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Infiltration Rates of Rainwaters in Sri Lanka Measured by Using Tritium Tracer

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Tritium tracer, injected below the surface soil, is used to follow the movement of soil moisture in the unsaturated zone at several geo-hydrologically different sites in Sri Lanka. Depth profiles of tritium activity and moisture contents have been measured after rainfall. For two well-established aquifers, Vanathavillu and Mannar, the recharge to groundwater is close to 30% of the rainfall. Infiltration is much higher. The moisture movement is apparently like piston flow. In the central highland regions, where the surface cover is composed of an overburden of fractured rocks overlain by a few metres of soil cover, the infiltration rate is very high.

Introduction

Movement of soil moisture in the unsaturated zone can be conveniently studied by means of tritium tracer. Environmental tritium, which has entered the hydrological cycle from atmospheric detonation of thermonuclear devices, has been used for this purpose by several groups (Smith et al. 1970, Andersen and Sevel 1974, Foster and Smith-Carington 1980). Extensive studies have also been carried out by injecting artificially produced tritium (Zimmermann et al. 1966, Datta et al. 1973, Goel et al. 1977, Athavale et al. 1980) to obtain information about the infiltration of water into the soil. In the present study we describe some experiments, using artificial tritium, that enable us to estimate infiltration rates of rainfall through the top soil at several places in Sri Lanka – a country near the southern-most tip of India.

Geohydrological Considerations

Rainfall pattern in Sri Lanka has been recently described by Baghirathan and Shaw (1978). The monsoonal rains (May to August, south-westerly; December to February, north-easterly), the intermonsoonal showers, (March-April) and the cyclonic rains (October-November) contribute to the water resources of the island. Part of the rainfall percolates down through the top-soil and is stored in groundwater aquifers, provided these exist. Most of the country is covered with gneisses and metamorphic rock. In north western and northern coastal regions sedimentry formations are seen where the carbonate rock lie deep overlain by unconsolidated marine sediments. These limestone formations provide karst aquifers. Better known aquifers are: Vanathavillu, Mannar and Jaffna Peninsula. Since the aquifers are in coastal regions where fresh groundwater interfaces with the saline sea water, the depletion of the former might result in the increasing intrusion of sea water. Thus, even though maximum groundwater exploitation from the aquifers must be done, it has to be judiciously planned to avoid long terms deliterious effects. A knowledge of the recharge rates to the aquifers is therefore very valuable.

In most regions of the island the surface material is composed of an overburden of fractured rock mixed with weathered material. Rainwater enters through these highly permeable formations, stays in-transit in the overburden, and eventually leaks down the slopes into streams. One may tap this fissure and pore water by digging shallow open wells of low yield – a possibility that might be of economic significance.

Experimental

Several sites for direct recharge measurements were chosen with the following considerations and constraints: availability of permanent landmarks for precise location; approachability; absence of major hydrological singularities (e.g., slopes, vicinity of rivers); absence of large trees; etc. Brief geohydrological information about the sites chosen in the first phase (see Fig. 1) is given below:

Vanathavillu ARS (1): This was a cultivated field located in an Agriculture Research Station. The soil was deposit of red sandy loam, about 50 m thick, on karstified limestone. At a depth of about 12 m, water was available in an unconfined aquifer of about 3 m thickness. This presumably leaked into a deeper (depth 50 m and more) confined aquifer. The site was on the border of the main recharge area for the Vanathavillu karstified aquifer.

Madhu Road (3): The site was in a mango garden. Sandy loam, about 10 m thick, lay on fractured and weathered rocks. The site was beyond the limestone bound

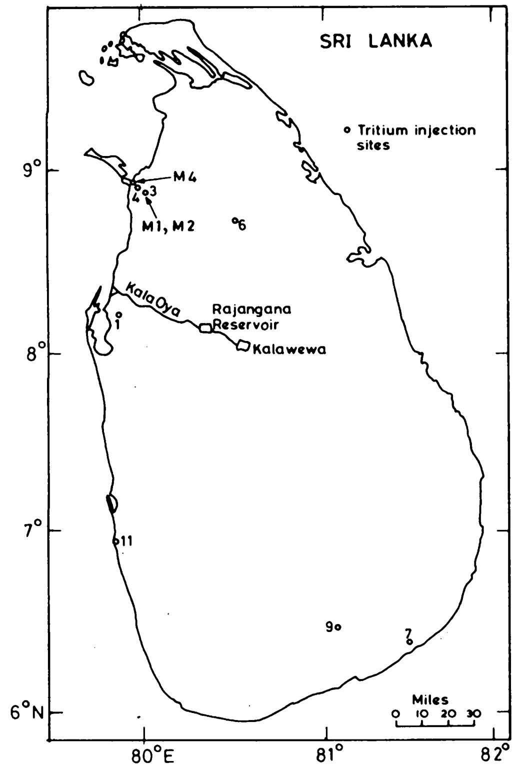

Fig. 1. Index map of Sri Lanka showing the sites of tritium injections.

and had no karst formation.

Mannar Quarry (Parappakadanthan) (4): In this region basement limestone outcroppings were seen at many places. The overburden was about 50 cm thick. Injections were made in a fallow field, a few hundred metres away from a limestone quarry. The 'fill' (top soil) was a thin layer of reddish brown sandy loam mixed with pices of limestone.

Vavuniya (6): A mixture of sand and clay, several metres thick, lay on an overburden of weathered rocks. The basement igneous rocks were fractured. The field was cultivated and irrigated from a dug-well.

Yala (Buttawa) (7): The site was in Yala Wild Life Sanctuary in the vicinity of a tank. There were many trees on this sandy loam soil. The region had significant run off into a nearby drain.

Tanamalwila (9): This highland site, with characteristics somewhat similar to that of Vavuniya (No. 6), was in a pineapple field having red earth as top soil.

In the second phase of work, during the summer of 1977, fresh injections were made at five more sites. These were chosen in an around the Mannar aquifer. Only three could be subsequently sampled. These sites, within 10 km of the sites No. 3 and No. 4 in Fig. 1, are described below.

Madhu Road (M1): On the side of a jungle road from Madhu Church to Parappakandanthan in forest, the site was in the highest recharge area. The soil was yellowish sandy clay (latasolic). Large trees were in the vicinity.

Madhu Road (M2): On the same forest road, near an open dug well, this site had the same characteristics as M1.

Murunkan (M4): The site, close to site No. 4, was in a house graden (unploughed). The fields in the vicinity were tube-well irrigated. The soil was heavy clay.

Tracer Injections

At each site a 'set' of three injections were made so that one could collect samples at three different intervals. All 'sets' were laid along a line which was bounded by 'markers' (burried at about 30 cm depth) that could be located conveniently at a later time by reference to the permanent location land marks (e.g. electric poles, trees, buildings, etc.). At each 'set'five (as in Goel et al. 1977) or three (triangular, 10 cm distance or linear 10 cm apart along the alignment line) injections were made. Each 'set' was generally separated from the other by 2 m so that disturbing of one 'set' during sampling did not affect the recharge condition at the neighbouring undisturbed 'set'. At the point of injection, drive rods (1 m long, 6 mm diameter) were hammered into the soil upto 70 cm depth. The drive rods were taken out (sometime with great difficulty) leaving clear holes. Tritiated water (25 micro – curie, 2.5 ml) was introduced through a 1 m long copper tube inserted into each hole. The injectors were removed and the holes were filled by lateral collapse. Normal farming in the field could continue. Since the sites M1, M2 and M4 were in a forest (no ploughing and farming), the injection points could be located precisely by placing a nail at the surface at that point. Injections at these sites were made at one point only.

For several sites, away from the injection 'sets', soil samples, were collected up to about 2 m depth in successive sections of 10 cm with a hand auger. These samples were stored in screw cap plastic bottles and brought to the laboratory for moisture determination.

Sampling

The first sets of samples were collected in May and June 1977. At a site the 'markers' were dug out and, with a measuring tape, the region of activity was located. Soil was removed with a 4″ hand auger in successive depth of 10 cm, starting from 30 cm down to about 300 cm. Samples of soil were stored in screw cap plastic containers and brought to the laboratory for analysis. Measurements on bulk density were carried out in the field for some sites. Total mass of the soil collected from various depths was recorded and the volume of the hole was measured by filling it with a known volume of sand.

Laboratory Analyses

Aliquots of all soil samples were weighed and dried in an oven to determine their moisture contents. A multiple sample distillation unit was assembled to distil pore water from soil samples. Ten samples could be distilled in one run. The distillation was done under reduced pressure (about 10 cm Hg) and at a temperature of about 80°C. In almost all cases we could easily collect about 2 ml water within one hour's distillation time.

Tritium activity of the water collected from the distillation unit was measured by liquid scintillation coincidence counting technique. One ml water was mixed with 10 ml INSTA GEL and the samples were counted on a Tri-Carb (Model 3300, Packard) spectrometer.

Results and Discussion

First Phase

The tritium activity and moisture contents of the soil samples at various sites are given as profiles in Figs. 2 to 7. The results are summarized in Table 1, which also gives data on *in-situ* density determinations. Rainfall data for each site were collected from the nearest rain – gauge station. These, summed up fortnightly intervals, are also presented in the figures. Total rainfall during the interval between the dates of injection and sampling is entered in Table 1. The recharge is calculated as the amount of moisture contained in 1 cm^2 column of soil between the peak position and the depth of injection.

The results of the two sites, Vanathavillu and Madhu Road, where good groundwater aquifers exist, are the most interesting. From an examination of the profiles (Figs. 2 and 3) and the data given in Table 1, we note that: i) inspite of

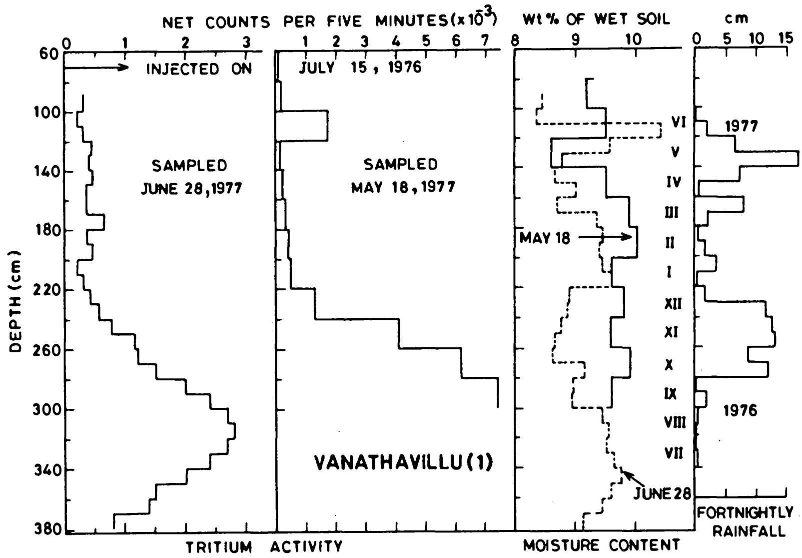

Fig. 2. Depth profiles of moisture contents and tritium from Vanathavillu. Fortnightly rainfall data for the intervening period are also given.

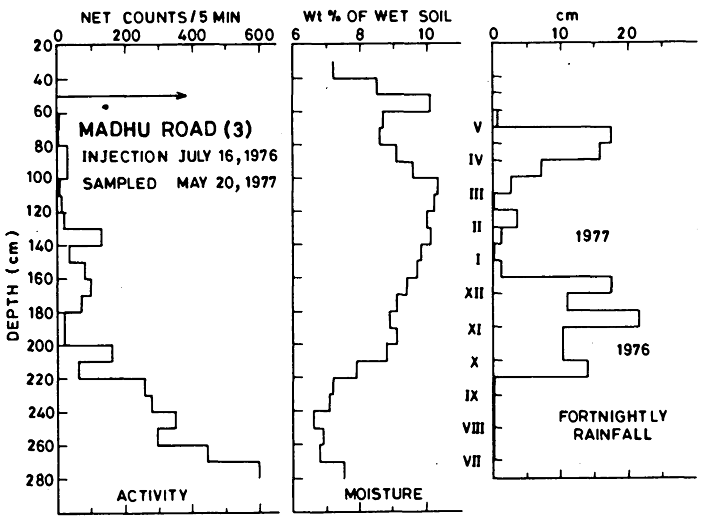

Fig. 3. Depth profiles of moisture contents and tritium activity from Madhu Road. Fortnightly rainfall data for the intervening period are also given.

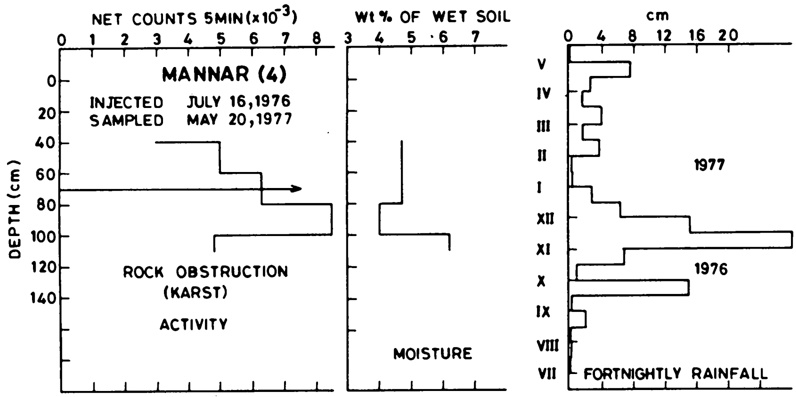

Fig. 4. Depth profiles of moisture contents and tritium activity from Mannar (Parappakandanthan). Fortnightly rainfall data for the intervening period are also given.

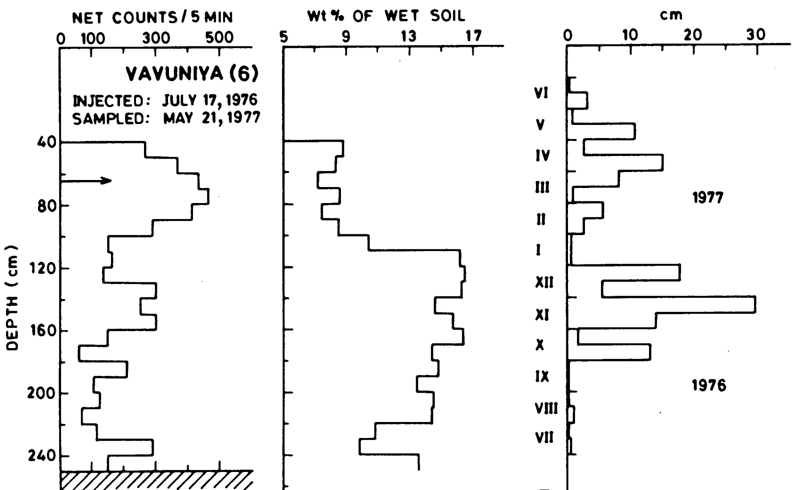

Fig. 5. Depth profiles of moisture contents and tritium activity from Vavuniya. Fortnightly rainfall data for the intervening period are also given.

extreme dry climate, the tracer has not moved upwards, ii) the tracer movement downwards is layered, and iii) the fractional recharge is 30% to 40%.

The concept of piston type movement of water in unsaturated soil zone, originally suggested by Zimmermann et al. (1966), is now well established in semi-arid climatic conditions (Goel et al. 1977). The present results confirm this for still

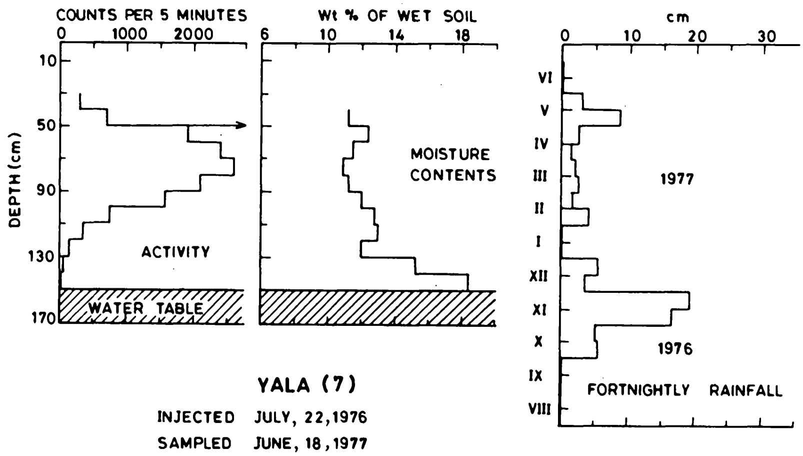

Fig. 6. Depth profiles of moisture contents and tritium activity from Yala. Fortnightly rainfall data for the intervening period are also given.

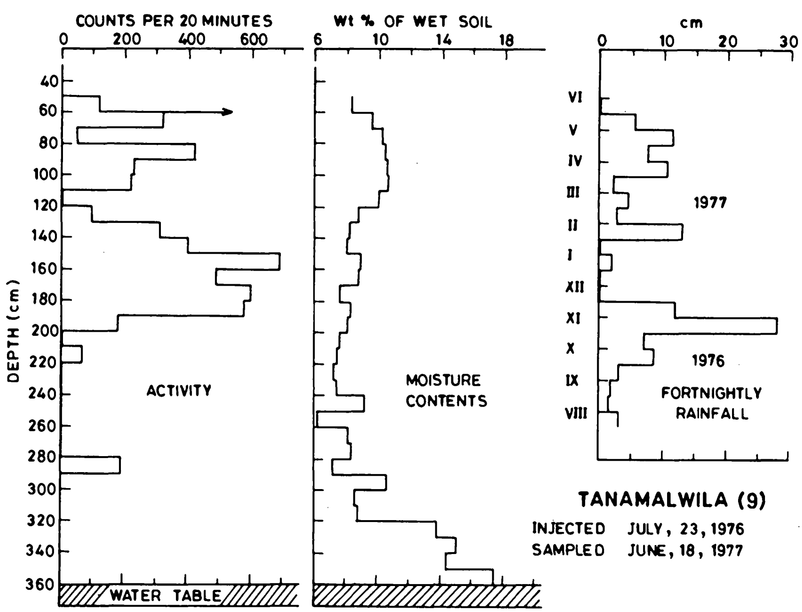

Fig. 7. Depth profiles of moisture contents and tritium activity from Tanamalwila. Fortnightly rainfall data for the intervening period are also given.

Table 1 – Data on tracer displacement collected during first phase

Data	Vanathavillu ARS (1)		Madhu Road (2)	Mannar (4)	Vavuniya (6)	Yala (7)	Tanamalwila (9)
Data of injection (1976)	July 15		July 16	July 16	July 17	July 22	July 23
Date of sampling (1977)	May 18	June 25	May 20	May 20	May 21	June 18	June 18
Bulk density, wet soil (g cm^{-3})	1.80	–	1.84	–	–	–	2.0
Peak position (cm)	270	320	280	90	Smear	70	170
Displacement of tracer (cm)	> 200	250	> 230	20	–	25	110
Recharge, *Re* (cm)	> 35	43	> 38	–	–	–	–
Rainfall, *R* (cm)	100	105	120	100	130	80	120
Irrigation	No	No	No	No	Yes	No	Yes

drier conditions. The surprising feature is the absence of serious evapotranspiration loss of the tracer injected at only 50 cm depth and a very high fractional recharge. It may be pointed out that the value of recharge (43 cm) at Vanathavillu is close to the value (38 cm) as estimated from hydrological parameters (Wijesinghe 1977).

We next focus our attention on two other sites which are also geohydrologically similar. Vavuniya (Fig. 5) and Tanamalwila (Fig. 7) are both highland sites where the bedrock is at a shallow depth. The water table in the dry month of May-June is within a mere 3.5 m depth. During rains this must have risen up considerably and must have bitten the lower edge of the activity profile. At the same time the tracer must have moved downwards. The movement is not layered. It is not possible to estimate a recharge at these sites. However, the tracer head, at both the sites, has migrated through a distance of about 1.5 m which is indicative of high infiltration of rainfall and irrigation water. The soil, being mostly sand mixed with gravel, acts likes a filter bed. As the porewater in the sub-surface soil exceeds the field capacity, it must flow down slopes into nearby streams since no stable aquifers exist. A possible "appropriate technology" (Schumacher 1973) would be to dig open wells to arrest this water so that it could be pumped for irrigation purpose during lean period. This mode of supplemental irrigation would be suitable for small farms since in Sri Lanka labour – intensive agricultural practices are followed. Such small artificial aquifers could be provided with proper lining at the lower portion to eliminate losses due to seepage from the bottom of the well (Helweg and Smith 1978). Since most of the agricultural land in Sri Lanka is in the "dry zone", with arid climate in-between the monsoons, availability of water during dry spells from such aquifers would have a very significant influence on the food production. More extensive studies on this aspects of water resources exploitation must be pursued.

At Yala (Fig. 6) the profile is almost Gaussian. It appears that the tracer movement has not been influenced by the water table despite the latter being very shallow. This site was chosen under severe constraints due to absence of land-

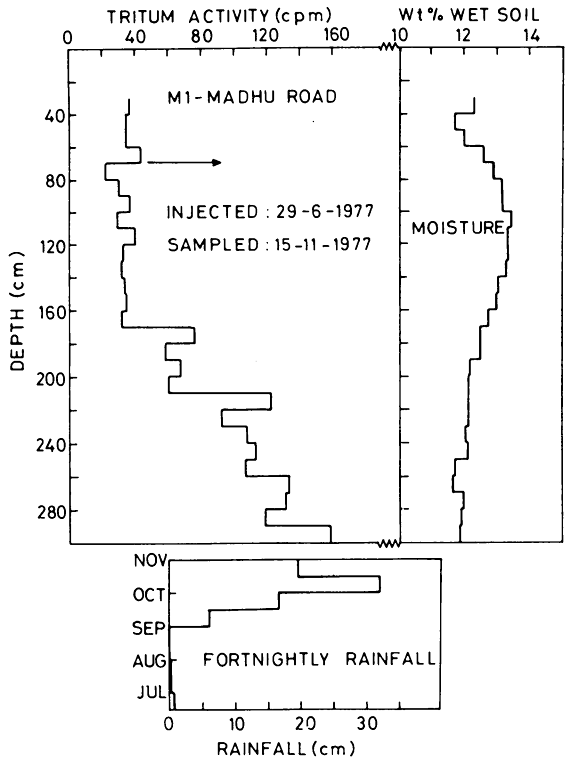

Fig. 8. Depth profiles of moisture contents and tritium activity from Madhu Road, M1 (second phase). Fortnightly rainfall data for the intervening period are also given.

marks and approach road. There was drain in its vicinity facilitating heavy run-off which might have been responsible for low recharge. The results of the other site, Mannar (Fig. 4), are also of little significance due to the obstruction of moisture movement by limestone rock at 120 cm depth.

Second Phase

The activity and moisture profiles for the sites studied in the second phase (M1, M2 and M4) are shown in Figs. 8, 9 and 10. The Murunkan site (M4) was in clayey soil and its low recharge is expected. The other two sites near Madhu Road belong to the area of very high recharge. However, certain caution is to be exercised before we estimate recharge values for these sites.

Both the bulk density and moisture contents of the soil that go into the calculations of recharge were determined at the time of sampling. The moisture that was initially in the soil volume between the displaced tracer position and its initial position (70 cm) has been pushed downwards by displacement flow and has thus contributed to the recharge. It is reasonable to assume that the initial moisture

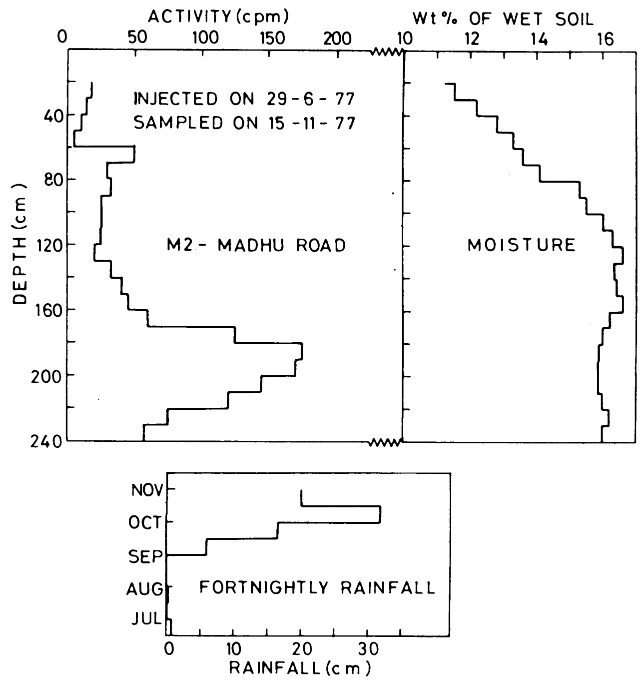

Fig. 9. Depth profiles of moisture contents and tritium activity from Madhu Road, M2 (second phase). Fortnightly rainfall data for the intervening period are also given.

content was 7% and that the bulk density was 1.8 g cm^3 as measured during summer months for similar areas of Vanathavillu and Madhu Road (Table 1). The values of Re are: M1; 30 cm and M2; 15 cm. Infiltration values are 92% and 77% at M1 and M2 respectively (Table 2).

Table 2 – Data on sites studied in the second phase

Site	M1 Madhu Road	M2 Madhu Road	M4 Murunkan
Date of injection (1977)	June 29	June 29	June 29
Date of sampling (1977)	Nov. 15	Nov. 15	Nov. 14
*Bulk density (g cm^{-3})	2.34	2.98	2.41
*Average moisture content (wt % wet soil)	12.4	16	13.5
Peak position (cm)	> 300	190	100
Tracer displacement (cm)	> 230	120	30
Infiltration (cm)	> 67	57	10
Rainfall, *R* (cm)	73	73	65

* These refer to time of sampling.

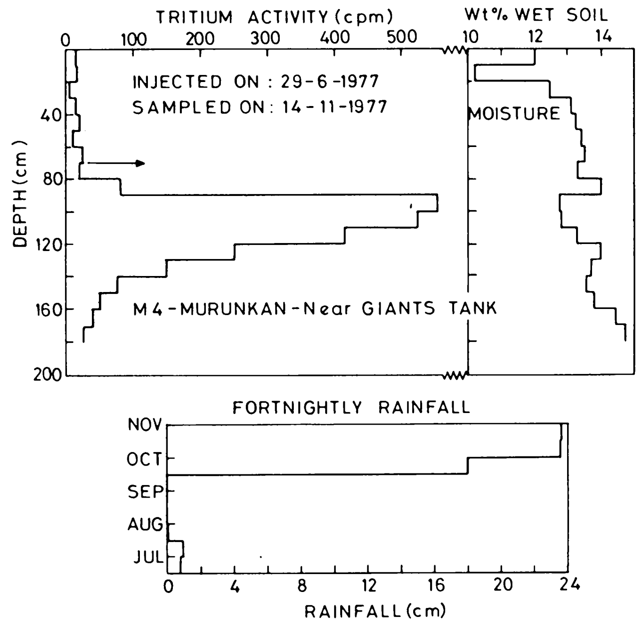

Fig. 10. Depth profiles of moisture contents and tritium activity from Murunkan, M4 (second phase). Fortnightly rainfall data for the intervening period are also given.

The values of fractional recharge at four somewhat similar sites are: Vanathavillu (1), 40%; Madhu Road (2), 32%; Madhu Road (M1) 30%; Madhu Road (M2), 15%. It is difficult to explain the low value at M2. It could be a point of singularity or the assumed value of the initial moisture content may be incorrect.

Tracer Balance

At several sites, listed in Table 3, the tracer has appararently remained as a 'closed system' since the profiles are bell shaped. A material balance calculation for tracer can be done if one knows the tracer distribution in a horizontal plane. Alternatively, from tracer balance, one can calculate the effective range in the horizontal plane to which the tracer has spread. Assuming that the activity profile in the vertical plane has a Gaussian shape, we estimate σ, the width parameter, by curve fitting (Goel et al. 1977). We calculate diffusion coefficient D from σ by the relation $\sigma^2 = 2\,D_t$, and present the results in Table 3. These values are somewhat higher than the values found for a north Indian province (Goel et al. 1977) presumable due to higher ambient temperature.

Diffusion process would cause the activity to spread in a horizontal plane as

Table 3 – Tracer balance and tracer diffusion

Site		n	T($\times 10^{-6}$) cpm	ς g cm^{-3}	m	k	σ (cm)	D $\times 10^5$ (cm^2 sec^{-1})	r_e (cm)
Vanathavillu	(1)	5	28	1.8	0.10	560	40	2.7	29
Madhu Road	(2)	2	11	1.8	0.09	180	45	3.7	37
Mannar	(4)	3*	17	1.8	0.05	1,800	40	3.0	18
Yala	(7)	2	11	1.8	0.12	540	22	0.8	24
Madhu Road	(M2)	1	5.6	3.0	0.16	180	27	2.8	25
Murunkan	(M4)	1	5.6	2.4	0.15	570	28	3.0	17

* triangular arrangement.

well, within a few decimeters as governed by the spacing of the injection points, and σ. We assume it to be uniformly dispersed within a circle of effective radius r_e and calculate the total activity A, at a set as

$$A = \rho m \pi r_e^2 \int_{-\infty}^{\infty} k e^{-z^2/2\sigma^2} dz = \sqrt{2\pi^3}\ \rho m \pi r_e^2 \quad = T$$

where

ρ – bulk density of the wet soil (g cm^{-3}).
m – moisture content of the soil (mass fraction of the wet soil).
k – activity at the maximum of the profile (cts min^{-1}).

The total activity, T, injected at a set is $5.6\, n \times 10^6$ cts/min where n is the number of injection points in that 'set'. Various parameters and the calculated values of r_e are given in Table 3. These, being generally less than σ, appear to be quite reasonable and indicate that material balance for the tracer is satisfactorily met. If the samples were collected off-centre due to poor alignment, the measured activity would be lower than the actual value and a somewhat higher value of r_e would be obtained. This might be a factor for the sites Madhu Road (2) Yala (7).

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