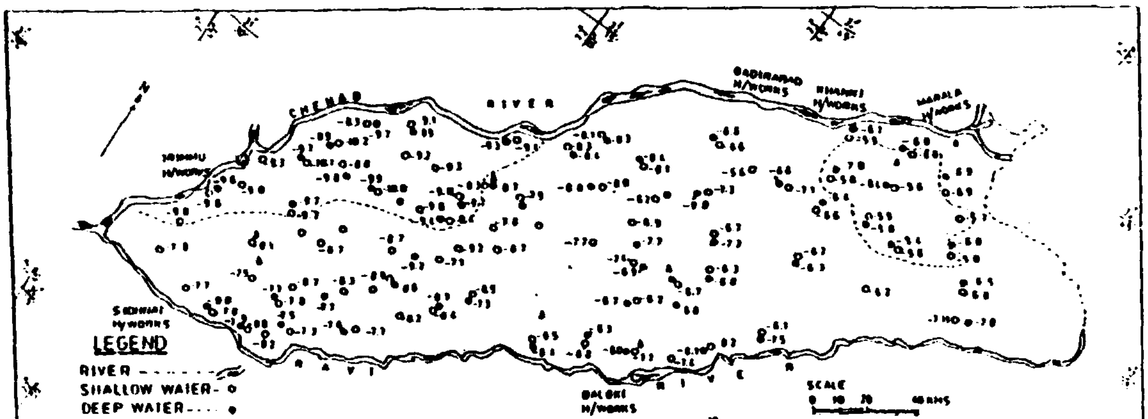


FIG.10. SPATIAL DISTRIBUTION OF $\delta^{18}O$ OF SHALLOW & DEEP GROUNDWATER IN RECHNA DOAB

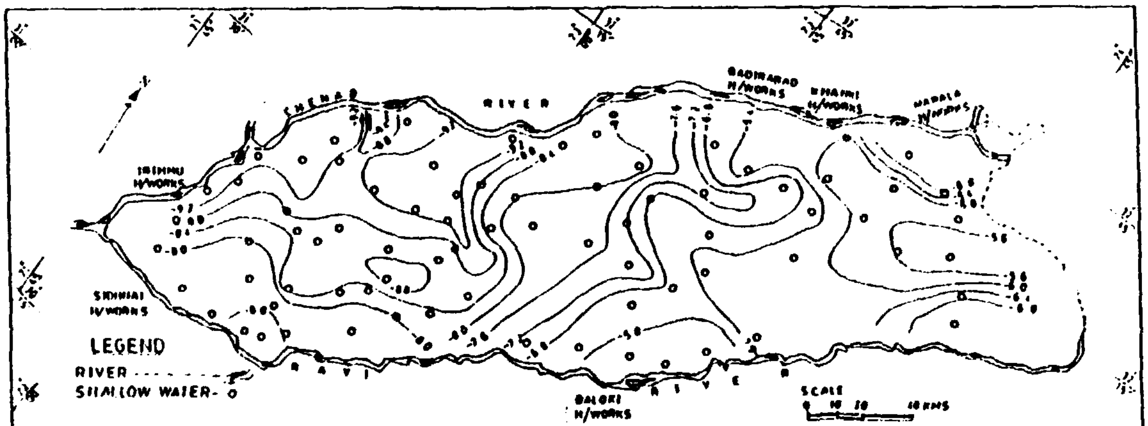


FIG.11. CONTOURS OF $\delta^{18}O$ OF SHALLOW GROUNDWATER IN RECHNA DOAB

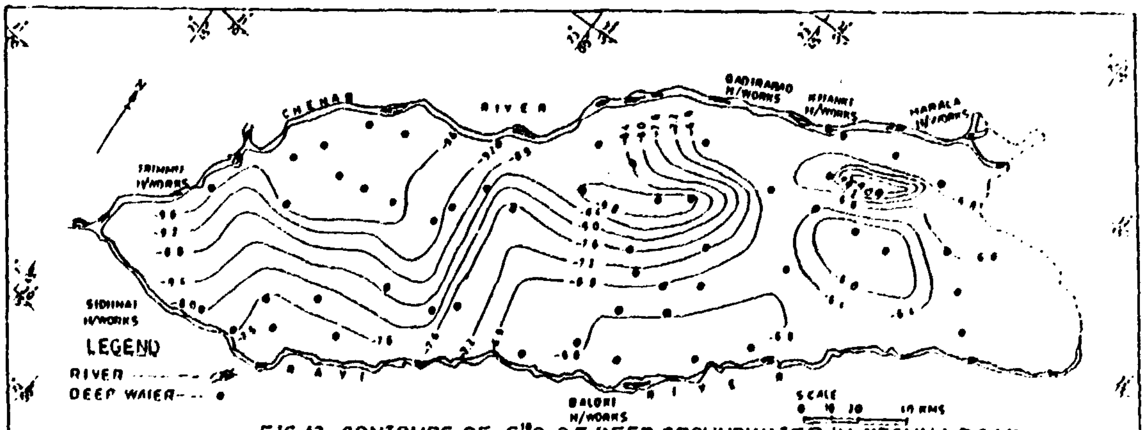


FIG.12. CONTOURS OF $\delta^{18}O$ OF DEEP GROUNDWATER IN RECHNA DOAB

Fig. 13 : Frequency Histogram of δO-18 of Shallow Groundwater (Mean Values)

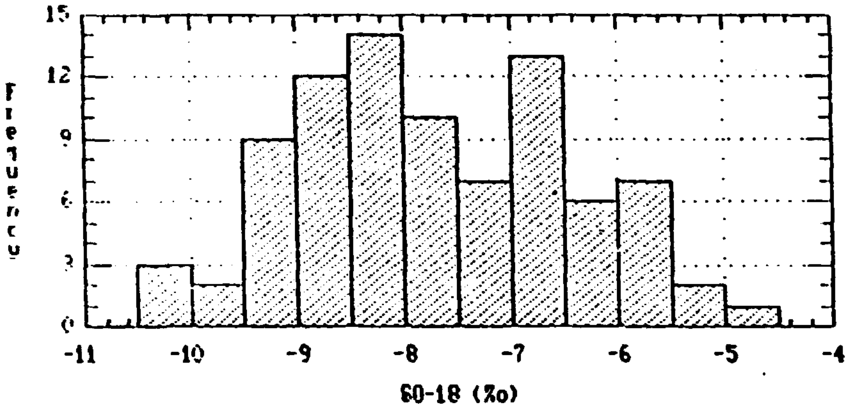


Fig. 14 : Frequency Histogram of δO-18 of Deep Groundwater (Mean Values)

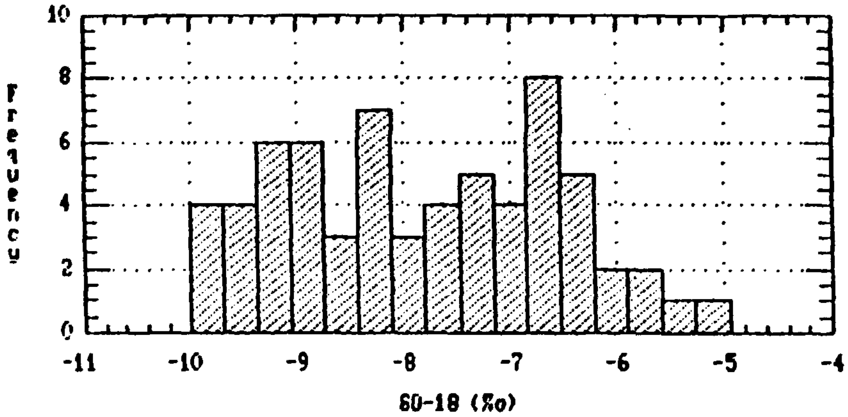
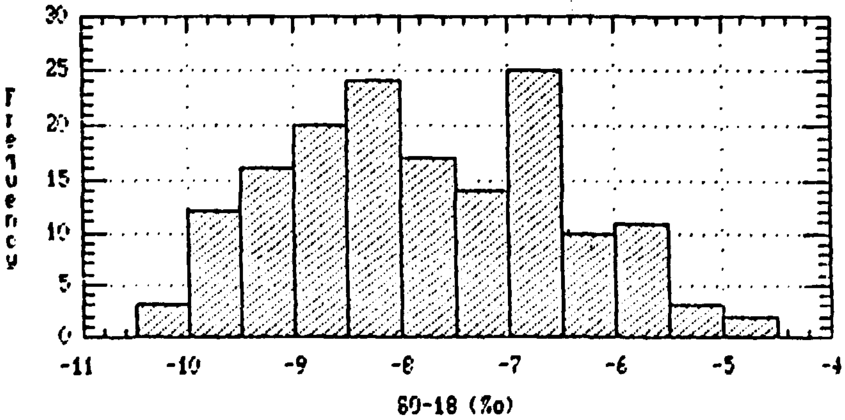


Fig. 15 : Frequency Histogram of δO-18 of Shallow & Deep Groundwater (Mean Values)



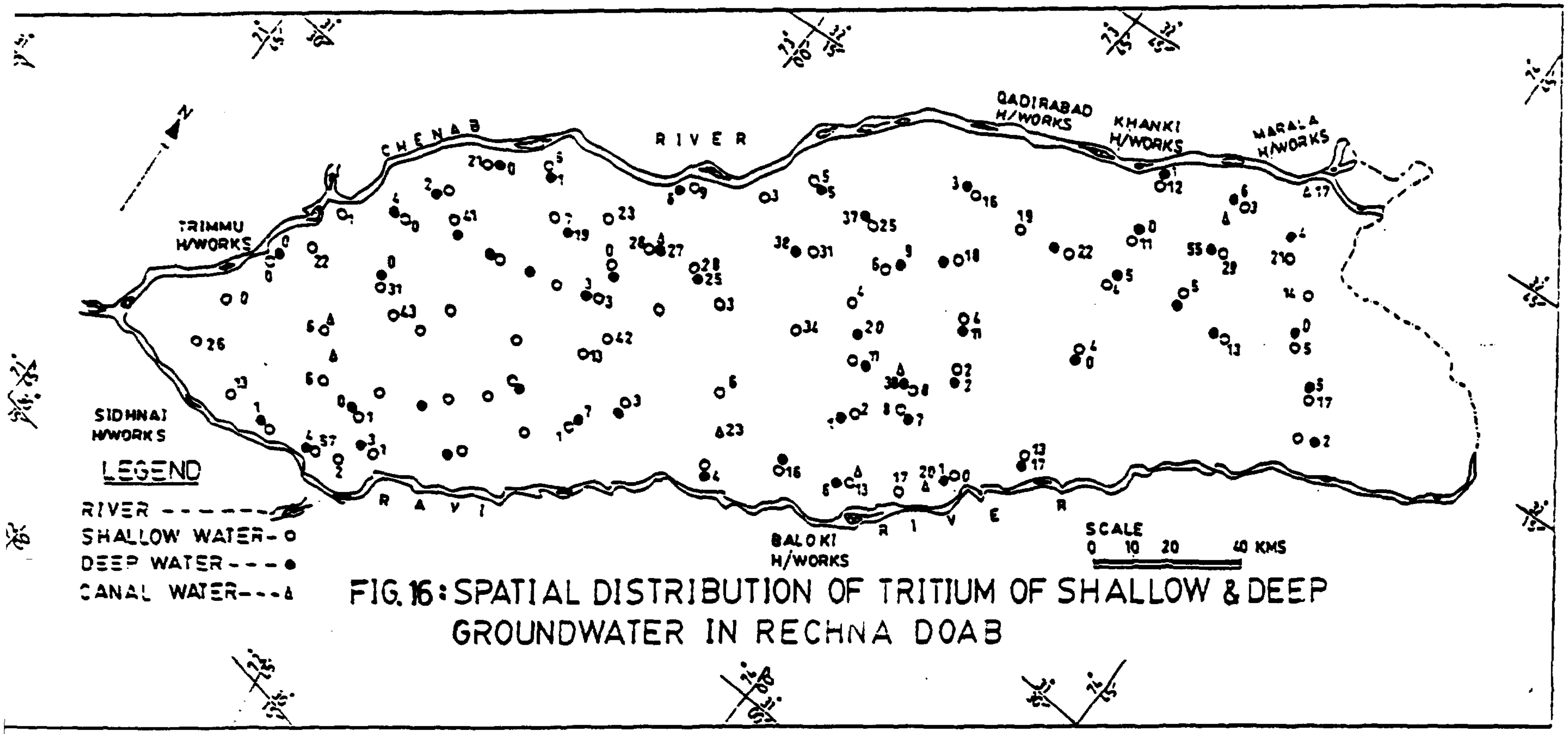


FIG. 16: SPATIAL DISTRIBUTION OF TRITIUM OF SHALLOW & DEEP GROUNDWATER IN RECHNA DOAB