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Hydrology

HYDROLOGICAL INVESTIGATIONS IN SABARMATI BASIN

I. GROUNDWATER RECHARGE ESTIMATION USING TRITIUM TAGGING METHOD

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Tracing of soil moisture movement using tritium tagging method has been used to estimate the groundwater recharge in alluvial plains of Sabarmati basin. Results indicate that in major parts of the basin groundwater recharge is limited to 5–7 per cent of the water input (precipitation + irrigation). Total quantum of groundwater recharge is estimated to be 660 MCM/Yr. Of this, approximately 323 MCM/Yr is recharged to saline aquifers in southern parts of the basin. Net utlisable groundwater recharge to both phreatic and confined aquifers (337 MCM/Yr) is too inadequate to meet even the present groundwater pumpage in the basin. It is, therefore, desirable to develop suitable techniques for artificial groundwater recharge to meet the growing demand.

INTRODUCTION

TRITIUM tracing of soil moisture movement for estimation of groundwater recharge was first suggested by Zimmermann *et al.* (1967) using environmental tritium. In India Sukhija and Rama (1973) ascertained the validity of environmental tritium tagging methods for semi-arid alluvial tracts of Gujarat. Subsequently, Datta *et al.* (1973), Datta and Goel (1977) and Goel *et al.* (1977) utilized artificial tritium for tracing of soil water movement in parts of Ganga basin. Recently, Datta *et al.* (1980) have developed a conceptual model in which transport of water or recharge through unsaturated zone is visualized in pulses of infiltrating sheet through a series of hypothetical expandable mixing cells subdividing the soil profile. The model has been tested using the tritium tracing data of Datta *et al.* (1973), Datta and Goel (1977) and Goel *et al.* (1977). A linear relationship was obtained between the number of rainy days (having rainfall greater than the computed pulse size) and the estimated recharge during the period of tracing experiment. By making use of this model and the available rainfall records it is possible to estimate the average groundwater recharge in a region for the past several years from a limited number of tritium tracing experiments. In this paper, the authors report the results of a few tritium tracing experiments and estimate net recharge to phreatic aquifers in alluvial tracts of the Sabarmati basin in Gujarat State.

CLIMATE AND GEOHYDROLOGY

The Sabarmati basin extends over an area of about 22,000 sq. km and lies between east longitudes 72° 15′ and 73° 49′ and north latitudes 22° 15′ and 24° 53′. Located in western India, the basin covers areas in the states of Rajasthan and Gujarat. The

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drainage area of the Sabarmati basin in Gujarat state is ~ 17,550 sq. km (*Irrigation Commission Report*, 1972). The basin is bound on the north and northeast by the Aravalli hills, in the east by a ridge separating it from the Mahi Basin, in the south by the Gulf of Cambay and in the west by a ridge separating it from the basins of minor streams draining into Rann of Kutch and the Gulf of Cambay (Fig. 1).

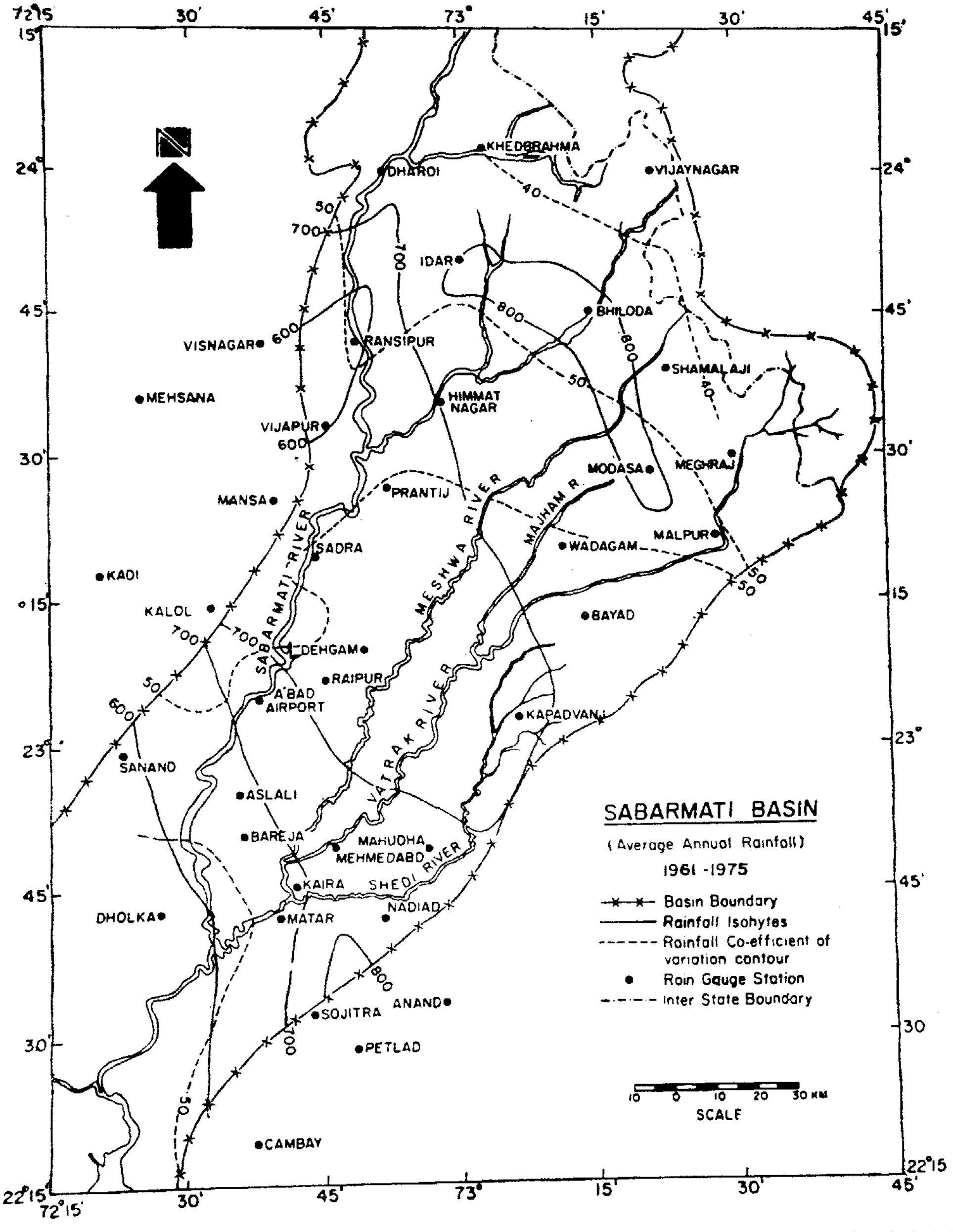


FIG. 1. Average annual rainfall isohytes and coefficient of variation contours of annual rainfall in Sabarmati basin. In major part of the basin co-efficient of variation is between 40–50%.

The winter season begins in December and continues till the end of February. From March onwards, the hot weather continues till the middle of June. The south-west monsoon normally sets in by the middle of June and continues to be active till September. Ninety five per cent of the annual rainfall occur during this period. The upper reaches of the basin receive an average rainfall of over 90 cm against about 65cm in the lower reaches. The average annual rainfall over the entire catchment is about 80cm. Isohytes drawn using rainfall data (WRI, Hydrological data books 1961–75) for the last fifteen years are shown in Fig. 1. The coefficient of variation of rainfall in major part of the basin is between 40–55 per cent. During winter season average minimum temperature remains about 10°–11 °C. During summer (May is generally the hottest month), the maximum temperature remains about 42–44 °C. In the rainy and post-monsoon period, the day temperatures are moderate and range from about 26 °C to 30 °C. Mean monthly and annual potential evaporation at Ahmedabad is given in Table I.

It may be noted from Fig. 2 that about 49 per cent of the basin area (~10,300 sq. km) is occupied by rock exposures (or rock at shallow depth) belonging to Aravallies, Delhi is, Lava flows and Createaceous sand-stone/shale complex (known as Himmatnagar Sandstone). In this area, the soil cover is thin (except over Himmatnagar sandstone). The rock has only secondary porosity (cracks, joints, fissures, etc.). Due to high gradient and undulating topography, the run-off is high. These factors limit aquifer storage. There is no hydraulic continuity of the phreatic aquifer of this area with the phreatic aquifer in the alluvial area which lies in the lower reaches of the basin.

Alluvial deposits occupy approximately 11,300 sq. km in the lower reaches of the basin. Alluvial outwash deposits are found in a belt approximately 8 to 20 km along the rock-alluvial boundary (Fig. 2) and occupy an area of approximately 1500 sq. km. The soil in this area is sandy and even in deeper sections aquiclude/aquifer ratio is low (Groundwater Cell, PRL, 1977). This area is tentatively demarcated as the recharge area of deep confined aquifers in lower parts of the basin.

EXPERIMENTAL

A layer of soil moisture at a depth of 0.75 m (below the root zone of crop plants) was tagged with tritiated water (10 μCi/ml) at twenty-five stations in the Sabarmati river basin. The stations were selected all over the basin to represent different soil types. Locations are shown in Fig. 2. The injection work was done during January 1976. The field implements and injection layout is shown in Fig. 3. Selection of three or more sets ensured that more samples at different times could be collected without affecting the natural soil and flow conditions. For injecting tritiated water, the drive rods were first pushed or hammered into the soil upto a depth of 0.75 m or as required. The rods were then pulled out and brass injection needles inserted. Tritiated water (2.5 ml) was injected into each hole. Two markers (M_1 and M_2) were put for subsequent location of the injection sets.

First soil sampling was done in June-July, 1976 with the intention to observe upward movement (if any) of the tracer during the warmer period. Soil samples were taken in successive depths of 10 cm with a 5 cm diameter hand auger. Soil

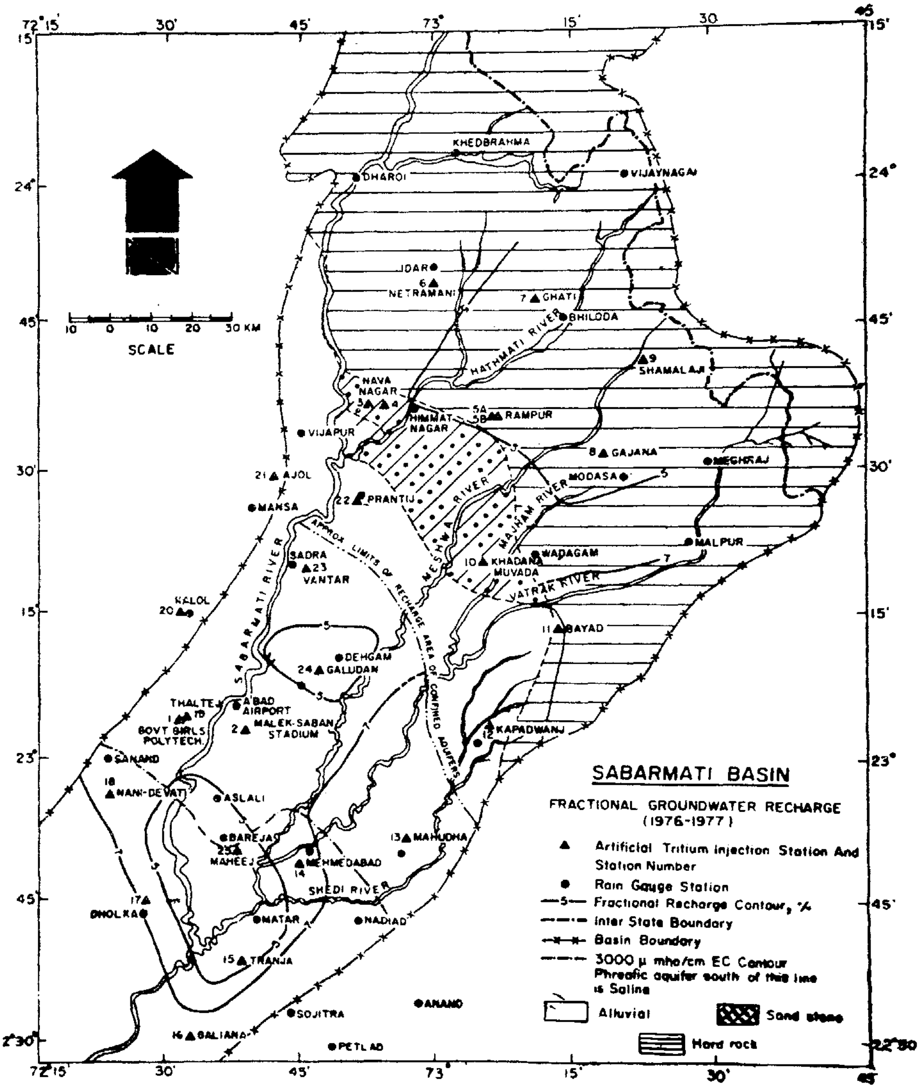


FIG. 2. Locations of tritium injection sites, raingauge station, geological boundaries and fractional recharge contours in Sabarmati basin based on tracing of soil moisture movement (1976–77).

samples were stored in air-tight screw cap plastic containers and brought to the laboratory for further analyses. *In-situ* density of soil was also measured at each site by sand logging. The station (No. 9) near to sub-mountain zone and those in the Himmatnagar sandstone region (Nos. 3, 4) could not be sampled because of presence of large size pebbles and boulders in the soil. The second sampling was done in January-February 1977 after the completion of about a year.

The moisture contents of the soil samples were measured gravimetrically. The pore water from the soil samples was extracted using a specially designed batch distillation set up (Fig. 4). The tritium concentration of the extracted pore water

TABLE I

Data of artificial tritium studies for estimation of groundwater recharges (1976–77) : *Sabarmati basin*

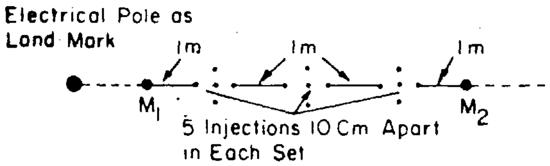
Station No.	Location name		Dates			Source of water† (cm)			Tracer displacement (cm)			Recharge (cm)		
	Long.	Lat.	Injected (t_0)	1st sampling (t_1)	2nd sampling (t_2)	Rain fall	Irrigation.[a]	Total	t_1–t_0	t_2–t_1	t_2–t_0 annual	t_1–t_0	t_2–t_0	t_2–t_0 in % water input
1	2		3	4	5	6	7	8	9	10	11	12	13	14
1	Ahmedabad 72° 35′	23° 01′	19–6–75	22–5–76		60.0	—	60.0	42	—	42	3.3	—	5.5
2	Maleksaban Stadium 72° 35′	23° 01′	24–1–76	26–3–77		103.0	—	103.0	195	—	195	6.4	—	6.2
3	Navanagar 72° 09′	23° 34′	28–1–76	Could not be sampled as hard strata encountered at shallow depth										
4	Navanagar 72° 09′	23° 34′	28–1–76											
5A	Rampur 73° 06′	23° 33′	28–1–76	2–7–76	27–1–77	12.6 95.8	— 45.6	12.6 141.4	—10	55	45	—2.4	8.5	5.5
5B	Rampur (1 metre away from 5A)		28–1–76	2–7–76	27–1–77	12.6 95.8	— 45.6	12.6 141.4	—15	45	30	—2.5	6.8	4.4
6	Netramali (IDAR) 73° 00′	23° 47′	29–1–76	2–7–76	27–1–77	7.4 107.1	— —	7.4 107.1	10	30	40	2.3	8.7	7.6
7	Ghati 73° 13′	23° 47′	29–1–76	3–7–76	27–1–77	17.4 151.1	— —	17.4 151.1	—4	19	15	—0.7	2.5	1.5
8	Gajana 73° 18′	23° 31′	29–1–76	3–7–76	27–1–77	9.6 75.6	— —	9.6 75.6	10	5	15	1.9	3.4	4.0
9	Shamalaji 73° 22′	23° 39′	30–1–76	Could not be sampled as hard strata encountered at shallow depth										
10	Khada-Namuvada 73° 04′	23° 06′	30–1–76	3–7–76	26–1–77	8.0 83.3	— —	8.0 83.3	25	30	55	2.4	5.9	6.5
11	Bayad 73° 13′	23° 13′	30–1–76	3–7–76	26–1–77	10.3 88.5	— 38.0	10.3 126.5	25	40	65	3.6	11.4	8.3

12	Kapadvanj 73° 07′ 23° 04′	31–1–76	6–12–76		121.0	—	121.0	55		55	15.8		13.0
13	Mahudha 72° 57′ 22° 49′	31–1–76	24–6–76	8–12–76	34.0 103.7	— 22.8	34.0 126.5	10	92	102	1.3	14.2	8.9
14	Mehmadabad 72° 45′ 22°49′	31–1–76	24–6–76		24.6	22.8	47.4	30		30*	5.9		12.5*
15	Tranja 72° 39′ 22° 38′	1–2–76	23–6–76	26–1–77	25.0 98.1	— —	25.0 98.1	—10	20	10	—2.4	2.7	2.2
16	Galiana 72° 27′ 22° 30′	1–2–76	25–6–76	25–1–77	47.0 96.2	—	47.0 96.2	19	21	40	4.5	10.4	7.3
17	Dholka 72° 27′ 22° 43′	1–2–76	25–6–76		27.9	—	27.9	—20		—20	—3.3		
18	Nani-Devati 72° 23′ 22° 56′	1–2–76	25–6–76	25–1–77	31.5 106.0	— —	31.5 106.0	37	23	60	5.5	8.4	6.1
19	Thaltej 72° 32′ 23° 03	1–2–76	7–7–76	27–3–77	22.0 80.6	— 15.2	22.0 95.8	8	32	40	1.8	6.8	5.8
20	Kalol 72° 30′ 23° 15′	1–2–76	1–7–76	28–1–77	29.8 50.4	— 30.4	29.8 80.8	10	35	45	1.9	7.4	6.7
21	Ajol 72° 41′ 23° 29′	2–2–76	2–7–76	28–1–77	13.3 79.4	38.0 38.0	51.3 117.4	72	43	115	10.1	14.4	8.5
22	Prantij 72° 51′ 23° 26′	2–2–76	7–7–76	28–1–77	20.6 87.2	— —	20.6 87·2	20	55	75	1.7	5.3	4.9
23	Vantar 72° 45′ 23° 20′	2–2–76	7–7–76	27–1–77	18.9 86.5	— 30.4	18.9 116.9	10	115	125	1.0	10.2	7.5
24	Galudan 72° 45′ 23° 08′	2–2–76	7–7–76	28–1–77	16.8 73.9	22.8 22.8	39.6 96.7	35	40	75	2.6	5.4	4.0
29	Navagam 73° 03′ 23 02′	8–12–76	19–5–77		—	68.4	68.4	57	—	57*	17.8*	—	26.0

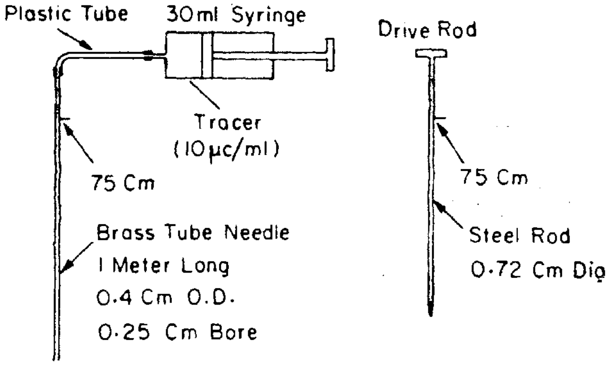
(a)Using empirical relation : 7.6 cm for each irrigation.

*Only for part of the year.

+In Column Nos. 6, 7 and 8, first number is for the period t_1—t_0 and the second for period t_2—t_1.



Layout of Injections in a Field



Syringes and Drive Rods

FIG. 3. Schematic diagram of injection layout and field implements for tritium injection.

was measured using a liquid scintillation system (LSS–20, manufactured by ECIL). The system had a background counting rate of 45 cpm during the analyses of the samples obtained from first sampling. During the analyses of the samples obtained from second sampling the background counting rate was reduced to 30 cpm by putting additional 13 mm thick lead shield around the photo-multiplier tubes and the sample chamber. The statistical counting error for any sample is less than 10 per cent.

The recharge has been estimated by computing the water content in 1 cm^2 cross-section column of soil between the depth of injection and the centre of gravity of the tracer profile.

RESULTS AND DISCUSSION

Experimental results together with other relevant data of tritium injection stations in Sabarmati basin are given in Table II. A few typical tritium profiles for the first sampling, done during June-July 1976, are shown in Fig. 5*a*, *b*. In spite of a few showers during June it was observed that at some stations (i.e., Ghati, Rampur, Tranja and Dholka) the tracer had moved upward. This upward movement of the tracer is apparently due to evapotranspiration losses during the period of January through June. The tritium profile obtained for station 5B (1 m away from station 5A),

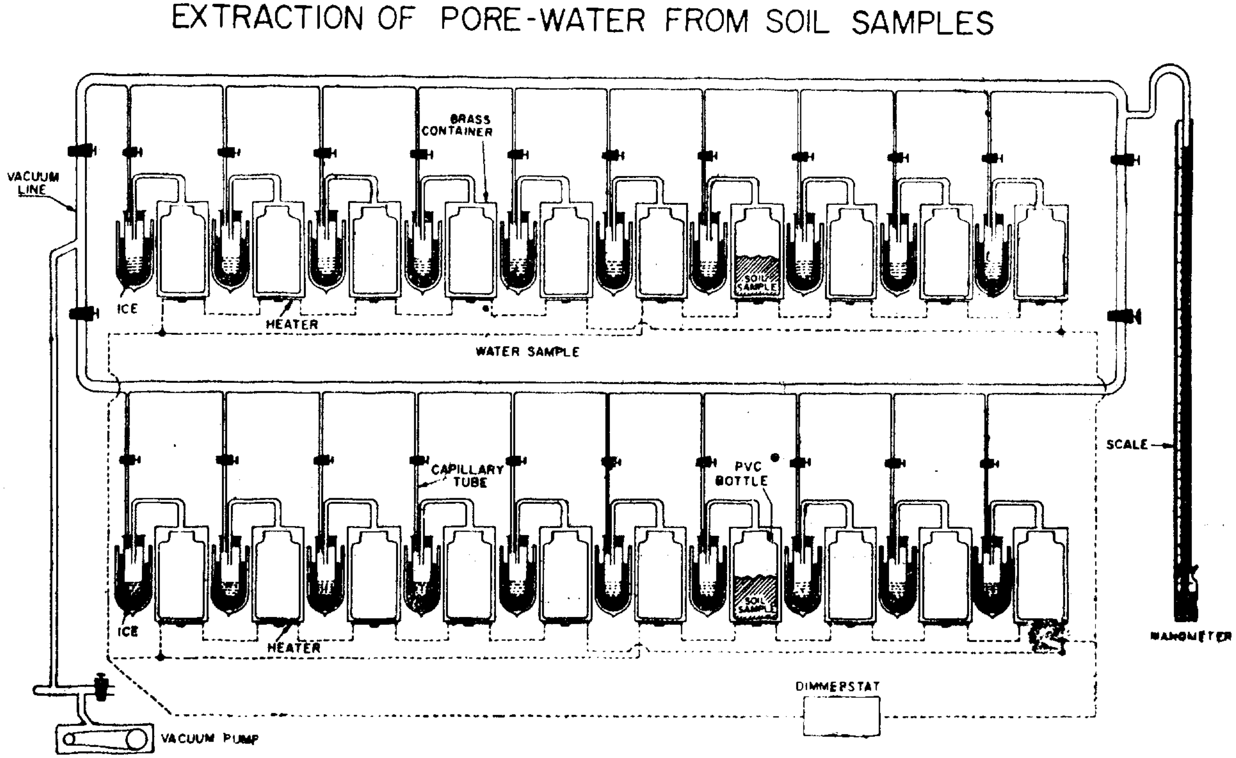


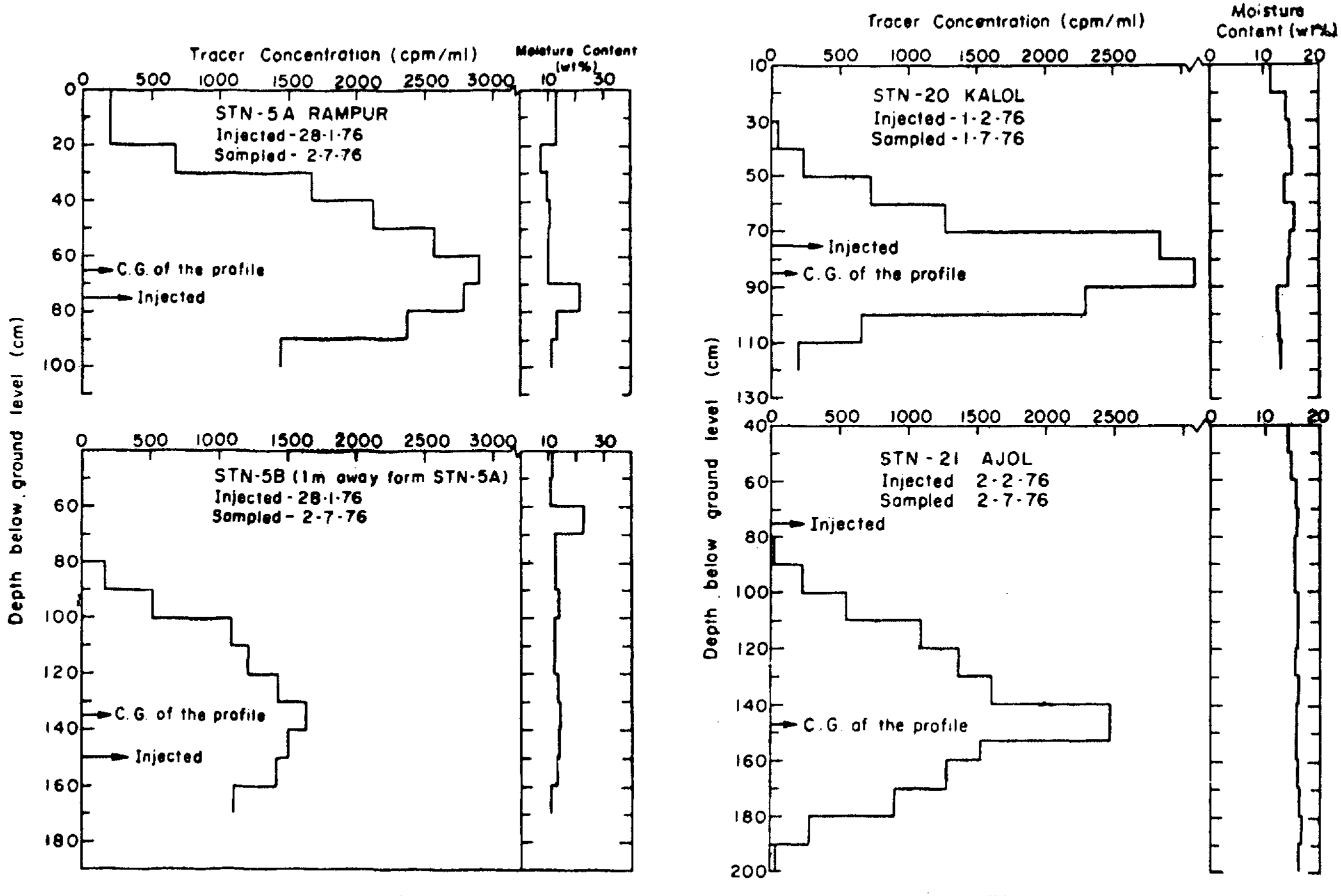
FIG. 4. Schematic diagram of batch distillation system for extraction of pore-water from soil samples.

TABLE II

*Mean monthly and annual potential evaporation (mm) at Ahmedabad***

Month	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
(*a*) Penman Formula	89.6	104.7	164.4	137.7	284.8	190.8	131.0	116.7	133.7	139.6	99.3	73.9	1676.8
(*b*) Thorntwaite Formula	47.0	62.3	182.0	208.7	200.6	185.1	170.0	156.3	149.5	92.0	49.7	182.0	1651.2
(*c*) Class A Pan Evaporation wire mesh covered	158.3	151.6	280.3	346.3	401.2	300.9	158.4	138.2	161.1	204.9	180.8	156.4	2638.3

**Data supplied by Dr A. Krishnan, Central Arid Zone Research Institute, Jodhpur.



(a) (b)

FIG. 5. A few typical tritium profiles showing displacement of tracer during premonsoon period in Sabarmati basin.

where injection was made at 1.5 m depth, indicates that under similar soil conditions the evapotranspiration losses are also effective from even deeper layers of the soil. At all the four stations, where an upward movement of the tracer was observed, it was also noted that the depth of the water table is less than 4 m. In regions with shallow water table a continuous supply of water to upper dry layers may be maintained during a prolonged dry spell, giving rise to a higher evapotranspiration than elsewhere with a deeper water table.

The second sampling was done after completion of almost a year. A few typical tritium profiles observed during second sampling are shown in Fig. 6, it can be seen from Table II that all the stations showed a significant downward movement of the tracer peak.

The net annual recharge in the Sabarmati basin is estimated to vary between 2.5 cm for Ghati to 14.4 cm at Ajol. Recharge values computed as fraction of precipitation plus supplemental irrigation in the investigated areas vary between 1.5 per cent for Ghati to 13 per cent at Kapadvanj with an average of 7 per cent. Statistical analysis of the estimated recharge using the method of coefficient of variation (Rao, 1977) indicate that the number of stations chosen is more than adequate to describe the geographical variation in recharge values within 90 per cent accuracy.

The data obtained from these experiments have been used to establish an empirical relation between the estimated recharge to the phreatic aquifer and input of water (i.e., precipitation plus irrigation) in the investigated area.

The empirical relation is

$$Re = 0.11\ (P - 41.8) \qquad \ldots(1)$$

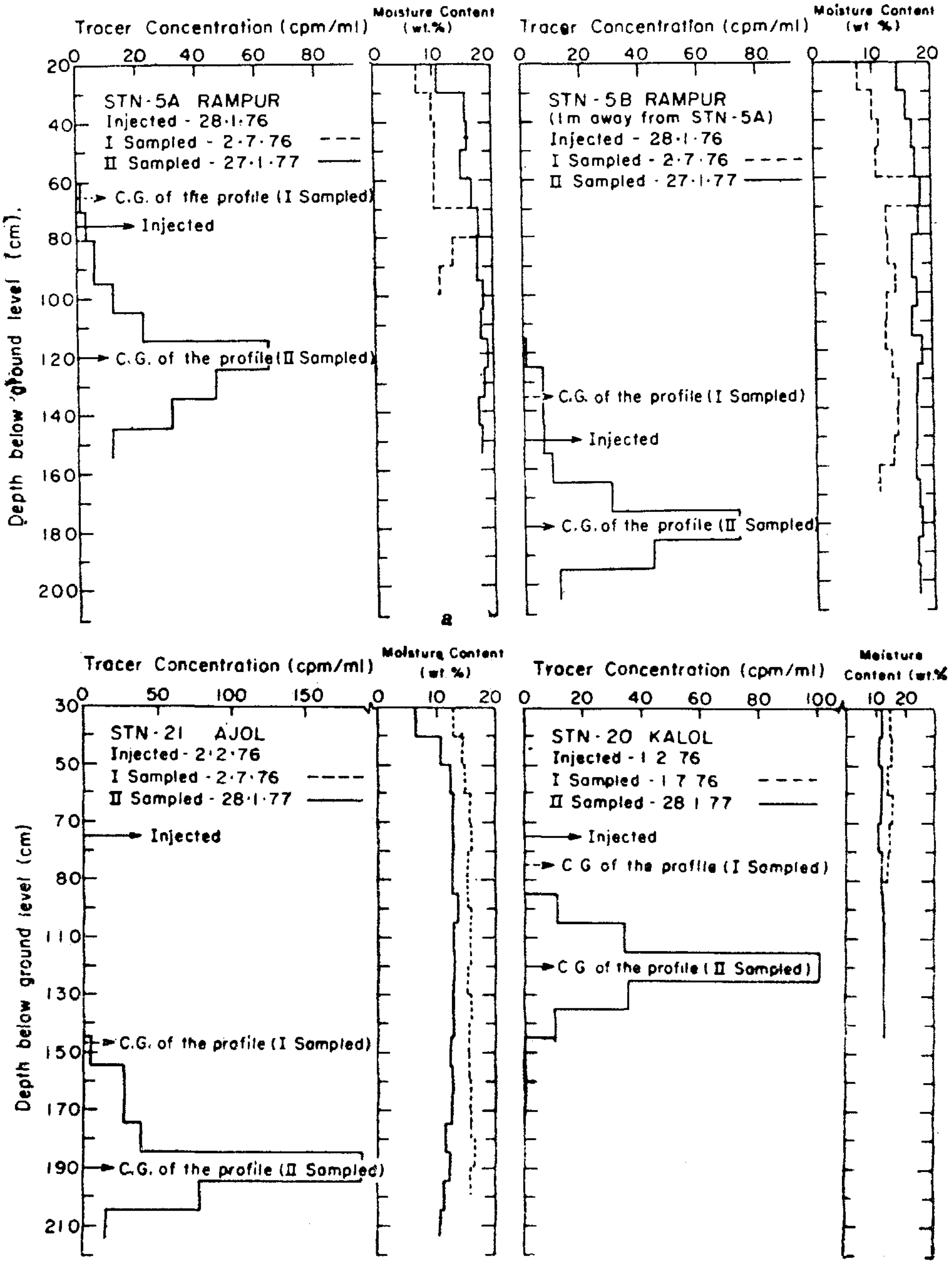
where, Re = Estimated recharge in cm

and P = Water input (precipitation + irrigation) in cm.

This relationship is shown graphically in Fig. 7. The trend indicated in Fig. 7 follows a least square fit linear relationship [eqn. (1)] with a correlation coefficient of 0.88. This relationship is applicable to sandy loam soils in the investigated area. In deriving this relationship, data of stations with shallow water table and clayey soils have not been considered.

The input due to irrigation in the above relationship was estimated from the number of waterings to the field, assuming one watering to be equivalent to 7.6 cm (Datta, 1975).

It would appear from eqn. (1) that in general no net groundwater recharge takes place in the Sabarmati basin area if the yearly rainfall is less than 42 cm. This may appear to contradict results obtained from first soil sampling, which represent the movement of tracer over a prolonged dry period (January to June). It was earlier pointed out that in spite of prolonged dry period all stations, where water table is deep, show a net downward movement of the tracer even for a small amount of water input. We hypothesise that this movement is not an effect of few scattered showers that took place in the study area in June 1976 (before first sampling) but represents a slow drainage of antecedent soil moisture from the previous years'



(b)

FIG. 6. A few typical tritium profiles showing displacement of tracer during 1976–77 in Sabarmati basin.

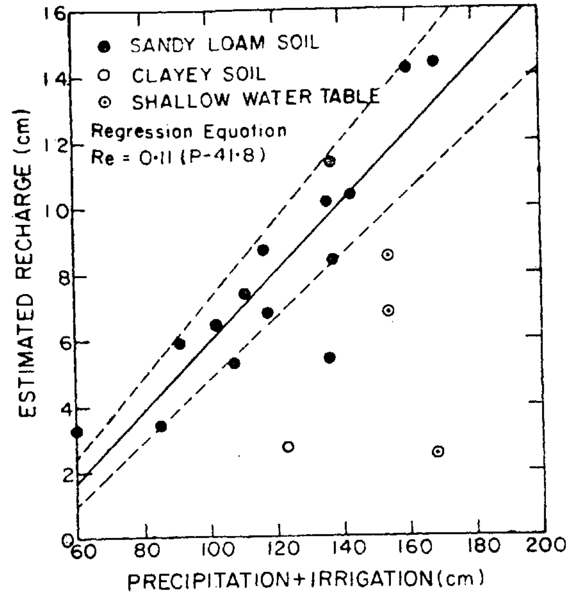


FIG. 7. Correlation diagram of estimated recharge with total water input (precipitation and irrigation). Limit of two standard deviations is indicated by the dotted lines.

(1975) monsoon rains. It is interesting to note that the commonly used Chaturvedi (1946) formula and Amritsar formula (Sehgal, 1973) also indicate that practically no recharge takes place if the yearly rainfall is less than 40 cm.

ESTIMATES OF AVERAGE ANNUAL RECHARGE TO PHREATIC AQUIFERS

Contribution of rocky area to the overall groundwater budget in this basin is limited because of hydrogeological factor enumerated earlier and is not considered further in this paper. It was earlier noted that, there is no hydraulic continuity of aquifers in the rocky area with the phreatic aquifer in the alluvial area of the basin (Groundwater Cell, PRL, 1977). The ratio of recharge/rainfall in the thin belt of alluvial outwash deposits (tentatively delineated as recharge area of confined aquifers) is expected to be considerably higher compared to the remaining alluvial area because of higher sand content of soils. Tritium tracing data of existing four stations (Nos. 11, 12, 22, 29) in this region indicate that the fractional recharge values are 8.3 per cent, 13 per cent, 4.9 per cent and 26 per cent respectively. The last of these values represent only half of the year and the recharge is due entirely to supplemental irrigation. These data at present are inadequate to compute an average value of recharge in this part of the alluvial region. Ten additional stations in this belt were set up recently to obtain a representative value of recharge in this region. Soil sampling at these stations will be done after the end of 1977 monsoon. Assuming a value of 15 per cent for fractional recharge in this region and taking the average rainfall of this region (800 mm), the estimated annual groundwater recharge amounts to about 180 million cubic meters from this belt. Amount of groundwater recharge to phreatic aquifer from the remaining part of the alluvial area, (~9800 sq km) is estimated to be 180 million cubic meters, using an average fractional recharge value of 7 per cent and the average annual rainfall of 700 mm. Thus, the natural recharge due to precipitation in the alluvial parts of Sabarmati basin is estimated to be (480 + 180 = 660) million cubic metres per year.

The analysis of the phreatic aquifer water in alluvial area of the basin indicates that approximately 6,600 sq. km area (corresponding to an estimated recharge of 323 million cubic meters) in south west of Ahmedabad has electrical conductivity greater than 3,000 μ mho/cm (Fig. 2). According to United States Salinity Laboratory's classification (1954), the phreatic aquifer water in this region belongs to C_4S_2 and C_4S_1 class and therefore not suitable for irrigation and/or drinking (Datta *et al.*, 1979). This part of the basin area needs special attention if the large amount of recharge ($\sim 323 \times 10^6$ m^3) of water is to be utilised for irrigation/drinking.

CONCLUSIONS

Based on field and laboratory data presented in the paper, the following conclusions may be safely drawn :

(1) Average annual groundwater recharge in major parts of the alluvial regions of Sabarmati basin is less than 7 per cent of the water input (both from precipitation and supplemental irrigation).

(2) Based on the past rainfall data, and the tritium tracing experiments during 1976–77, average annual groundwater recharge in the alluvial regions of basin is estimated to be about 660 million cubic metres. Out of this, recharge to the confined aquifers through their recharge areas is estimated to be about 180 MCM. Of the remaining 480 MCM, about 323 MCM is recharged to saline phreatic aquifers in the southern part of the Sabarmati basin. Thus the total amount of utilisable groundwater recharge both to the phreatic ($\sim$157 MCM) and confined aquifers ($\sim$180 MCM) is estimated to be 337 MCM.

(3) Since the current groundwater pumpage ($\sim$700 MCM/Yr) in the Sabarmati basin (Sharma, 1977) is considerably more than the estimated utilisable groundwater recharge, it is desirable that much of the groundwater activity for future development must come from artificial groundwater recharge.

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