PINSTECH/RIAD-141

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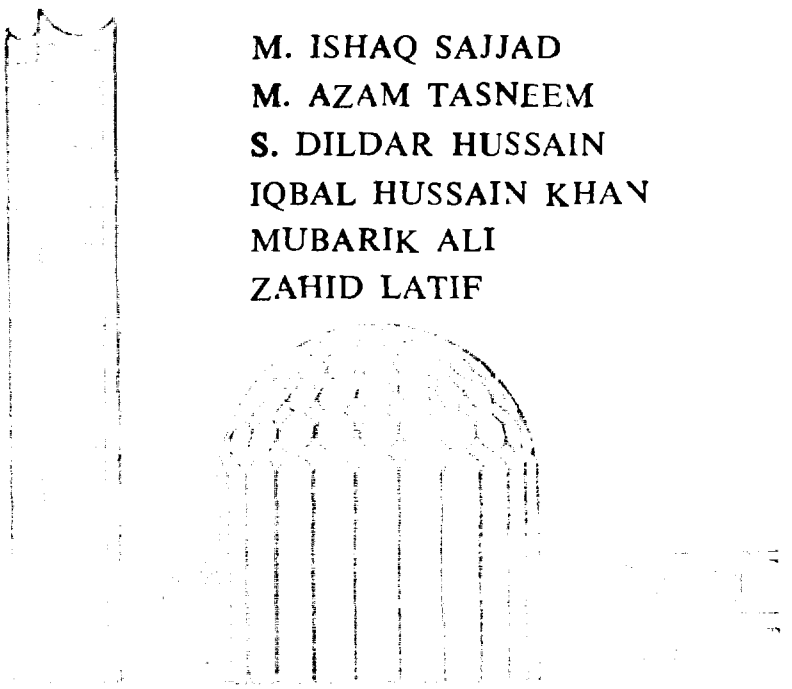

Radiation and Isotope Application Division
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C O N T E N T S

A B S T R A C T

Isotopic studies were carried out on the right side of river Indus, downstream of Tarbela dam to study the effect of Tarbela Reservoir on the groundwater system. The main objectives of the study were to determine the hydraulic connection, if any, between the Tarbela Lake and the groundwater appearing in the ponds near Gadoon Amazai, see the effect of Tarbela dam on the groundwater system in the downstream areas, compute the relative contribution of different recharge sources towards groundwater system and to estimate residence time of groundwater in the area. Isotopic data reveals that the ponds near Gadoon Amazai area are being recharged by local rains and there is no contribution of Tarbela lake. The area around Gadoon Amazai, Topi and Kalabat is solely recharged by local rains while the area around Swabi, Zaida and Lahor has mixed recharge with major contribution from local canal system. Tritium data suggests that the residence time of groundwater in the study area varies from a few years to 30 years. The groundwater in the area has low dissolved salt contents and is, generally, of good quality.

ISOTOPIC STUDY OF THE EFFECT OF TARBELA RESERVOIR ON THE GROUNDWATER SYSTEM IN THE DOWNSTREAM AREAS

1. INTRODUCTION

Tarbela Dam came into existence as a result of Indus waters Treaty signed in 1960 between India and Pakistan. Under the Treaty, waters of the three eastern rivers; Sutlej, Beas and Ravi went to India's share and three western rivers; Chenab, Jhelum and Indus were reserved for exclusive use of Pakistan. In order to restore water to canal system fed by the three eastern rivers, the Indus Basin Settlement (Replacement) plan envisaged construction of two storage dams, Mangla Dam on river Jhelum and Tarbela Dam on Indus, five barrages, one gated siphon and eight inter-river link canals.

Tarbela Dam, the giant multi-purpose dam, completed in 1976 has been built across the river Indus. It is situated in northern Pakistan (figure 1), about 64 km (40 air miles) in the north-west of Islamabad at the latitude 34° - 5'N and longitude 72°-41'E. Emerging from the land of glaciers on the northern slopes of Kailash ranges, some 5182 meters above mean sea level, the river Indus has its source near the lake Mansrowar in the Himalayan catchment area.

The Tarbela reservoir is 97 km long, 260 square kilometer in area and has a gross storage capacity of 17.109 million cubic meters at the maximum lake elevation of 472 m, a residual capacity of 2.802 million cubic meters at the assumed level of maximum drawdown of 396 m and a net capacity of 14.307 million cubic meters. The total catchment area above Tarbela is spread over 168,000 sq.km. which largely brings in snowmelt supplies in addition to some monsoon rains. Two main upstream tributaries join the river Indus; the river Shyok at an elevation of 2438 meters above m.s.l. near Skardu and the river Siran just north of Tarbela. Appendix-A gives the hydrology, meteorology and other particulars of Tarbela project [WAPDA, 1984].

Initially, hundreds of sinkholes and cracks were developed in the damsite bed during the first filling of the reservoir. Excessive seepage through the dam foundation and its abutment also presented serious problems. These were, later on, rectified. However, it is still observed that water table rises in the downstream areas when the reservoir attains its highest level in the monsoon season. There has been a perception that water table rise may be associated with the rise of reservoir level and creation of sinkholes at the bottom of the reservoir bed.

The national press repeatedly pointed out the appearance of water in the ponds near Gadoon Amazai and related it to the seepage from the Tarbela dam. Keeping in view the

above, it was decided to apply the isotopic techniques help understand the real situation.

Isotopic studies were planned to achieve the following objectives:

i) To determine the hydraulic connection, if any, between Tarbela lake and the groundwater appearing from ponds near Gadoon Amazai.

ii) To see the effect of seepage from Tarbela reservoir on the groundwater system in the downstream areas.

iii) To compute relative contribution of seepage from Tarbela lake and other recharge sources such as rain to the groundwater system.

iv) To estimate the residence time distribution of the groundwater regime.

2. GEOLOGICAL ASPECTS OF THE TARBELA DAMSITE

Tarbela Dam is located in the Hazara Hills, which are part of the mountain group known as the Lesser Himalayas. The Hazara Hills are composed of a succession of sedimentary, igneous and metamorphic rocks ranging in age from Pre-cambrian to Permian. The present geologic structure is the result of extensive folding, shearing and faulting associated with regional crystal deformation arising from the northward sub-duction of Indian Subcontinental plate below the Eurasian plate.

There are three distinct geological formations at the Tarbela damsite: The Salkhala Formation, forming the right bank; the Hazara Formation, forming the bedrock base of the Indus Valley; and the Kingriali Formation, forming the left bank. The right and left banks are separated by 1.8 km wide flood plain of the Indus River. The river flows past the site in a braided stream pattern on alluvial deposits at about El. 338 meters. The alluvium in the valley is, at places, up to 200 m deep and consists mainly of boulder gravel choked with fine sand. At some places, lenses of fine sand occur and at others, openwork cobble gravel, and medium to coarse sand is present, resulting in a kind of skip graded material. At one time, alluvium filled the valley above El. 448 m. Above the flood plain the hillsides are generally steep, with slopes often controlled by the dip of bedding on joint systems.

The right bank is formed by the Salkhala Formation which is highly metamorphosed. It is composed of strongly folded, sheared and jointed schists and lime stone and is intruded by a joint spacing of one to two feet. The left bank is formed by the Kingriali Formation, which consists of sequences of dolomitic limestone with phyllite quartzite and sills of basic igneous rocks.

The geological feature of greatest potential concern relative to Tarbela dam is the Darband fault, which passes through the damsite. This fault is considered to be inactive, however, and may be too deeply buried by river alluvium to promote leakage. The schistose rocks in the west abutment are weak, permeable, and cut by numerous shear zones. The dolomite rocks of the Abbottabad Formation in the east abutment area, although much jointed, are rigid and relatively impermeable in comparison with the rock in west abutment area.

3. CLIMATE

The local climate is characterized by two seasons: summer, extending from April through September; and winter, for the remaining months. Although some precipitation occurs each month, there are two well-defined periods of rainfall. The more important is the monsoon during July, August and September; less precipitation falls during the late winter-early spring period. Annual rainfall at Tarbela averages about 76 cm per year with nearly one-half of this amount occurring in July and August and one-quarter in the winter-spring period. In the mountainous upper portion of the river basin the reverse is true: winter precipitation, almost entirely snow, equals and in places exceeds that of summer. Average daily temperatures at Tarbela range from 7 °C in January to 41 °C in June. Extreme maximum and minimum temperatures range from 45 °C to 3 °C. Relative humidities are low, exceeding 50 percent only during the monsoon season [WAPDA, 1984].

4. RECHARGING SOURCES IN THE PROJECT AREA

The project area, being downstream of the Tarbela reservoir, is located on the right bank of the river Indus and extends upto Sulai Dher & Swabi in the north, and Lahor in the west. While the river Indus itself flows along the southern boundary of the project area.

The sub-soil regime in the study area can be recharged by the local rains, the river Indus (higher reaches contributing to downstream sites), Swat canal system in the western parts of the area and Tarbela reservoir itself.

5. SAMPLE COLLECTION AND ANALYSIS

60 water sampling stations, selected from the existing open wells, tubewells, springs, drains, the river Indus, Tarbela lake were established as shown in figure 2. Water samples were collected from these sampling points during September, 92 and January, 1993. Temperature and electrolytic conductivity measurements were made in situ. Analyses of samples for $\delta^{18}O$, $\delta^{2}H$, ^{3}H(tritium) and radicals like Na, Mg, Ca, CO_3, HCO_3, SO_4, Cl, etc. were carried out in the laboratory. Rain samples from

Tarbela damsite were also collected and analysed. Tarbela lake was sampled more frequently to find its mean isotopic index.

Delta (δ) given above is defined as:

$$\delta \text{ \%o} = [\{ R_{sample} / R_{standard} \} - 1] \times 1000$$

where 'R' is ratio of $^{18}O/^{16}O$ or D/H for sample and standard, and %o is per mil(per 1000).

6. MATERIALS AND METHODS

Nuclear techniques, based on the use of isotopes, have been employed in this study. Isotopes are generally of two types: stable and radioactive. Stable isotopes occur naturally in the elements. The material does not decay. Thus, without being concerned about a time factor, its long term effects can be studied accurately. The radioactive isotopes can be prepared artificially. In nature these are also produced by cosmic rays or testing of nuclear devices in atmosphere. Radioactive isotopes decay with time and can be detected in very small quantities.

Environmental stable isotopes are readily available as a part of water molecule. Their fractionation effects are particularly useful for hydrological research. Very commonly used isotopes for hydrological studies are deuterium, oxygen-18 and tritium. Deuterium and tritium are isotopes of hydrogen while oxygen-18 is an isotope of oxygen (with mass 18). All these are a part of water molecule. Oxygen-18 and deuterium are ideal tracers and their amounts in environment cannot be changed by man. Their variations established in water by natural processes can be observed and interpreted to solve hydrological problems.

It would be interesting to know how the isotopic variations are registered in the water bodies. Water molecule contains various isotopes of hydrogen (protium, deuterium) and oxygen (oxygen-16, oxygen-18). The water molecules containing heavier isotopes such as deuterium & oxygen-18 have slightly lower vapour pressure than the water having lighter isotopes. Fractionation is a process that separates the different isotopes of the same element. This happens in both physical and chemical reactions. Due to different thermodynamic properties, molecules with different masses have different rate of evaporation, condensation and freezing. Thus, during the condensation of rain or evaporation of water, different isotopes are partially separated from each other.

The biggest water body on the earth is in the form of oceans. During the evaporation from the ocean surface, water molecules with lighter isotopes evaporate more rapidly compared to those with heavier isotopes(i.e. deuterium & oxygen-18). This way, the evaporating vapour mass is said to be depleted in heavier isotopes compared to the remaining ocean water. Mathematically speaking, the relative difference of heavier

isotopes in the departing vapour mass with respect to the ocean would be a negative number.

While on condensation, exactly reverse happens i.e. during each rain event, the heavier molecules condense first leaving the remaining vapour mass(clouds) depleted in heavier isotopes or abundant in lighter isotopes. This way, as the vapour mass moves towards the higher altitudes, the remaining vapour front, after successive rain events, becomes lighter and lighter isotopically. Similarly, the oxygen-18 and deuterium contents in water decrease with the increasing distance from the oceans in the direction of vapour transport. When measured on a mass spectrometer with respect to a standard ocean water, the relative difference would be a negative number and is expressed in per mil(i.e. per thousand). Thus, a rain at high mountains of the Himalayas range, being at high altitude and far distant from sea, would be more depleted in oxygen-18 isotopes compared to a rain at Islamabad.

The rain events occurring at low temperatures and high latitudes also contain less oxygen-18 and deuterium. Similarly, oxygen-18 contents in heavy rains are lesser than in the light rains. This way, the different waters are labeled with isotopes which can be accurately measured with a mass spectrometer.

The radioactive part of the water molecule i.e tritium has shorter half-life as compared to carbon-14. Therefore, tritium is of special value in detecting recent recharge(upto 50 years) because of its short half-life and high levels of tritium in atmosphere due to testing of the nuclear devices in 1952. Carbon-14 with its half-life of thousands of years makes it especially valuable for dating slow-moving groundwaters.

The tritium(T) and carbon-14 (C-14) contents of groundwaters are affected by the same natural mixing processes as stable isotopes. However, the T and C-14 inputs have, especially in recent years, been controlled by processes both natural and artificial. These processes were completely different from those controlling the stable isotopes. As a result, these present an entirely different picture. Thus, groundwaters tend to show a distinct layering of T and C-14 content with radioactivity decreasing with depth. In systems characterized by relatively rapid movement of groundwater, longitudinal dispersion is very important and the initial variability of isotope input may be quickly damped. This way, the different isotopes: stable and radioactive play an important role as tracers in hydrological studies.

The cost of such investigations is often relatively small in comparison with the cost of classical hydrological techniques. In addition, they are able to provide information which sometimes can not be obtained with other techniques. The time span required to obtain a particular information is significantly small for isotope techniques as compared to classical methods.

For mass spectrometric analysis of D/H ratios, the water sample is totally reduced and hydrogen produced is used as measuring gas. 8 μl water sample is introduced under vacuum into a specially designed glass container which already had 0.25 mg of cleaned and degassed zinc shots(0.5 - 2.0 mm size). The container is heated in an aluminum furnace at 480 °C, where after 30 minutes, all the water is converted into H_2 gas [Sajjad, 1989].

$^{18}O/^{16}O$ measurement in water samples is made by CO_2 equilibration method. Under vacuum, cylinder CO_2 is introduced into reaction vessels containing water (27 samples at a time). The reaction vessels, coupled to the manifold, are immersed into a constant-temperature water bath (at 22 ± 0.1 °C) and are shaked for three hours. The equilibrated CO_2 is then used as measuring gas [Sajjad, 1989].

The isotopic ratios; $^{18}O/^{16}O$ or D/H were measured on a Varian Mat. GD-150 mass spectrometer (modified). The measuring accuracies in 'δ' are 0.1 ‰ and 1 ‰ for $\delta^{18}O$ and δD respectively. Tritium in water samples was measured by a scintillation spectrometer after electrolytic enrichment. The error in measurement is around 1 TU (1 TU equals to 1 atom of ^3H in 10^{18} atoms of H_2). A rigorous treatise on environmental isotopes is given in the appendix 'B' under **Isotope Hydrology**.

7. R E S U L T S

The results of the isotopic data of surface and groundwater are given in tables I & II. These have also been plotted and depicted in figures 3-16.

7.1. Isotopic Index of Rain

Rain samples from Tarbela damsite were collected and analysed for $^{18}O/^{16}O$ and D/H ratios. Tritium measurements were also made in selective samples. However, to determine the representative isotopic indices, a much longer study period is required whereas the present study was limited to only nine months.

Haripur plain, located on the eastern boundary of Tarbela lake, is recharged by the rainfall on adjacent mountains [Sajjad, et.al., 1992]. The rainfall there has mean $\delta^{18}O$ and δ^2H values as -5.38 and -30.0 ‰ respectively. Mardan valley, being on the western side of Tarbela dam, has rain index values of -5.0 and -30.0 ‰ for $\delta^{18}O$ and δ^2H respectively. While $\delta^{18}O$ of rainfall over the bedrock outcrop, along the northern boundary of Mardan valley, was estimated to be -5.6 ‰ [Sajjad, et. al., 1987].

In the project area, sampling points 54, 54A, 55, 57 and 58 have $\delta^{18}O$ as -5.0, -5.1, -4.9, -5.2 and -5.1‰ respectively. Out of these, three deep wells (tubewells) as shown

in figure 13, have mean $\delta^{18}O$ of -5.07‰ while two shallow wells(open wells) of -5.05 ‰. This vividly proves that whole strata around these sampling points, from top to the depth of tubewell, is recharged from the top surface and that too by a single source. Due to their location, being highly elevated compared to the bed of the river Indus, these are only recharged by the local rains. So the isotopic index of local rain can safely be taken as $\delta^{18}O$ = -5.06 ‰(mean of above wells). This value is identical to that of local rain of nearby Mardan valley[Sajjad,et.al.,1987].

The spring at sampling point T-8, sampled twice during September 1992 and January 1993, has mean $\delta^{18}O$ equal to -5.6‰ which is very much the same value as that of rainfall at the mountains bordering the northern boundary of Mardan valley. The isotopic index of rainfall at mountain ranges, in the east of Haripur plain, is -5.38 ‰ for $\delta^{18}O$ similar to that of spring in the project area [Sajjad,et. al., 1993]. The relatively depleted $\delta^{18}O$ value (-5.6‰) of the spring compared to that of local rain(-5.06‰) indicates that the spring is being recharged by rain at the high mountains(100-200 m high). This is further supported by the lower tritium content of 17 TU compared to the average value of 23 TU of other wells surrounding it. This reflects longer transit time during which the tritium decays to lower value.

7.2. Isotopic Indices of Tarbela Lake

Tarbela lake was sampled at the dam channel from September 1987 to March 1993 on monthly basis. $\delta^{18}O$ and δD variations with time are shown in figures 3 & 4. These variations are closely related with the volume of storage water(lake level). The lake water is isotopically most depleted in September-October when the lake level is maximum (472 m) and enriched in April-May when lake level is the lowest. At the time of maximum level, the contribution from the snow-melt and precipitation at high mountains, is maximum and water is depleted in heavy isotopes.

The mean isotopic indices of lake over the period of 1987-93 are -12.41, -86.04 ‰ and 31 TU for $\delta^{18}O$, δD and tritium content respectively.

7.3. Seepage from Tarbela Lake and Mixing Theory

Having determined the isotopic contents of two possible recharging sources of the groundwater regime in the project area, we now consider the mixing theory that computes the isotopic contents of groundwater due to seepage from Tarbela lake, and predicts the extent of the seepage.

Considering two component (rain, lake) mixing of water, the percentage(%) contribution of each component to the aquifer

is given by the relation [IAEA, 1983]:

% contribution from Tarbela lake, $f_l = [(\delta_m - \delta_r)/(\delta_l - \delta_r)]x100$

% contribution from rains, $f_r = [(\delta_l - \delta_m)/(\delta_l - \delta_r)]x100$

where; δ_l = delta value of Tarbela lake,

δ_r = delta value of rain,

δ_m = delta value of mixture of two sources.

According to above relations, in case of seepage/ leakage from Tarbela lake and its contribution to the downstream aquifer, one would expect isotopic contents of mixture to lie between the isotopic indices of local rain (-5.06 %o) and Tarbela lake (-12.41 %o).

To support the general findings of the stable isotope data as regards mixing processes occurring in the groundwater system, the cumulative-probability-distribution curve for $\delta^{18}O$ can be effectively employed.

The basic philosophy is that a random sample of sufficient size (in a statistical sense) collected from a population where the occurrence or the cause-effect relationship is governed by a certain given type of process (which in itself may include a large number of factors effecting the outcome) would be expected to result in a certain type of probability distribution, which is usually a normal distribution for most natural processes. The plot will be a straight line on normal-probability paper when considered as a cumulative probability of occurrence. Thus, the cumulative probability distribution curves can be used as a graphical method to infer whether the samples collected are governed by a unique type of process or whether more than one process is involved.

7.4. Isotopic Contents of Groundwater in Project Area

On having a look at figures 12 & 13, depicting the spatial variations of $\delta^{18}O$, one observes that:

a) two groups I & II encircled by dotted lines (fig.13) have isotopic values similar to that of rain.

b) tubewell in Abasin colony (sampling point T-40) has $\delta^{18}O$ values -11.1 and -10.8 %o during September 1992 and January 1993 respectively.

c) another group on the western boundary of the project area and outside circle I has $\delta^{18}O$ between -12 and -6 %o.

7.5. Water Chemistry

To collect informations about salt contents of groundwater and its variations in aerial and vertical extent, the electrical conductivity (EC) of water was measured in situ. The distribution of EC in space is shown in figure 17. The data shows that ranges of EC values of groundwater samples from open wells and tubewells are as below:-

Water source	No. of samples	EC value in μS/cm	
		Minimum	Maximum
Open wells	24	312	1915
Tubewells	13	318	1485

It is evident from the perusal of EC data that the groundwater in the study area has low dissolved salt contents. Hence its chemical quality is good.

The water samples collected from different sampling stations (open wells and tubewells) were analysed for their dissolved ionic concentrations. All the major ions such as Na^{+}, K^{+}, Ca^{+2}, Mg^{+2}, Cl^{-}, NO_3^{-}, SO_4^{-2}, HCO_3^{-} were determined. The results of chemical analyses are given in Table III. The water chemistry data has also been presented on a Piper trilinear diagram in figures 18 & 19.

It was observed that in case of open wells, Ca is the dominant cation at most of the locations which is generally balanced by HCO_3 anion giving rise to Ca-HCO_3 type of waters. Such type of waters are found at 13 locations out of 24 locations. Sodium constitutes 50% or more of the total cationic concentration in only 4 samples resulting into formation of Na-HCO_3 type of water.

At the remaining sampling sites, groundwater has a mixed character in terms of cations. As for as tubewells are concerned, their major ion chemistry shows that in this case too, Ca is the dominant cation in most of the samples. HCO_3 is the dominant anion in all the samples except one (T-7) where SO_4 is the dominant anion . So the most common type of groundwater is Ca-HCO_3 type. Na-HCO_3 type or mixed type waters are rare in the study area.

8. D I S C U S S I O N

The principle objective of the study was to determine the effect of Tarbela reservoir on the groundwater system in the downstream areas; especially to establish connection, if any, of the water appearing in ponds near Gadoon Amazai with Tarbela

reservoir, relative contributions of different recharge sources to groundwater and the residence time distributions in various parts of the project area.

8.1. Recharge Source of Pond Water near Gadoon Amazai and Surrounding Areas

Ponds were sampled during the months of August & November 1992, and January & February 1993. It is observed that the discharge from these ponds fluctuates and even at some occasions the discharging channel dries out. In the flowing conditions, the mean $\delta^{18}O$ of ponds is -5.03 %o identical to that of local rains. Otherwise, the isotopic content is -4.57 %o and this higher value is attributed to evaporation effect in the standing water. During the evaporation, water molecules with lighter isotopes(oxygen-16) escape preferentially compared to heavier one(oxygen-18). In this way, the remaining water becomes enriched in heavier isotopes as in the above case. The isotopic content of pond water (-5.03%o) is far different from that of Tarbela lake (-12.41%o). It may be noted that the error of measurement is only 0.15 %o. This fact proves it beyond any doubt that there is no contribution of Tarbela lake towards the ponds.

All the sampling points in areas encircled as I & II (figure 13) are grouped together as 'C' in $\delta^{18}O$-δD diagram in figures 5 & 6 and lie on the equation $\delta D = 8\ \delta^{18}O + 14$. This equation very well represents the local rain in Pakistan [Hussain, et.al.,1991]. The group 'C' has its middle value at -5.0 %o on the $\delta^{18}O$ axis which is identical to that of local rain index in the project area.

This is further supported by the cumulative-probability distribution curve (figure 15) for $\delta^{18}O$ values of all the sampled wells in the project area. All the wells in areas I & II lie on the straight line 'C' which has middle value of $\delta^{18}O$ = -5.0 %o, again proving the fact that pond and the areas I & II are solely recharged by the rains.

8.2. Source of Recharge of Tubewell in Abasin Colony

The tubewell in Abasin colony (sampling point T-40) has $\delta^{18}O$ values as -11.1 and -10.8 %o during September 1992 and January 1993 respectively. These isotopic values are closer to that of Tarbela lake(-12.41 %o) as compared to the isotopic content of rain water(-5.06 %o). According to the mixing theory, as discussed above, the contribution of lake water to this tubewell is around 80 % while 20 % comes from local rains. The big question now arises is that how Tarbela reservoir water is making its way to the tubewell. Is it directly connected with the tubewell or through the river Indus and its distributory i.e. Pihur canal? The isotopic techniques again help us in this matter. The tritium content of the tubewell is 34 TU (Fig. 14 and Table I) which is similar to that of Tarbela lake(31 TU). Had

the Tarbela reservoir contributing directly through the subsoil, the residence time of water would have been longer. In that case, the tritium content of the tubewell water would have considerably been lower than that of the lake (half-life of tritium = 12.43 years). The similarity in their tritium contents indicates that transit time is short. So the tubewell may be recharged by the river Indus itself or through its canal system.

8.3. Source of Recharge in Swabi, Zaida and Lahor Areas

$\delta^{18}O$ values of water from the wells in the above areas varies from -12 to -6 %o and lie in the mixing zone 'B' in figures 5 & 6 indicating more than one sources of recharge. On the cumulative-probability-distribution (fig. 15), all the wells representing the above areas group along the straight line 'B' which is the result of mixing between rain and some other source with $\delta^{18}O$ values much more depleted than rain. Figure 16 gives a negative correlation of tritium with the corresponding $\delta^{18}O$ values. The increasing trend in tritium concentration with the depletion in $\delta^{18}O$ values provides an evidence that the recharge in these areas is quick. So the areas are recharged by a local source which could only be the local canal system. The possibility of direct recharge from the river Indus is remote as the general groundwater movement is towards the river itself.

8.4. Relative Contribution from Different Input Sources

The frequency distribution of $\delta^{18}O$ values of all the sampled wells in the project area are plotted in figure 7 and figure 8 for the first and second samplings respectively. In the both figures, maxima is at $\delta^{18}O$ = -5.0 %o proving the fact that the major contribution is from rainfall. Again in the cumulative-probability- distribution curve, a large majority of wells group along line 'C' which represents contribution of rainfall. Some areas near Swabi, Zaida and Lahor have relatively depleted values of $\delta^{18}O$ in groundwater. The major contribution towards theses areas comes from local canal system.

8.5. Residence Time Distribution in the Project Area

Residence time distribution (transit time of groundwater) is estimated from the relation of tritium levels in groundwater with respect to those in rainfall and surface water. Tritium in the groundwater through its decay scheme with a half-life of 12.43 years provides residence time when compared with the present levels in the surface waters.

The spatial variations of tritium content of groundwater and surface waters sampled from the area, are given in figure 14 and their frequency distribution in figure 9. The majority of samples as indicated in figure 9 lie in the range of 17 to 35 TU with peak at 26 TU. The present tritium level in

Tarbela lake/river Indus is 31 TU while that local rain would be similar to that of Tarbela lake.

The residence time of groundwater in the study area varies from a few years to 30 years.

9. C O N C L U S I O N S

On the basis of isotopic data available so far, the following conclusions are drawn:

i) The whole study area can be divided into two groups. One being recharged solely by rain while the second group represents a mixed recharge. The area around Gadoon Amazai, Topi & Kalabat is solely recharged by local rains.

ii) While the areas of Swabi, Zaida and Lahor villages, are having a mixed recharge. Isotopic data show a mixture of local rain and canal system. Tritium and oxygen-18 correlation proves that the recharge in this area is relatively quick which is a clear evidence that the area is being recharged by a local source.

iii) The ponds in Gadoon Amazai are recharged by local rain only and at present there seems no contribution from Tarbela lake.

iv) Major contribution to the tubewell recharge in Abasin Colony comes from lake/river water. However, tritium data suggests that this recharge is directly from river Indus and not from Tarbela reservoir.

v) The residence time of groundwater varies from a few years to 30 years.

vi) The chemical data show that most of the groundwater in the area is Ca-HCO_3 type and generally, the quality of water is good.

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Table-I: Isotopic & Physico-Chemical Data Of Water Samples(1st Sampling) (Sep. 92)

Sample No	Description	E.C	TEMP.	Del O-18	Del H-2	TRITIUM(T.U)
T-1	Open well	567.00	17.6	-5.39	-28.46	17
T-2	Drain	208.00	21.7	-5.12	-28.32	20
T-3	Open well	758.00	26.8	-4.86	-28.15	26
T-4	Tube well	898.00	25.1	-4.79	-24.77	22
T-5	Open well	1434.00	17.7	-5.05	-23.49	27
T-6	Open well	1380.00	19.3	-5.15	-25.71	12
T-7	Tube well	1485.00	21.4	-5.24	-27.17	14
T-8	Spring	1180.00	18.2	-5.36	-24.08	17
T-9	Tube well	318.00	18.3	-4.53	-18.42	30
T-10	Tube well	324.00	24.7	-4.55	-20.51	19
T-11	Tube well	334.00	24.8	-4.86	-21.25	16
T-12	Open well	424.00	24.8	-4.91	-25.02	18
T-13	Open well	374.00	17.7	-3.69	-17.59	19
T-14	Open well	585.00	25.1	-5.54	-22.74	20
T-15	Open well	509.00	18.4	-4.62	-23.30	22
T-16	Tube well	466.00	18.5	-4.46	-20.18	20
T-17	Open well	433.00	17.6	-4.73	-27.77	22
T-18	Tube well	613.00	17.8	-5.30	-30.41	22
T-19	Open well	1250.00	18.3	-5.18	-26.44	27
T-20	Tube well	730.00	23.3	-4.84	-29.50	6
T-21	Open well	860.00	21.3	-11.23	-79.16	28
T-22	Open well	312.00	26.6	-5.59	-35.38	50
T-23	Open well	1070.00	18.5	-5.52	-35.05	24
T-24	Tube well	583.00	17.1	-9.68	-64.68	31
T-25	Open well	952.00	16.1	-11.19	-75.76	31
T-26	Drain	316.00	22.0	-7.41	-50.76	24
T-27	Tube well	787.00	25.5	-6.81	-37.28	24
T-28	Tube well	557.00	23.5	-8.57	-61.70	23
T-29	Open well	597.00	17.8	-9.45	-62.52	38
T-30	Open well	641.00	17.2	-8.13	-47.21	27
T-31	Open well	736.00	18.2	-7.23	-44.28	38
T-32	Open well	928.00	17.3	-5.63	-27.45	10
T-33	Tube well	428.00	18.6	-5.35	-27.82	31
T-34	Open well	1614.00	25.8	-4.85	-23.45	25
T-35	Open well	933.00	23.3	-5.46	-31.28	33
T-36	Open well	1296.00	17.5	-5.46	-29.92	19
T-37	Open well	1419.00	16.8	-6.26	-33.21	23
T-38	Open well	1915.00	17.8	-4.95	-23.21	25
T-39	Open well	564.00	24.2	-4.74	-20.22	23
T-40	Tube well	496.00	15.6	-11.13	-77.21	34
T-59	Gandaf Ch.			-4.52	-24.53	15
T-61	T.LAKE MEAN (Sep.87 to Feb.93)			-12.41	-86.04	31

Table-II: Isotopic & Physico-Chemical Data of Water Samples (2nd Sampling) (Jan. 93)

Sample No.	Description	E.C.	TEMP.	Del O-18	Del H-2
T-1	Open well	533	16.50	-5.20	-25.75
T-2	Drain				
T-3	Open well	714	24.30	-4.74	-25.52
T-4	Tube well	934	23.40	-4.98	-23.55
T-5	Open well	1407	16.20	-5.24	-22.87
T-6	Open well	1495	18.60	-5.61	-26.56
T-7	Tube well				
T-8	Spring	1120	17.50	-5.65	-25.54
T-9	Tube well	290	15.30	-5.44	-26.80
T-10	Tube well				
T-11	Tube well	350	22.50	-5.04	-23.04
T-12	Open well	326	21.80	-5.11	-26.06
T-13	Open well				
T-14	Open well	6331	14.40	-4.96	-22.86
T-15	Open well	482	16.50	-4.87	-23.02
T-16	Tube well	468	16.60	-4.58	-22.80
T-17	Open well	472	11.90	-4.99	-26.05
T-18	Tube well	634	16.50	-5.16	-28.83
T-19	Open well	1365	14.10	-4.90	-25.37
T-20	Tube well	669	14.20	-5.00	-26.85
T-21	Open well	777	20.40	-11.18	-78.59
T-22	Open well	325	19.70	-5.90	-35.57
T-23	Open well				
T-24	Tube well	651	21.40	-9.67	-64.95
T-25	Open well	917	15.10	-11.85	-80.85
T-26	Drain				
T-27	Tube well	616	24.30	-5.59	-30.58
T-28	Tube well	569	20.70	-8.90	-63.70
T-29	Open well	697	20.10	-8.93	-62.19
T-30	Open well	614	19.50	-8.74	-45.98
T-31	Open well	808	16.20	-7.41	-40.93
T-32	Open well	919	15.20	-5.54	-28.00
T-33	Tube well	453	23.60	-5.52	-27.39
T-34	Open well	1691	18.70	-4.73	-22.70
T-35	Open well	912	13.70	-5.56	-27.68
T-36	Open well	1450	16.20	-5.92	-31.87
T-37	Open well	1445	15.80	-5.91	-32.44
T-38	Open well	1002	21.10	-5.10	-24.50
T-39	Open well				
T-40	Tube well	586	11.00	-10.80	-71.05
T-41	Open well	693	16.20	-4.92	-23.11
T-42(GV-1-A)	Open well	480	14.40	-5.52	-28.26
T-43(MSJ-10)	Open well	504	16.60	-4.81	-21.32
T-44(MRS-9)	Open well	748	16.40	-5.03	-23.38
T-45(MRM-8)	Open well	697	15.80	-4.74	-22.67

Table-III: Results of Chemical Analysis of Water Samples

Sample No.	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Cl (ppm)	Alkalinty as CaCO3 (ppm)	NO3 (ppm)	SO4 (ppm)
T-1	43	3	58	18	12	283	6	20
T-2	11	2	18	7	4	95	3	6
T-3	75	4	27	25	35	249	12	45
T-4	38	8	78	25	18	215	29	124
T-5	62	40	103	52	52	335	45	224
T-6	63	37	95	46	35	279	37	234
T-7	65	19	76	59	46	196	29	315
T-8	49	15	78	46	29	225	31	242
T-9	14	3	34	9	7	130	7	13
T-10	12	3	36	8	5	124	5	12
T-11	12	3	34	9	9	125	5	16
T-12	17	2	41	10	9	148	7	15
T-13	16	1	37	8	9	123	3	20
T-14	41	2	39	18	18	186	10	34
T-15	28	1	39	12	10	163	5	31
T-16	21	5	45	11	11	167	8	35
T-17	14	1	39	9	7	120	8	27
T-18	67	2	28	14	19	183	5	59
T-19	158	8	37	42	79	286	20	184
T-20	48	29	41	18	20	240	7	41
T-21	22	5	73	31	35	225	24	52
T-22	9	1	34	8	3	129	2	4
T-23	125	2	39	26	49	295	36	78
T-24	27	5	29	24	17	165	14	49
T-25	65	7	55	31	69	238	10	62
T-26	17	4	44	5	5	155	2	10
T-27	65	108	20	15	39	240	33	59
T-28	14	5	68	19	10	219	4	54
T-29	13	23	48	19	8	205	6	42
T-30	45	1	22	30	7	235	3	29
T-31	59	12	35	26	19	251	15	48
T-32	121	4	37	26	29	370	12	44
T-33	27	2	34	14	7	160	5	23
T-34	239		37	44	113	309	45	298
T-35	44	10	60	29	49	185	65	73
T-36	56	8	116	43	76	256	135	132
T-37	157	72	39	58	50	406	58	256
T-38	169	2	92	36	85	388	30	182
T-39	27	19	49	14	15	179	14	51
T-40	12	4	48	22	5	155	2	70

T-46	Tube well	581	17.20	-4.96	-24.07
T-47(KM-12)	Open well	388	16.20	-5.19	-25.30
T-48(GCH3A)	Open well	382	17.70	-4.99	-22.99
T-49(GC3)	Open well	372	17.40	-5.05	-22.35
T-50(TM)	Open well	452	19.40	-4.84	-21.48
T-51(TPS-6)	Open well	952	16.20	-5.41	-26.65
T-52(TCP-7)	Open well	972	20.50	-5.96	-31.52
T-53	Tube well	595	12.60	-7.25	-44.35
T-54	Tube well	428	18.80	-5.02	-23.60
T-54(A)	Tube well	510	18.40	-5.10	-22.77
T-55	Open well	602	15.10	-4.92	-22.10
T-56	Open well	298	14.80	-10.49	-68.37
T-57	Tube well	380	24.20	-5.05	-24.53
T-58	Open well	516	16.20	-5.20	-26.72
T-59	G.Channel	365	11.60	-5.03	-24.32
T-60	River Indus	215	8.60	-12.91	-91.27
T-61	T.Lake	MEAN (Sep.87 to Feb.93)		-12.41	-86.04

LIST OF FIGURE CAPTIONS

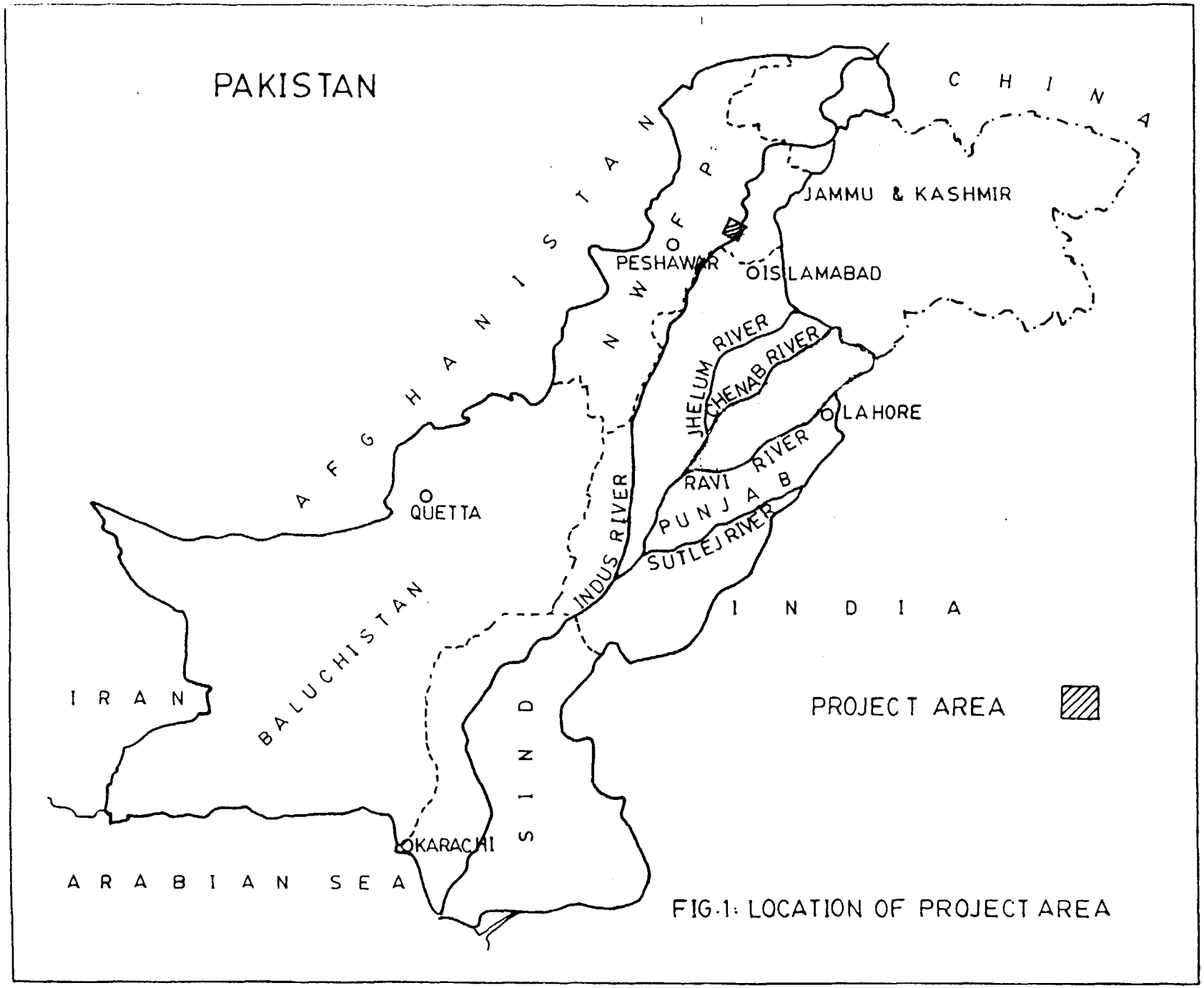


FIG-1: LOCATION OF PROJECT AREA

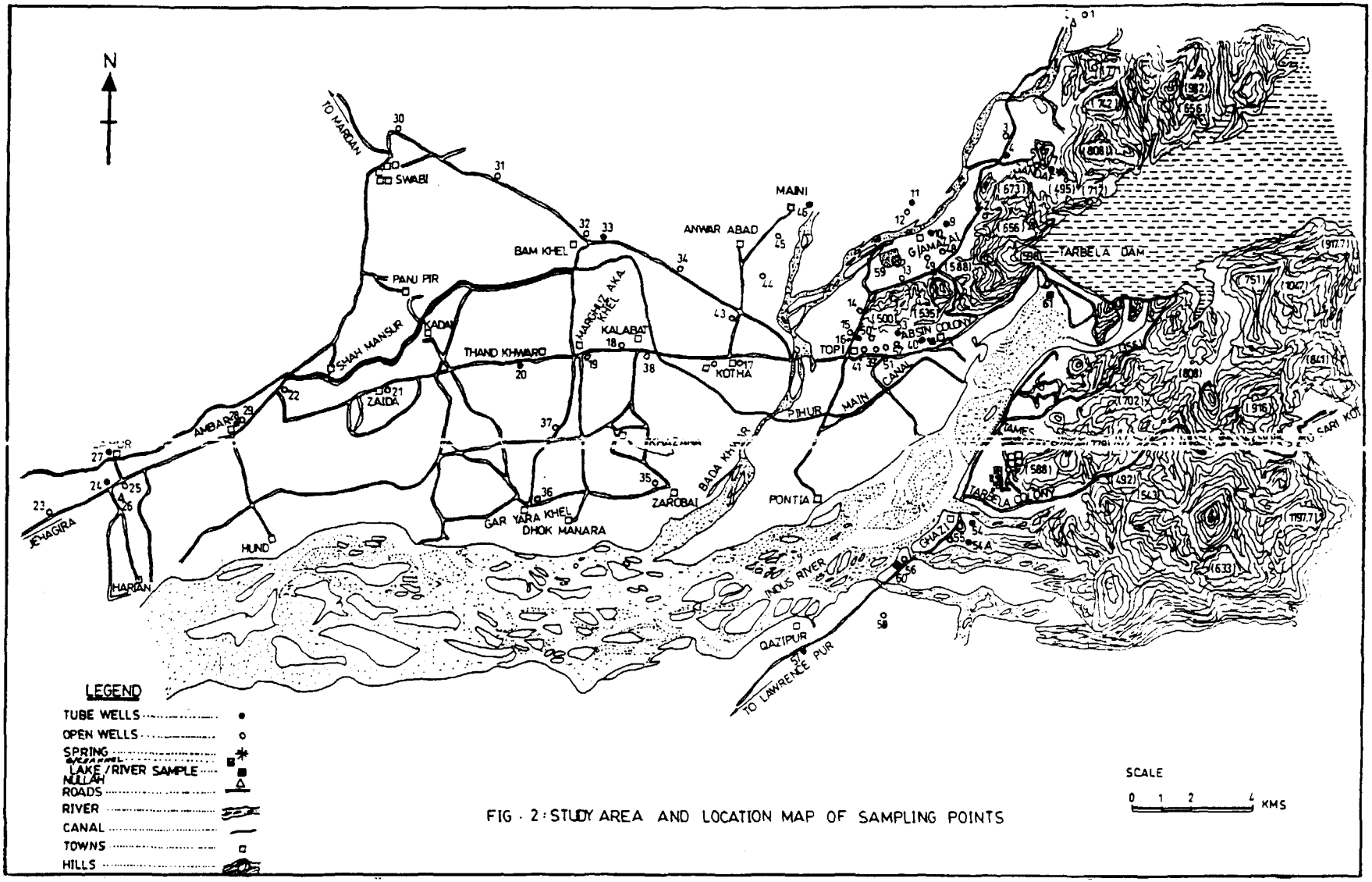


FIG · 2 : STUDY AREA AND LOCATION MAP OF SAMPLING POINTS

FIG. 3: VARIATION OF $\delta^{18}O$ AND LEVEL OF TARBELA LAKE

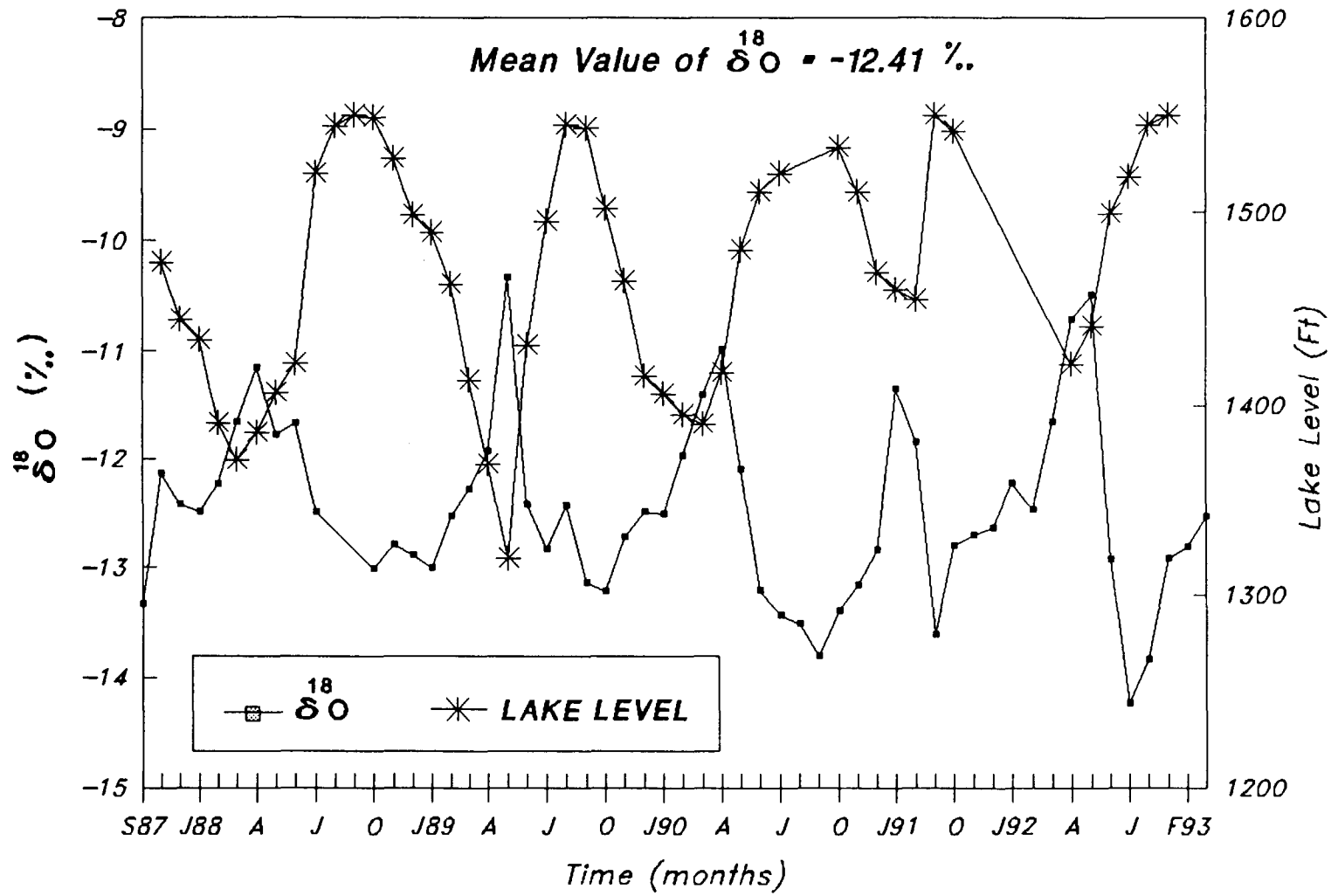
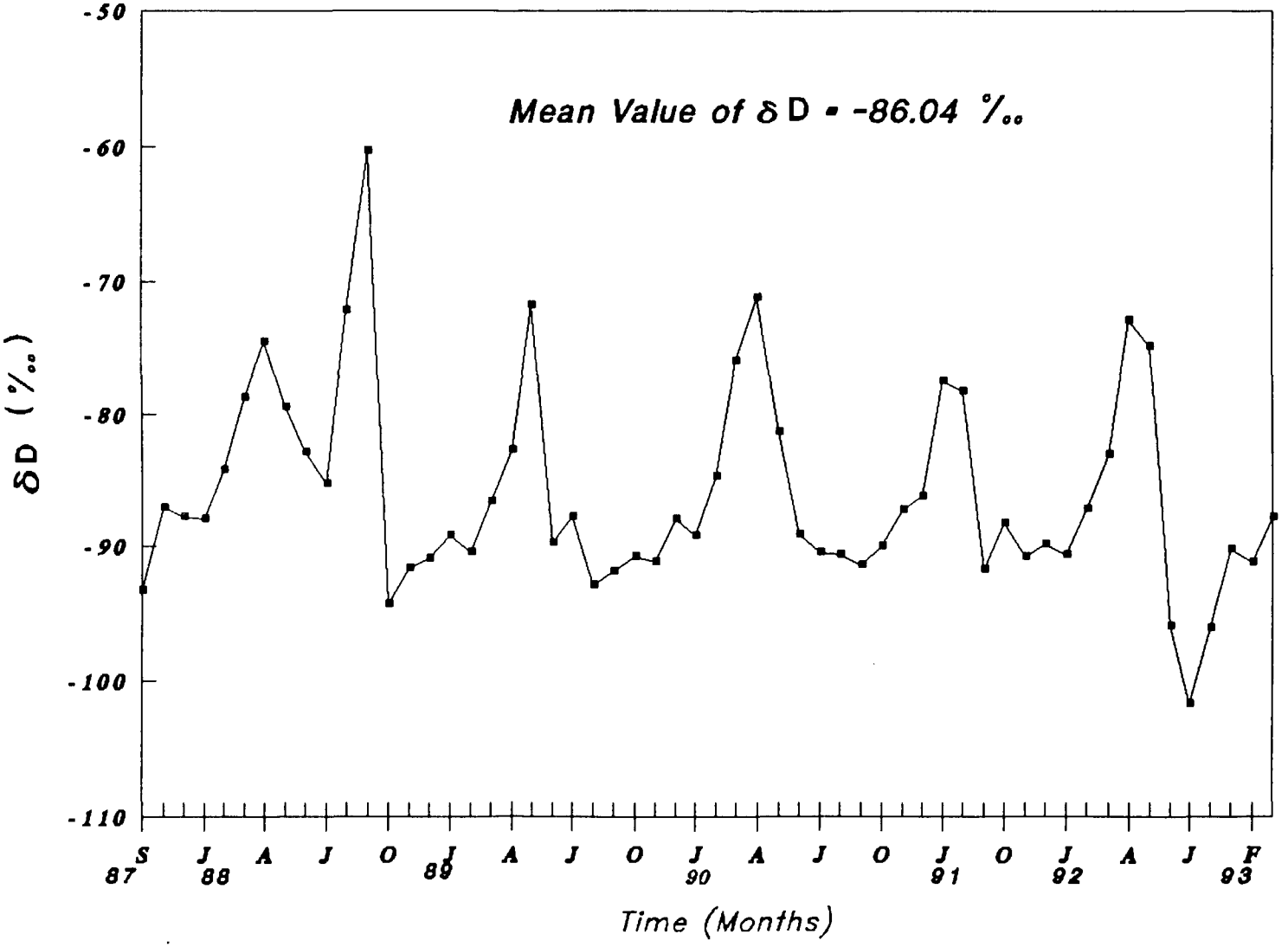


FIG. 4. VARIATION OF δD OF TARBELA LAKE



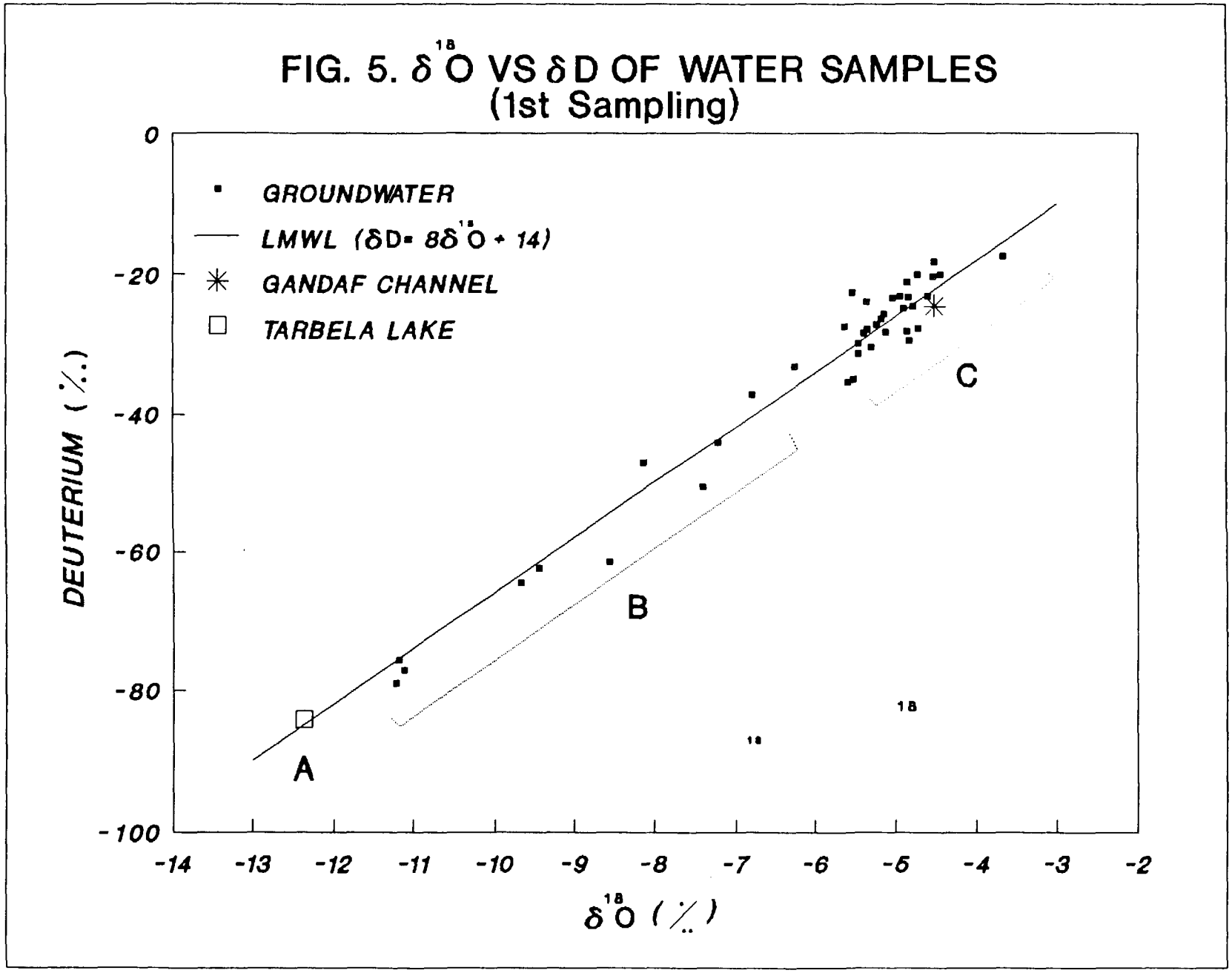


FIG. 5. δ 18O VS δ D OF WATER SAMPLES
(1st Sampling)
GROUNDWATER
LMWL (δD= 8δ 18O + 14)
GANDAF CHANNEL
TARBELA LAKE
A
B
C
DEUTERIUM (‰)
δ 18O (‰)
0
-20
-40
-60
-80
-100
-14
-13
-12
-11
-10
-9
-8
-7
-6
-5
-4
-3
-2

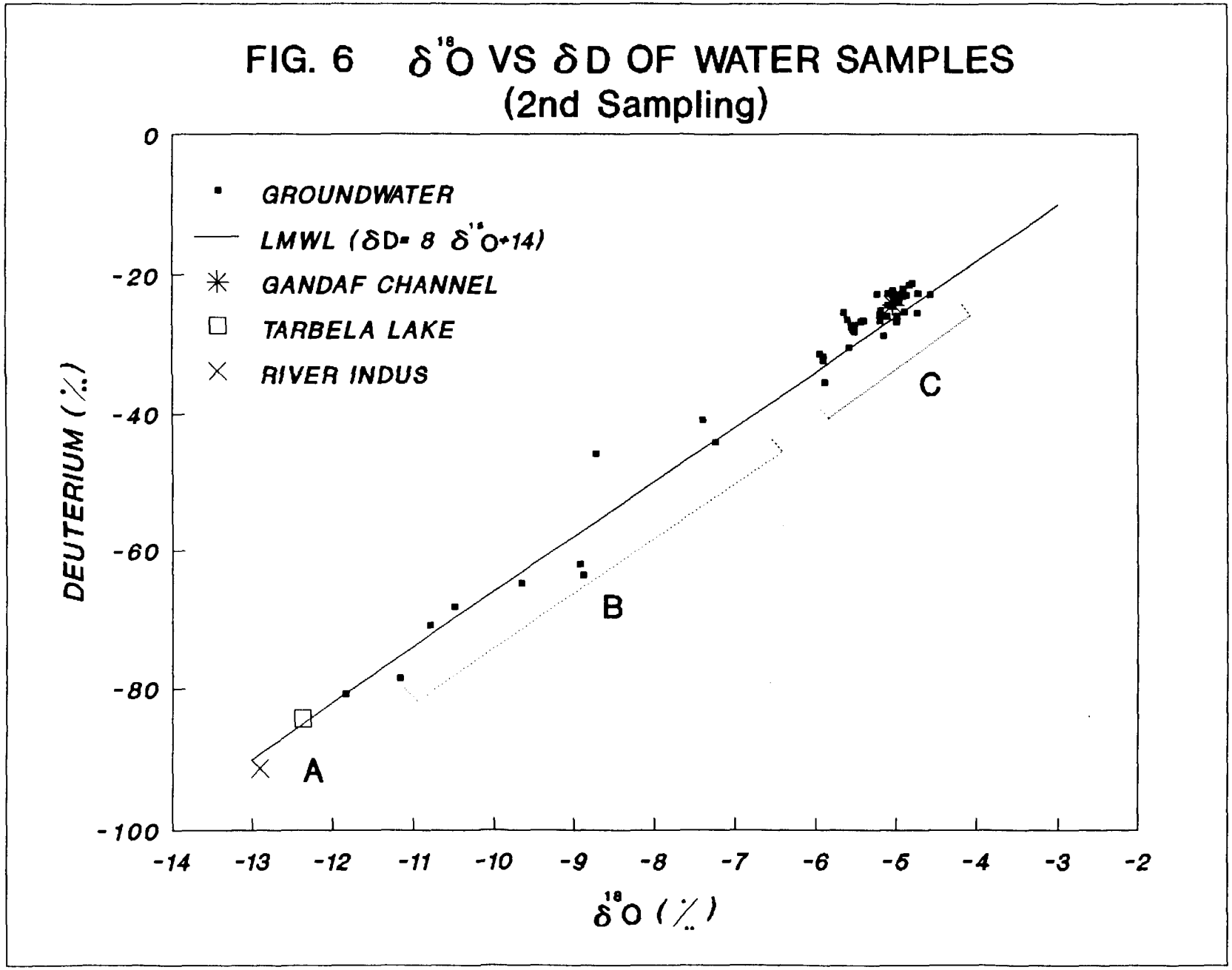


FIG. 6 δ18O VS δD OF WATER SAMPLES
(2nd Sampling)
GROUNDWATER
LMWL (δD= 8 δ18O+14)
GANDAF CHANNEL
TARBELA LAKE
RIVER INDUS
A
B
C
DEUTERIUM (‰)
0
-20
-40
-60
-80
-100
-14
-13
-12
-11
-10
-9
-8
-7
-6
-5
-4
-3
-2
δ18O (‰)

FIG. 7. FREQUENCY HISTOGRAM OF OXYGEN-18
(1st sampling)

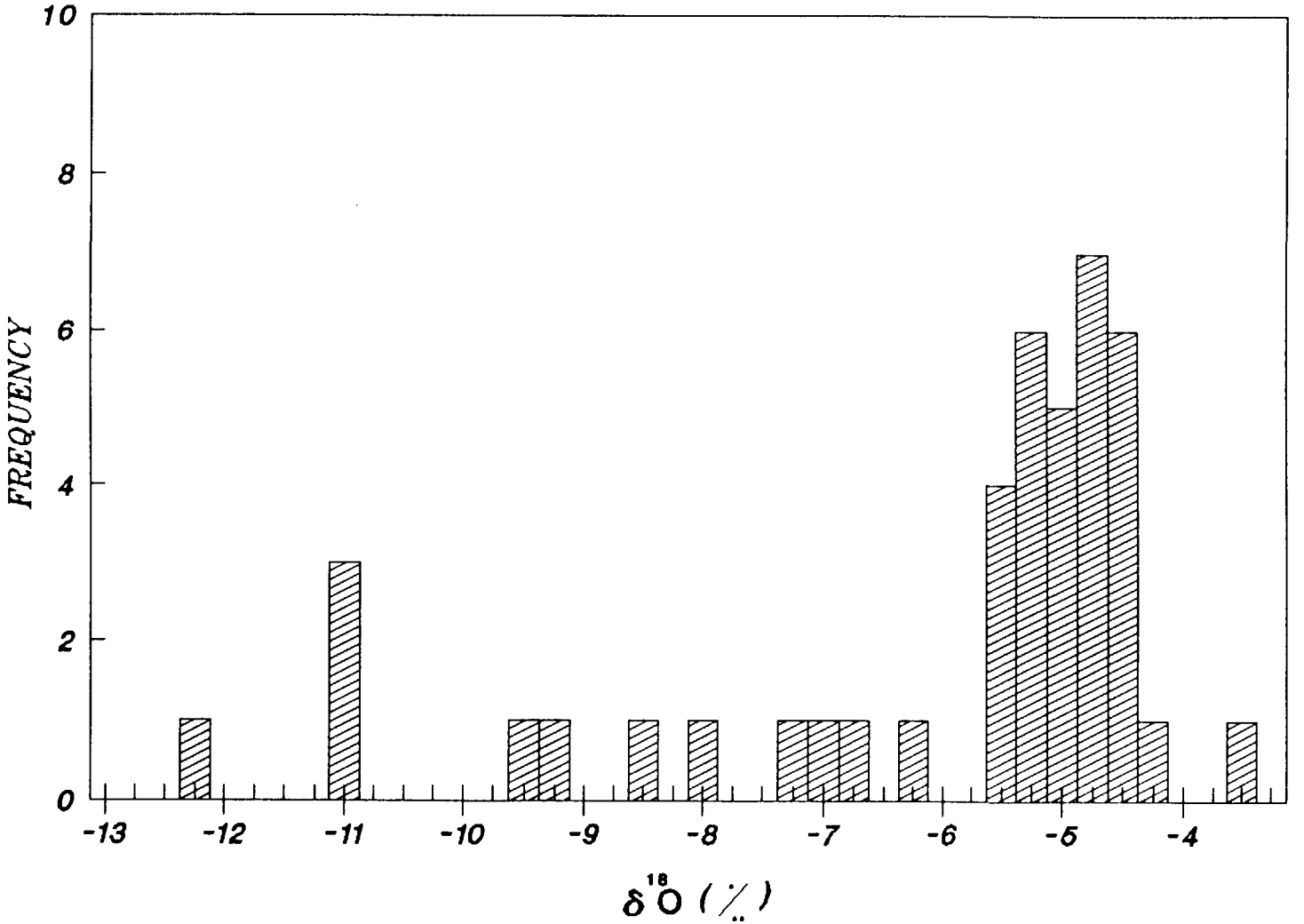


FIG. 8. FREQUENCY HISTOGRAM OF DEUTERIUM
(1st Sampling)

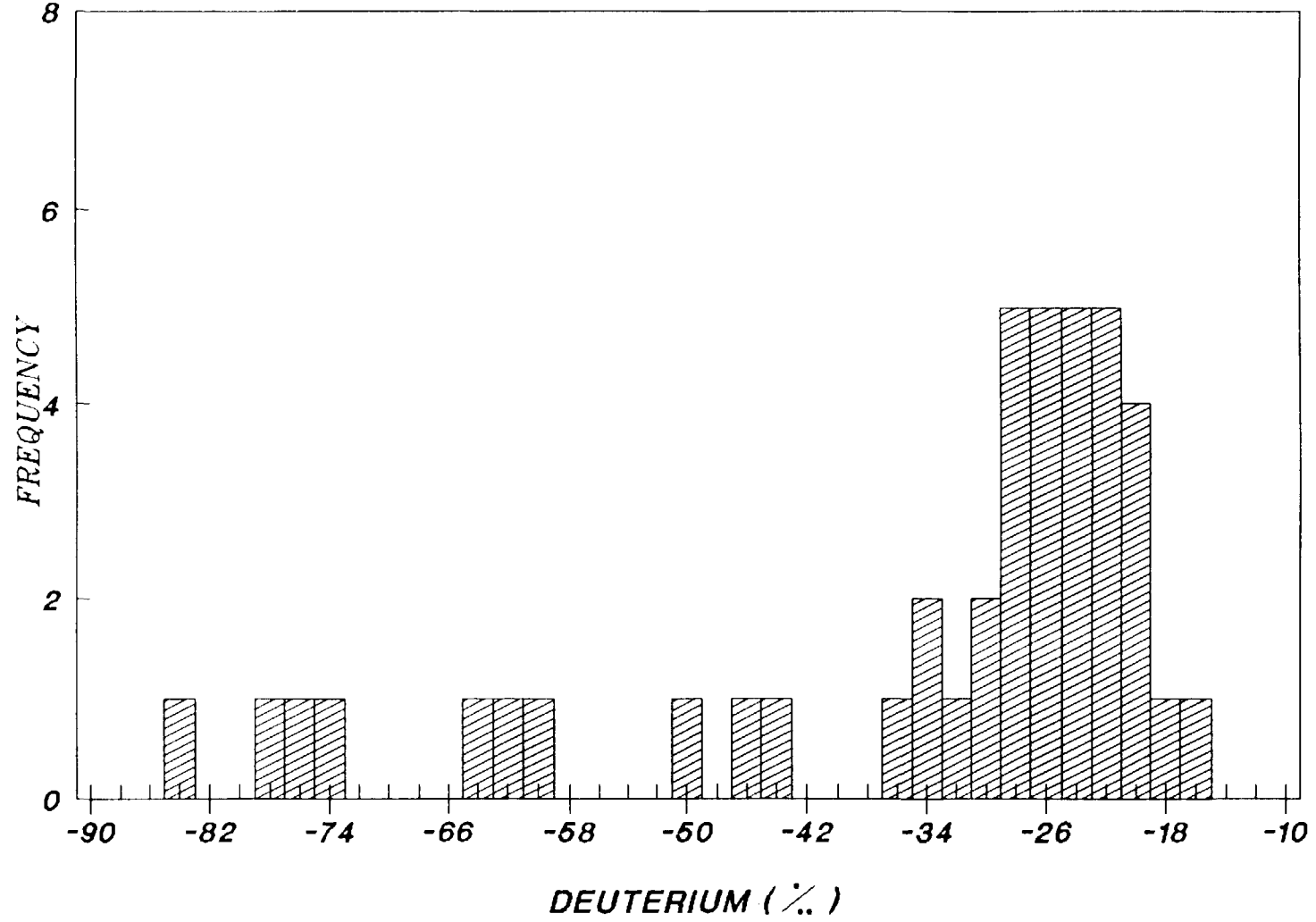


FIG. 9. FREQUENCY HISTOGRAM OF TRITIUM
(1st Sampling)

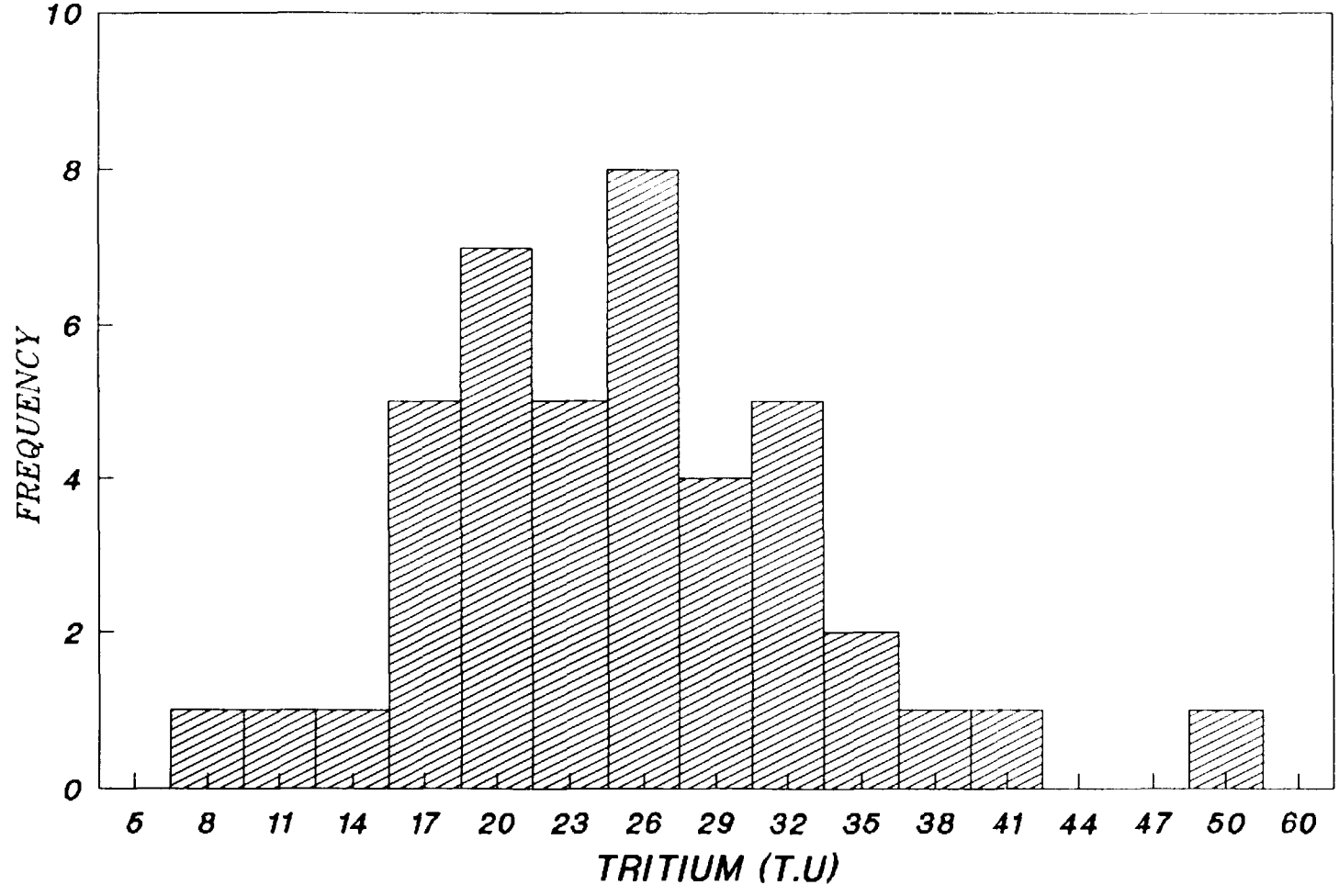


FIG.10. FREQUENCY HISTOGRAM OF OXYGEN-18
(2nd Sampling)

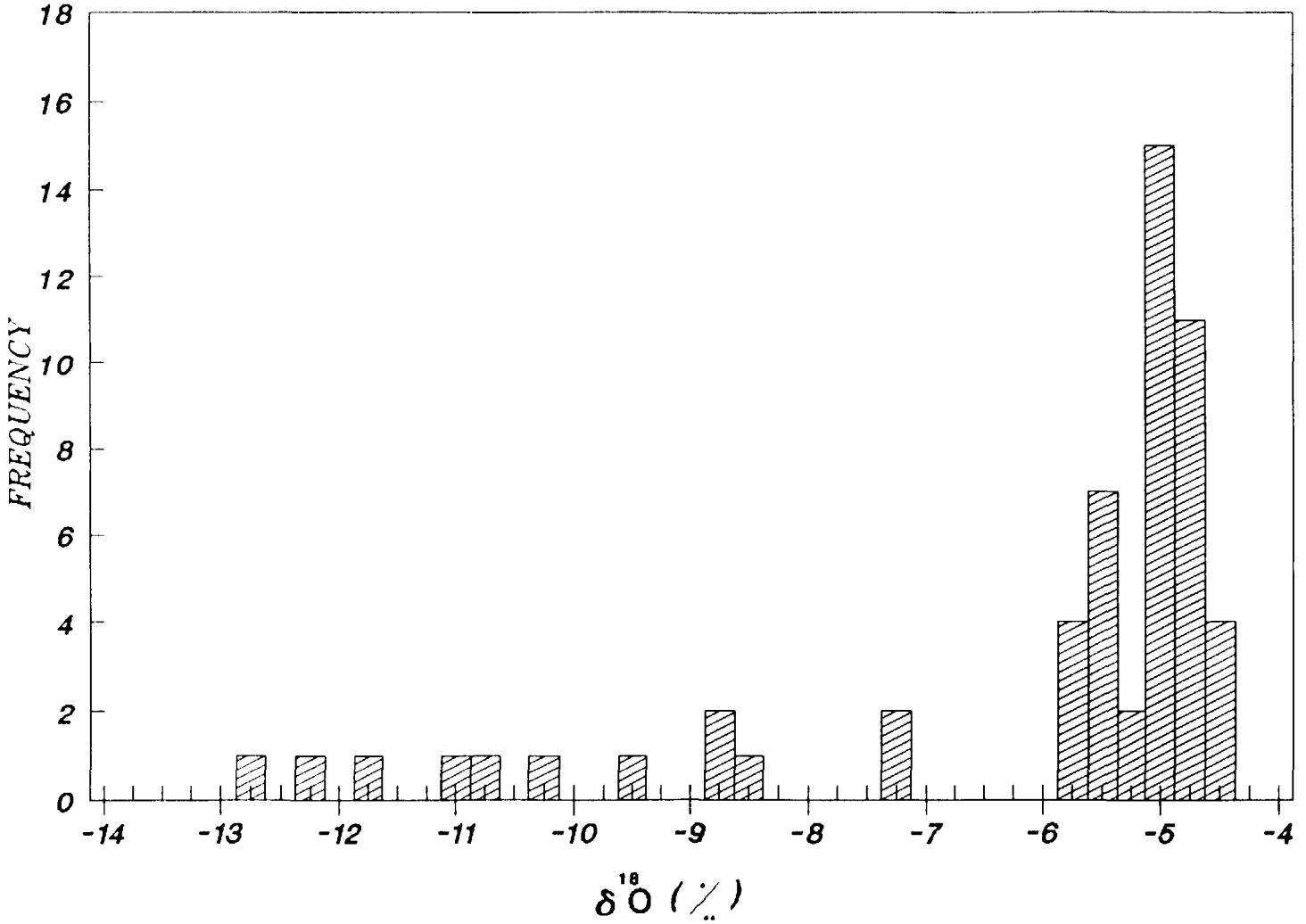
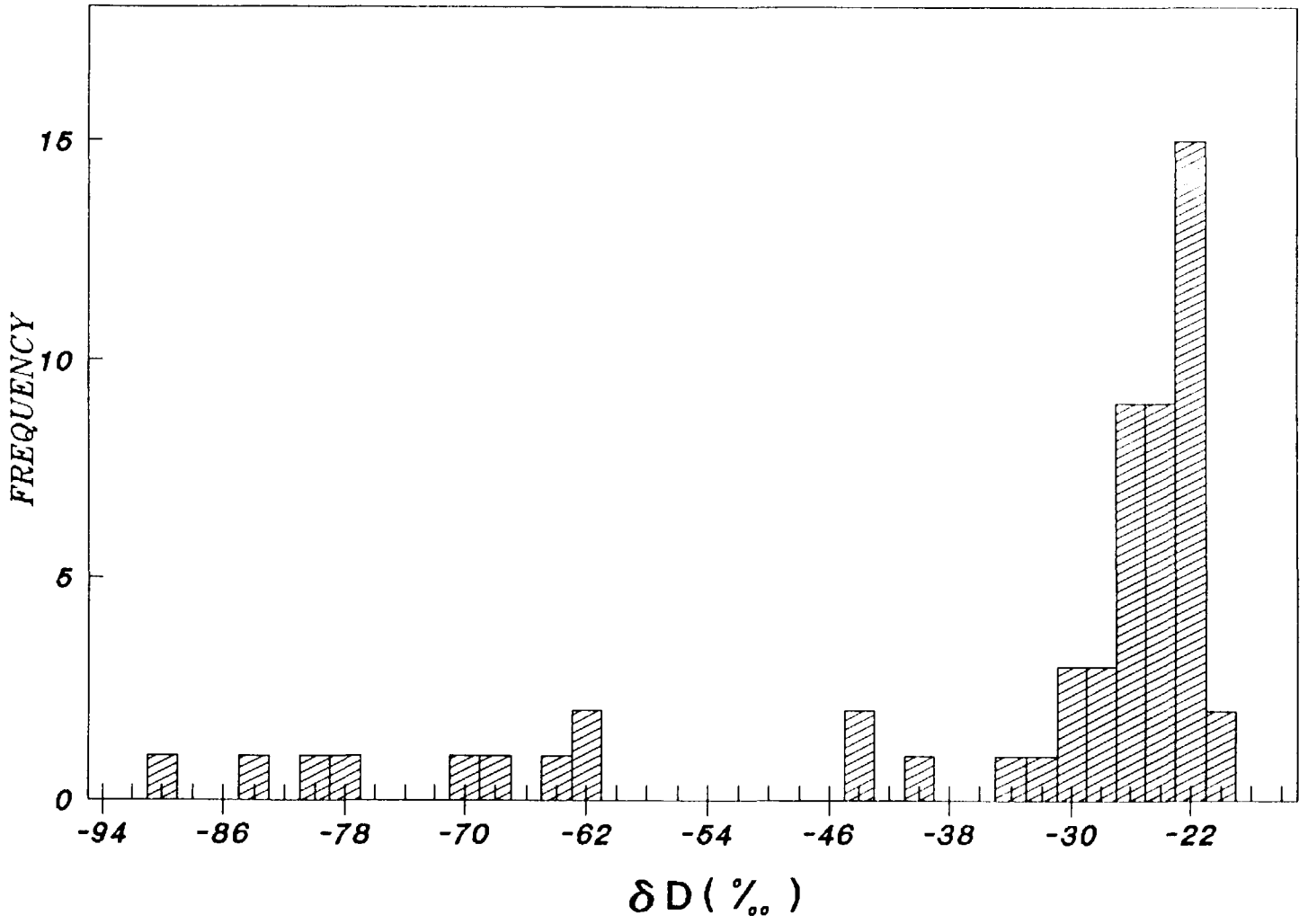


FIG.11. FREQUENCY HISTOGRAM OF DEUTERIUM
(2nd Sampling)



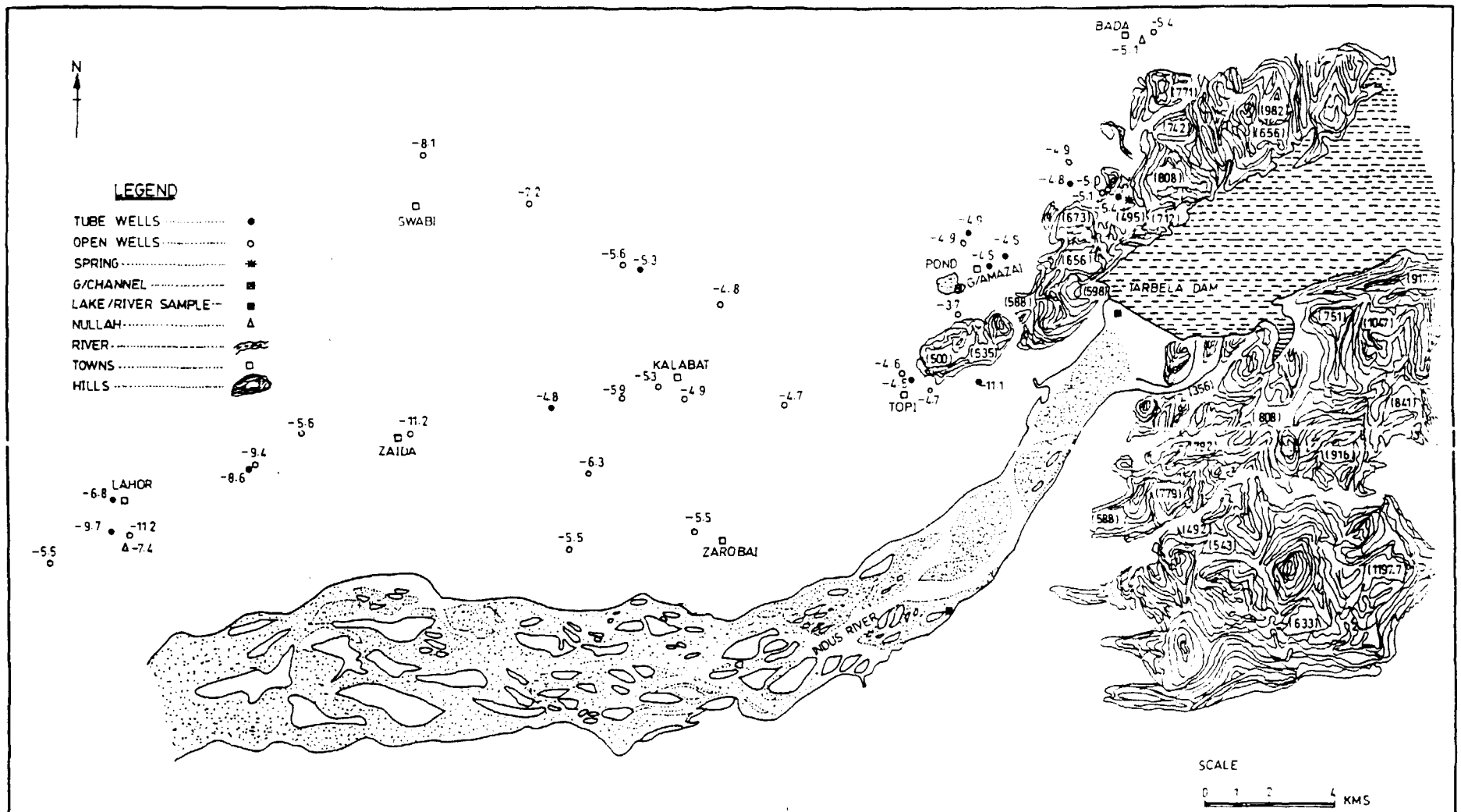


FIG42: SPATIAL DISTRIBUTION OF OXYGEN-18 IN PROJECT AREA (1st SAMPLING)

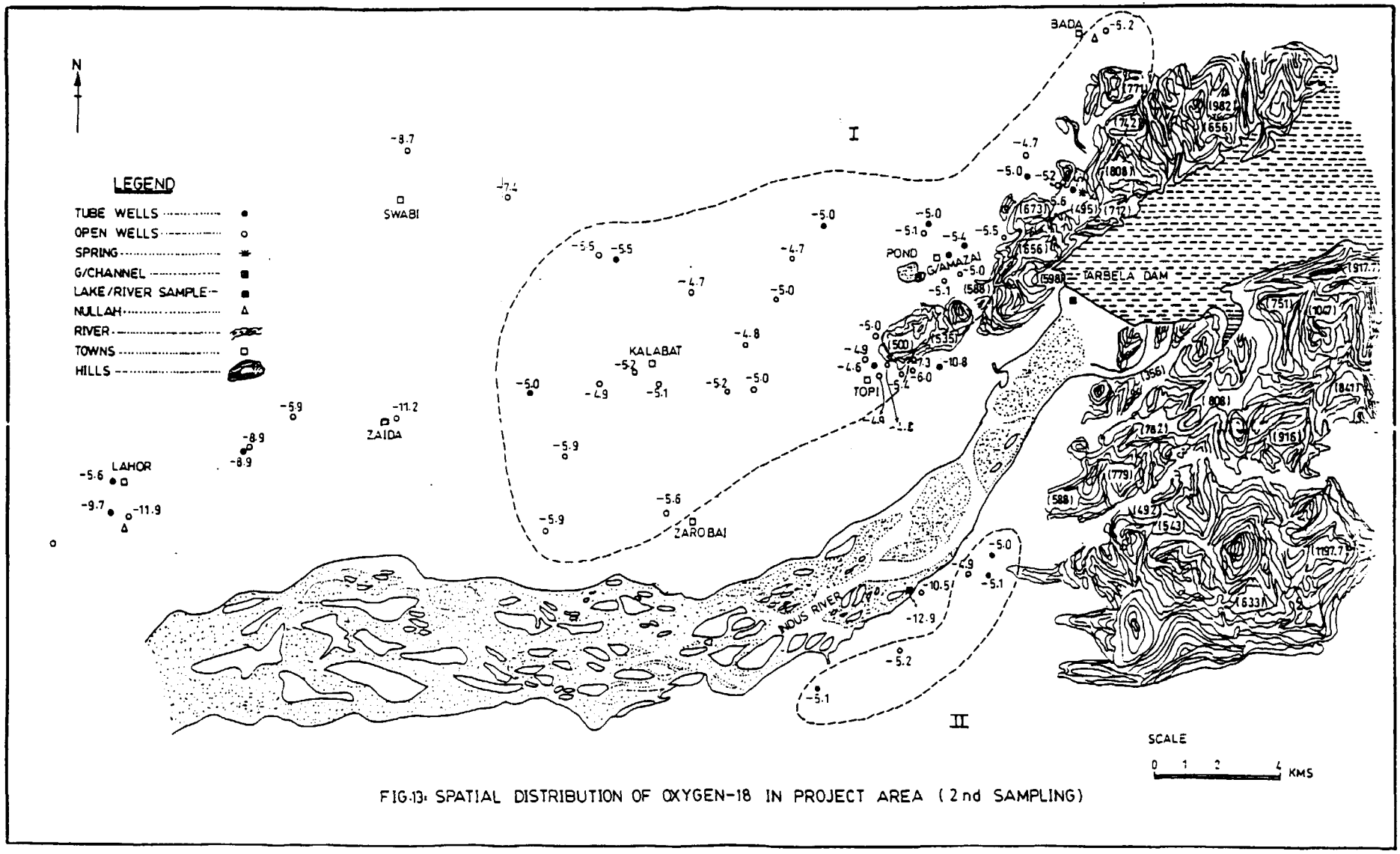


FIG.13: SPATIAL DISTRIBUTION OF OXYGEN-18 IN PROJECT AREA (2nd SAMPLING)

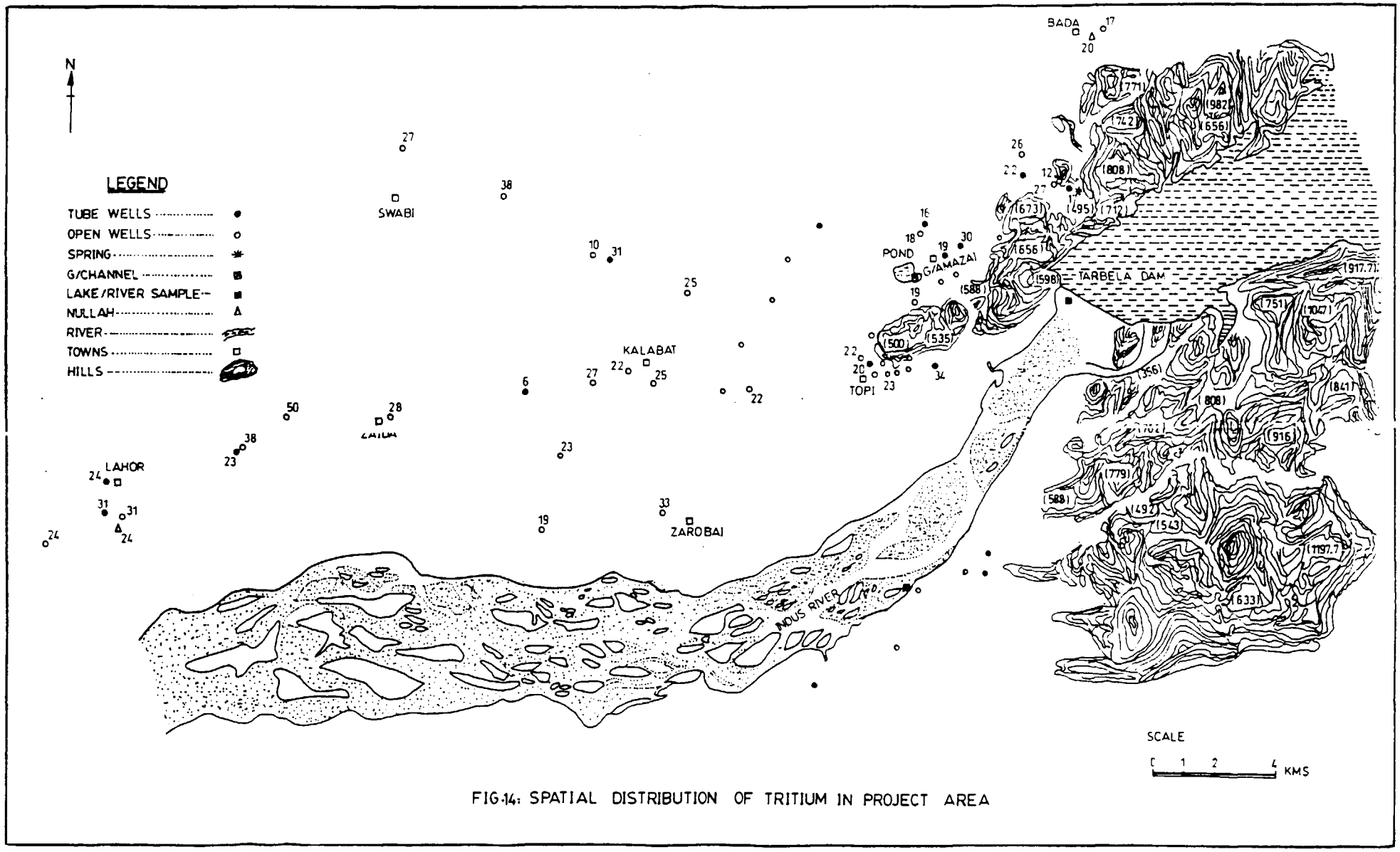


FIG-14: SPATIAL DISTRIBUTION OF TRITIUM IN PROJECT AREA

FIG. 15 NORMAL PROBABILITY PLOT OF δO-18

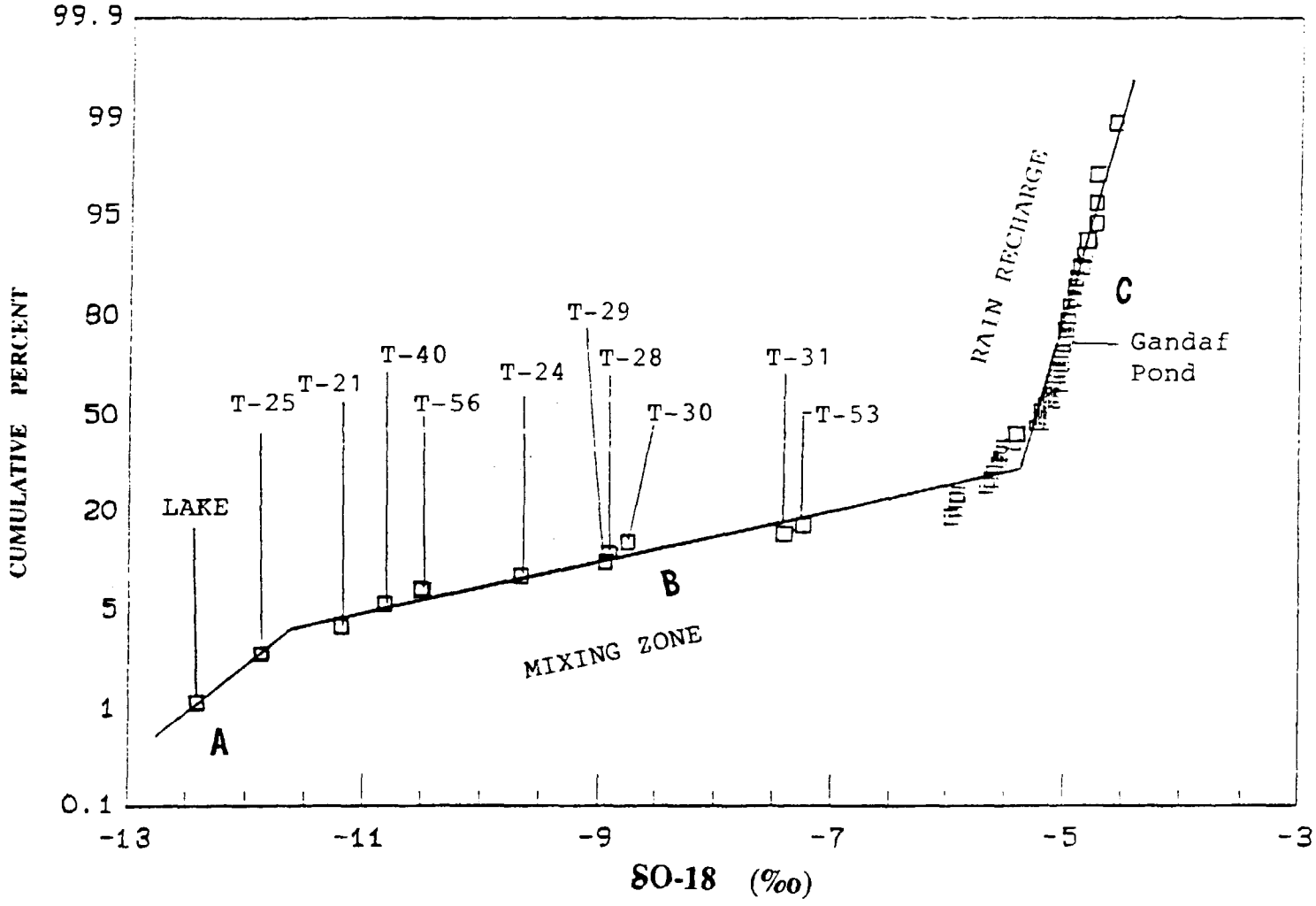
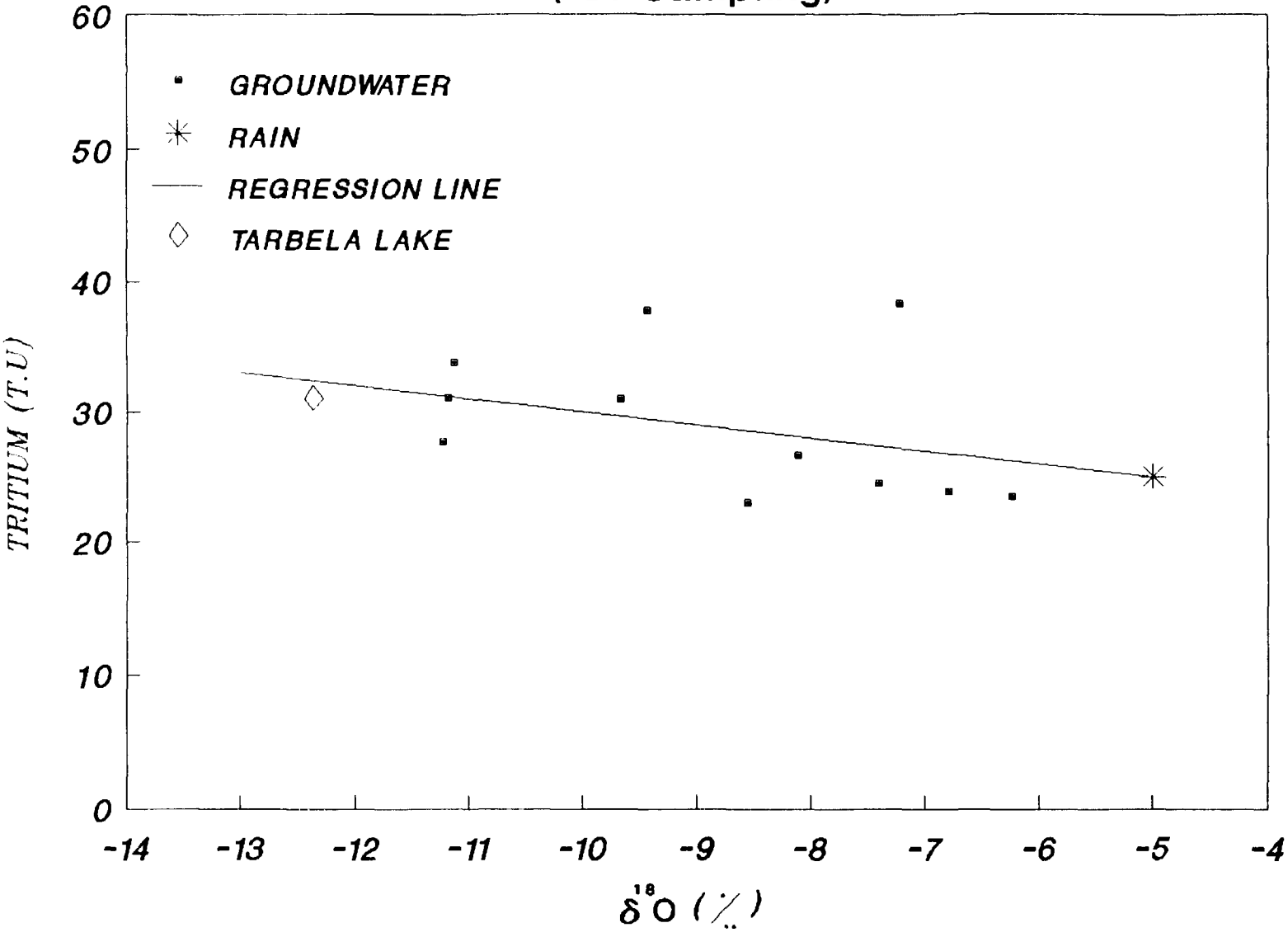


FIG. 16 $\delta^{18}O$ VS TRITIUM OF WATER SAMPLES (1st Sampling)



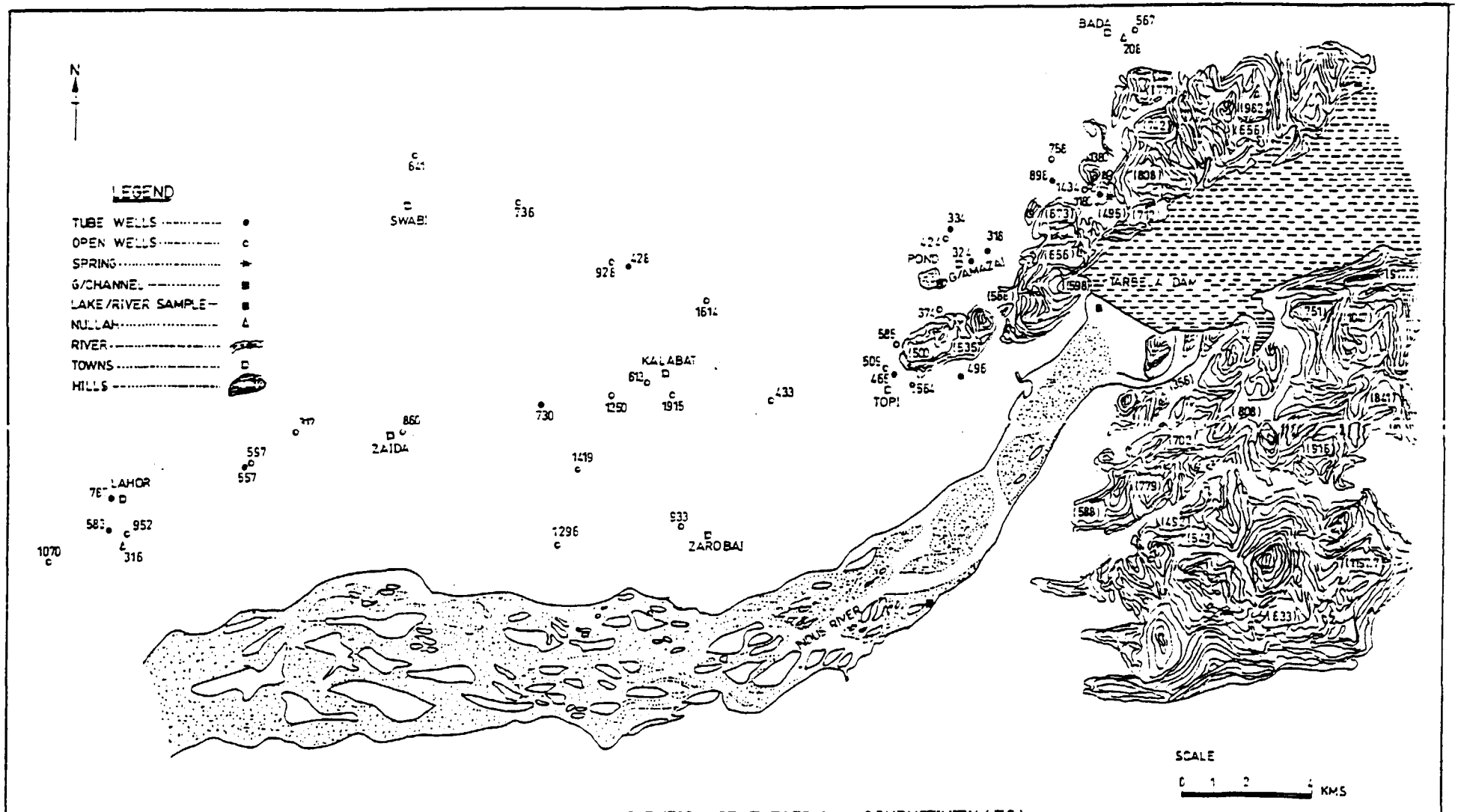


FIG. 17 : SPATIAL DISTRIBUTION OF ELECTRICAL CONDUCTIVITY (EC)

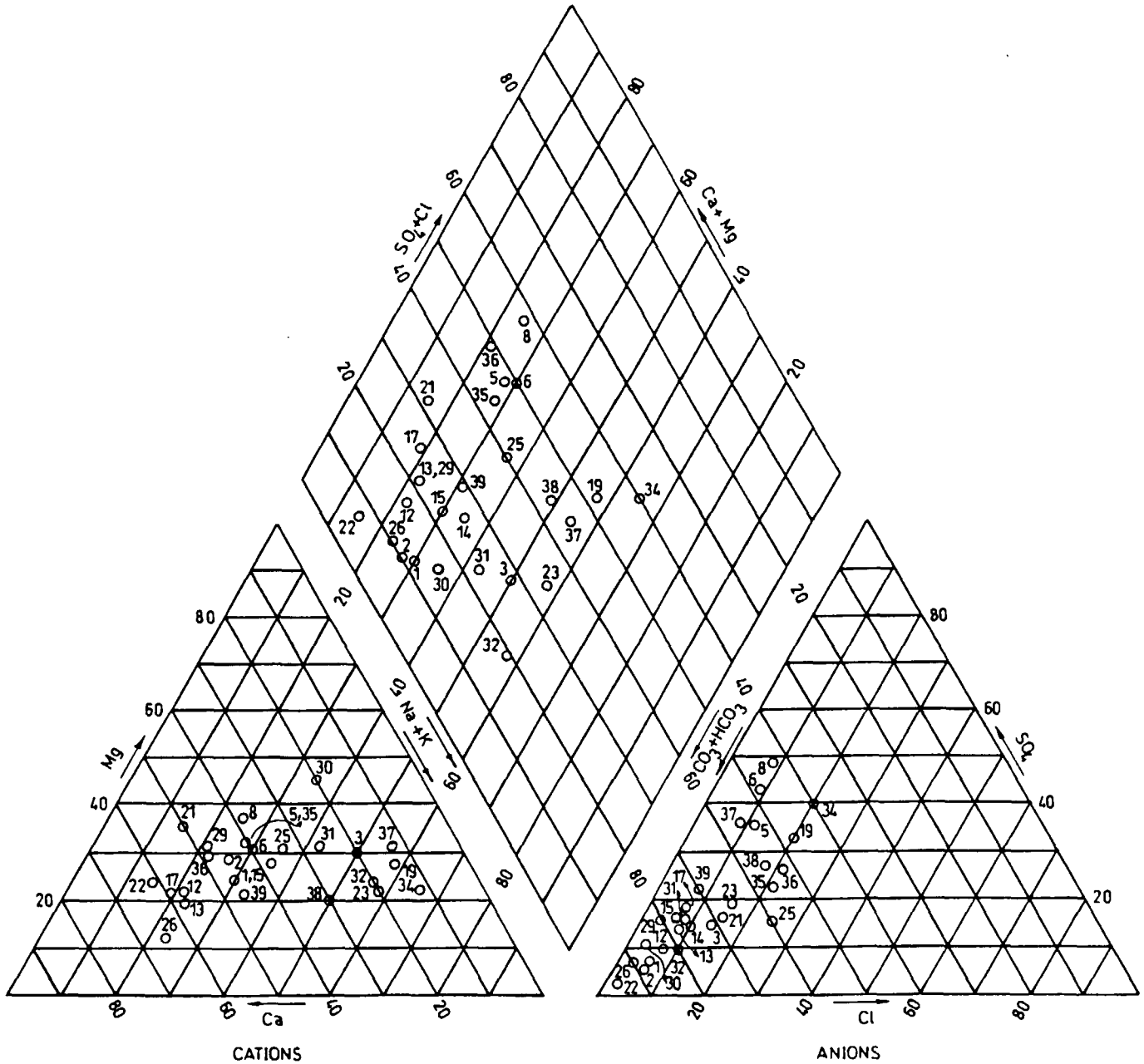


FIG -18: PIPER DIAGRAM OF WATER CHEMISTRY (OPEN WELLS)

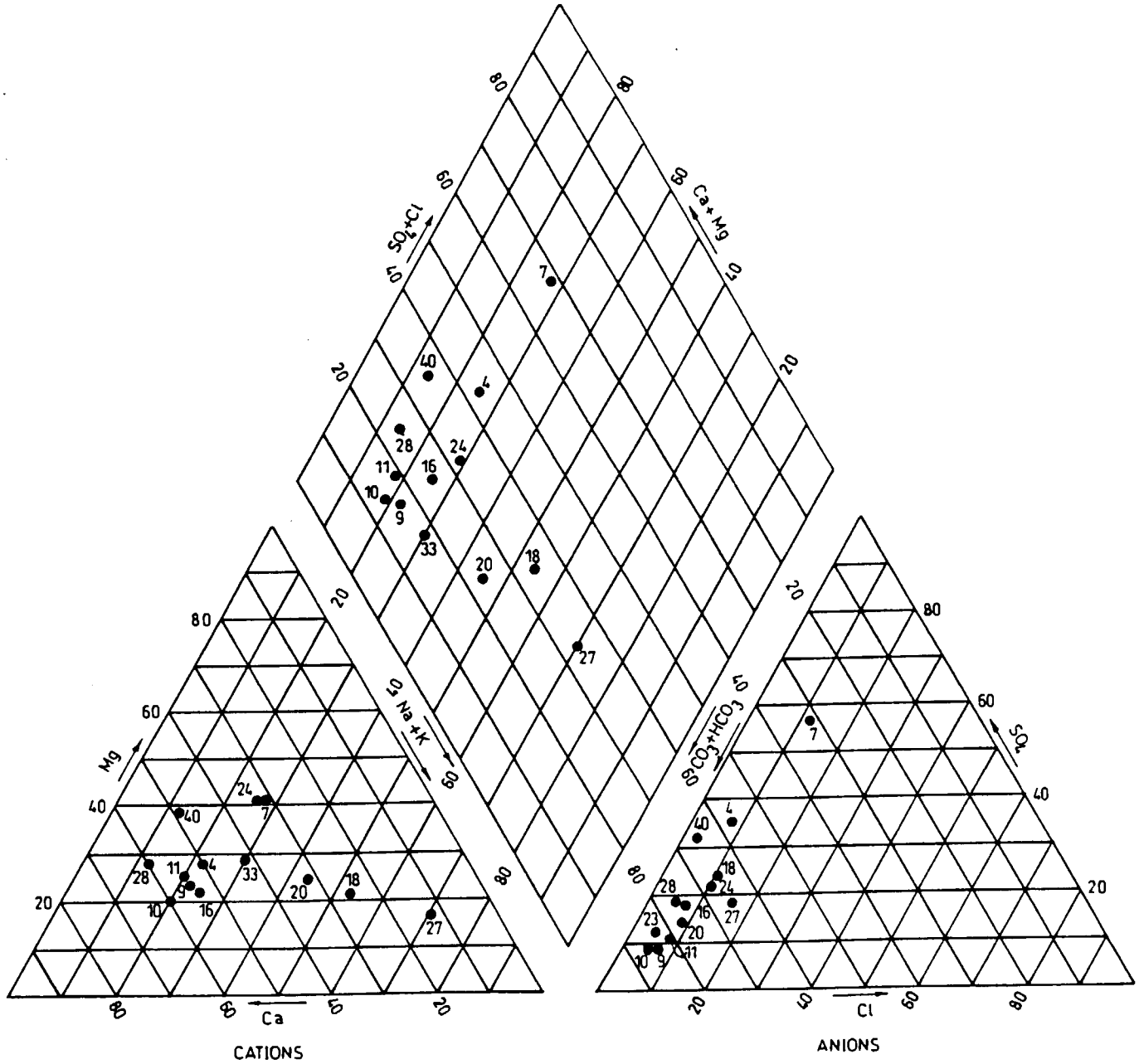


FIG .19: PIPER DIAGRAM OF WATER CHEMISTRY (TUBE WELLS)