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ESTIMATION OF GROUND WATER RECHARGE DUE TO RAINFALL BY STATISTICAL METHOD

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ABSTRACT

Direct ground water recharge from rainfall depends on the intensity duration of rainfall, the evaporative demand, soil moisture defficiency, the sorptivity, depth of unsaturated zone etc. Given all these parameters, it is possible to predict the groundwater recharge at a site due to rainfall. Rainfall recharge would result in rise of water table. There have been attempts to predict rainfall recharge by statistical methods using only the point rainfall data and point water table fluctuation neglecting the fact that water table fluctuation may be caused by recharge at some other point with varied conditions. In the present report an attempt has been made to check the validity of statistical approach. Using Green and Ampt infiltration equation and sorptivity of a known soil, the recharge due to rainfall has been predicted. The consequent water fluctuations have been determined using Hantush solution for water table rise due to recharge. Using these synthetic data of water table fluctuation and rainfall values the rainfall recharge has been estimated statistically and compared with true but synthetic recharge values.

1.0 INTRODUCTION

Recharge rates for aquifers need to be estimated for ground water resources evaluation. The major sources of recharge to aquifers in many areas are direct precipitation and downward percolation of stream runoff. Recharge from rainfall is irregularly distributed in time and place. During summer and early fall months, evapotranspiration and soil moisture requirements are so great that little rainfall percolates to the water table except during periods of excessive rainfall. In humid areas, when evapotranspiration is small and soil moisture is maintained at or above field capacity by frequent rains, recharge is generally more. Only a fraction of the annual precipitation percolates down to the water table depending upon the thickness of the soil, the topography, vegetal cover, soil moisture content, depth to water table, the intensity and duration of rainfall, and other meteorological factors.

Recharge from direct precipitation and by infiltration of soil water involves the vertical downward movement of ground water under the influence of gravity, suction and diffusion.

In the present paper recharge due to rainfall has been estimated using Green and Ampt solution. The recharge causes the water table to rise. The water table fluctuations have been determined using Hantush solution.

2.0 REVIEW

The natural phenomenon of rainfall recharge is very complex to study and analyse and any work on the estimation of recharge of aquifers by rainfall needs a clear understanding of the physical processes of the soil, vegetation and atmosphere systems. Rainfall is one of the main components of the hydrologic cycle. The rainfall after being affected by interception, reaches the land surface where it fills up the surface depressions and also infiltrates into the soil surface. Infiltration is the term applied to the process of water entry into the soil through the soil surface, vertically as well as horizontally. A portion of the infiltration reaches the ground water storage and is called ground water recharge.

For the study of recharge due to rainfall as a fraction of the infiltrated rain water, the possible losses from rainfall i.e. interception, depression storage, surface runoff and evaporation are to be separated. It is assumed that intercepted water and rain water stored in depressions are lost by subsequent evaporation into atmosphere. But the estimation of these losses is very complex and little work has been done on this.

Many formulae are established for determining the infiltration rate of rain water which is the controlling and contributing factor of rainfall recharge. The process of infiltration has been studied in detail by several researchers. Rainfall recharge has been studied by different methods.

Assuming that the amount of water that escapes evaporation and transpiration moves down as deep percolation and eventually joins the ground water, the rate of ground water accretion can be calculated as the difference between infiltration and evapotranspiration over a long period. A computer program for estimating seepage to a water table in this manner was developed by King & Lambert (1976).

A linear model using the recursive least squares method has been developed by Vishwanathan (1983). The model estimates the daily water level in borehole, given the rainfall on the same day and upto eight days before.

$$h^*_t = \lambda_t h_{t-1} + \alpha_{0,t} R_t + \alpha_{1,t} R_{t-1} \ldots\ldots\ldots + \alpha_{8,t} R_{t-8} + \beta t$$

The time dependent soil parameters α_t, λ_t and β_t are determined using recursive algorithms. The parameters λ_t account for drainage factor, β_t for various external disturbances that influence water table variations and α_t for parameters that determine infiltration rates. From the parameters obtained it appears that most of the recharge takes place within the first two days of the event. The parameter α_3 and α_4 were negative for most of the time suggesting that water level dropped after three or four days due to escape of entrapped air. Parameters α_5-α_8 were negligible indicating no infiltration took place after five days of rainfall.

Another technique for field evaluation of deep percolation is the water balance approach where deep percolation is indirectly evaluated as the difference between rainfall and runoff plus evapotranspiration. Runoff is determined by streamflow measurements.

In addition to estimating the infiltration and evapotranspiration components, deep percolation can be directly measured in the field by lysimeters or tensiometers.

Morel Seytoux et al, have determined the rate of recharge to an aquifer using the Green and Ampt approach. The position of wetting front at any time and the water content have been determined. Once the wetting front reaches the water table, recharge starts and the rate of recharge is determined.

In the present report, recharge due to rainfall has been estimated using the technique developed by Morel Seytoux which is based on Green and Ampt equation.

3.0 STATEMENT OF THE PROBLEM

Recharge to an aquifer takes place through an unsaturated transition zone. Flow takes place by infiltration beneath the surface. The infiltration rate is quite high in the beginning of rainfall. Upto time of ponding the infiltration rate is equal to the intensity of rainfall. The high rate of infiltration decays exponentially with time after ponding and excess water accumulates on the surface as surface storage. The surface of the soil is saturated to a cetain depth and below the zone of complete saturation is the zone of nearly saturated wetness known as transmission zone. Beyond this zone is the wetting zone in which soil wetness decreases with depth at at steepening gradient down to a wetting front where there appears to be a sharp boundary between the moistened soil above and dry soil beneath. The wetting zone move downward continuously. No recharge takes place until the wetting front finally reaches the water table.

If water supply is discontinued i.e. rainfall stops, the previously infiltrated water in storage will continue downwards but at a slower rate. It is aimed to predict eventual recharge due to successive rainfall. Using these recharge values, it is required to evaluate the statistical approach of predicting rainfall recharge.

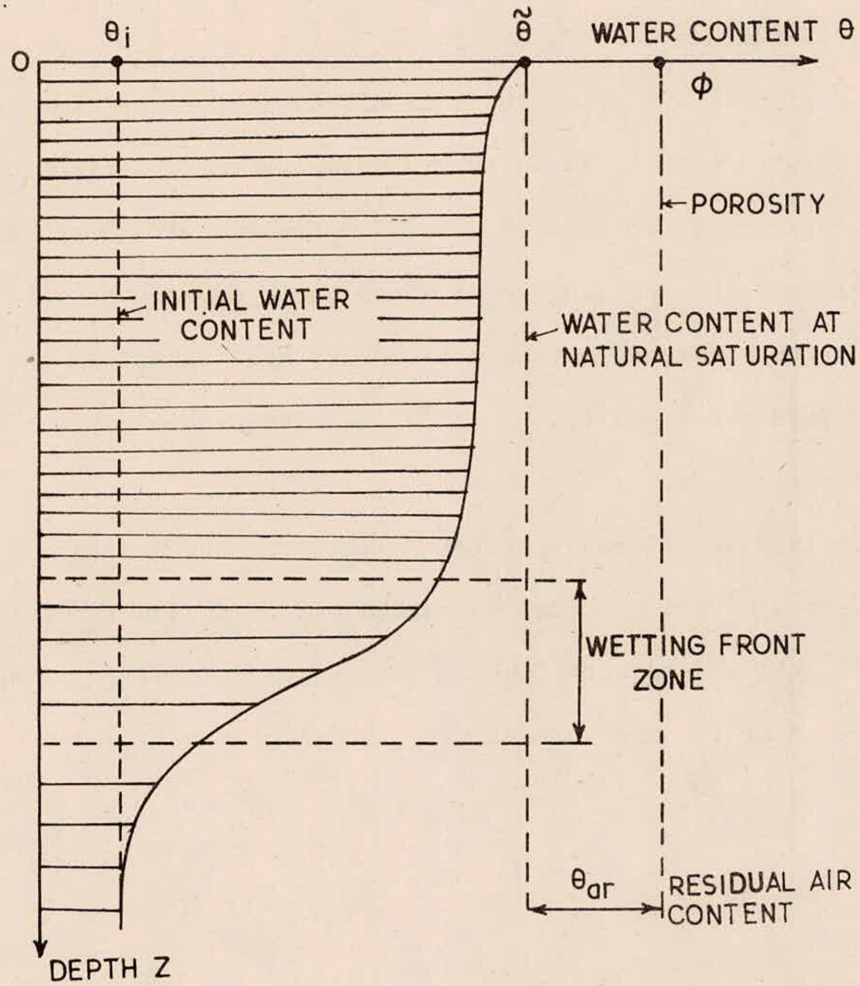

Fig.1: Variation of water content and soil colour with distance from water source

4.0 METHODOLOGY

Unsaturated flow in the vadose zone is analysed on the basis of Darcy's law, with the added complication that K is dependent on water content θ which in turn controls the pressure head. The hydraulic conductivity and soil moisture relationship and the capillary pressure-moisture content relationship are needed for the analysis presented here. These relationship could be determined experimentally.

The capillary pressure drive H_f that appears in Green and Ampt infiltration equation is to be found from the available soil moisture and capillary pressure relationship in the following manner as suggested by Bouwer

$$H_f = \int_0^{h_{ci}} k_{rw}(\theta)\, dh_c$$

where $k_{rw}(\theta) = \frac{K(\theta)}{\tilde{K}(\theta)}$ relative permeability to water

h_c - capillary pressure head

h_{ci} - capillary pressure head corresponding to the initial soil moisture θ_i prevailing before the onset of infiltration.

4.1 Time of Ponding

Upto time of ponding, water infiltrates as fast as it is supplied and so infiltration rate is equal to the intensity of rainfall. Assuming a constant rainfall rate R, the ponding time t_p has been found using the following relation given by Morel Seytoux

$$t_p = \frac{(\tilde{\theta} - \theta_i)H_f}{R(R^* - 1)}$$

where $R^* = \frac{R}{\tilde{K}}$

For the assumed variable rainfall pattern, the ponding time has been found using the relation

$$t_p = t_{J-1} + \frac{1}{R(J)} \left[\frac{(\tilde{\theta} - \theta_i)H_f}{R^*(J)-1} - \sum_{\gamma=1}^{J-1} R(\gamma)(t_\gamma - t_{\gamma-1})\right]$$

where $R(J)$ is the rainfall at J^{th} time and

$$R^*(J) = \frac{R(J)}{\tilde{K}}$$

Also the total amount of water w_p that infiltrates upto time of ponding is given by

$$w_p = \frac{(\tilde{\theta} - \theta_i)H_f}{R^* - 1}$$

Knowing the value of w_p, the position of wetting point Z_f at ponding time is given

$$Z_f = \frac{w_p}{\tilde{\theta} - \theta_i}$$

4.2 Soil Moisture Movement During Rainfall After Ponding

After ponding the saturation front moves downward as more and more water infiltrates. The cumulative infiltration w at any time t is given by the Green and Ampt infiltration equation

$$w - w_p = \tilde{K}(t - t_p) + (\tilde{\theta} - \theta_i)(H + H_f) l_n \left[\frac{(H+H_f)(\tilde{\theta} - \theta_i) + w}{(H+H_f)(\tilde{\theta} - \theta_i) + w_p}\right]$$

If at any time the rainfall is less than the infiltration capacity, the infiltration rate is equal to the rainfall intensity.

The position of wetting front Z_f at time t is obtained as before using the relation

$$Z_f = \frac{w}{(\tilde{\theta} - \theta_i)}$$

4.3 Soil Moisture Movement After Cessation of Rainfall

The initial position Z_f^0 of the wetting front and the cumulative infiltration w, when rain stopped are obtained from the previous analysis. Once the rainfall stops, infiltration from the surface will cease and the previously infiltrated water will continue to move downward at a slower rate. The actual profile at time zero (time being counted from the moment infiltration stopped) can be replaced by a simpler rectangular profile with a uniform value of water content equal to the limiting value θ_1. The value θ_1 is the water content necessary to transmit flux after capillary forces have become negligible as compared with those of gravity. One can write

$$Z_f^0 = \frac{w}{\theta_1 - \theta_i} = \frac{w}{(\tilde{\theta}-\theta_r)\ (\theta_1^* - \theta_i^*)} \qquad (1)$$

where

w - total infiltration at end of rain

θ^* - is normalised water content given by

$$\theta^* = \frac{\theta-\theta_r}{\tilde{\theta}-\theta_r} \qquad (2)$$

θ_r - is the field capacity

and θ_1 - has been defined as above.

For first rainfall the soil moisture can be assumed to be at field capacity before rain. Therefore for first rainfall $\theta_i = \theta_r$.

If saturation of soil surface has occurred at or before end of rain, $\theta_1 = \tilde{\theta}$ or $\theta_1^* = 1$ and

$$Z_f^0 = \frac{w}{(\tilde{\theta}-\theta_r)\ (1-\theta_i^*)} \qquad (3)$$

The infiltrated water w in storage in the vadose zone will move downwards to the water table.

If Z_f is the depth to water table and θ the water content of the distribution

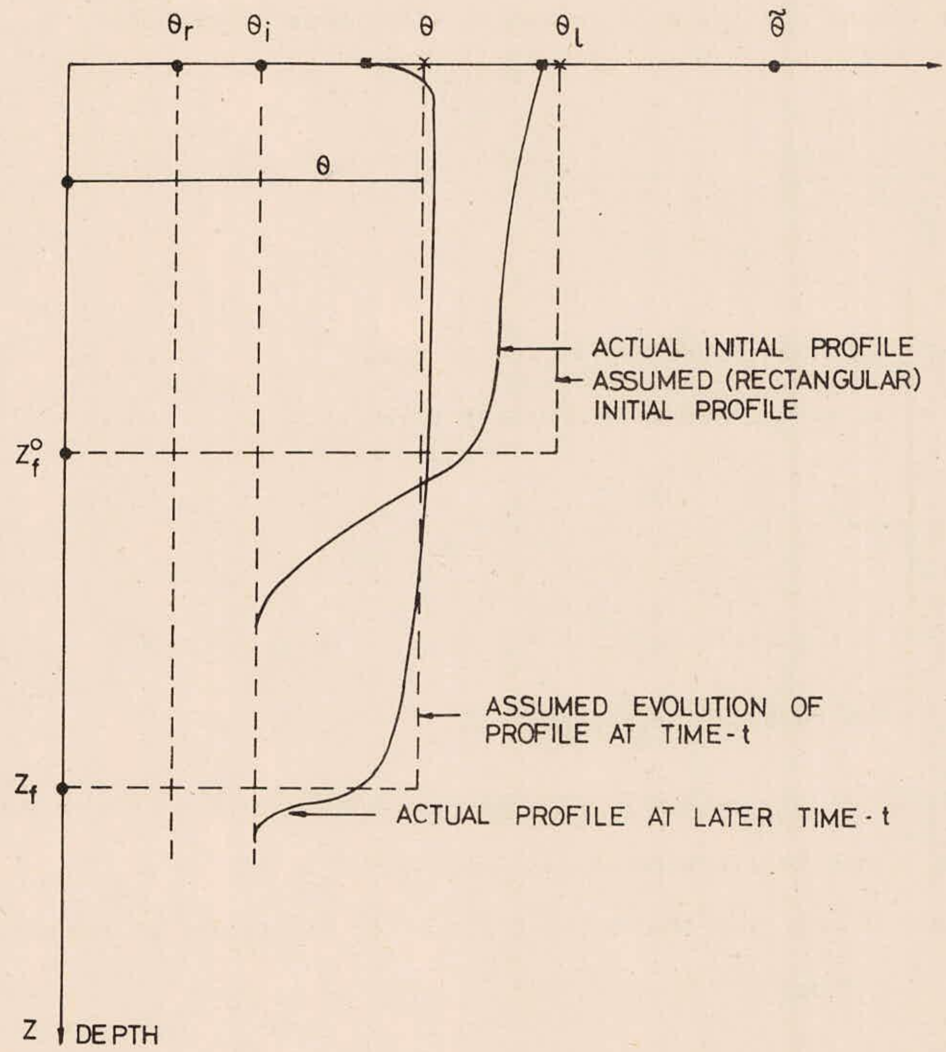

Fig.2: Actual shape of redistribution profile and assumed rectangular area

front at any later time, then

$$Z_f = \frac{w}{\theta - \theta_i} = \frac{w}{(\tilde{\theta}-\theta_r)\left[\frac{\theta-\theta_r}{\tilde{\theta}-\theta_r} - \frac{\theta_i-\theta_r}{\tilde{\theta}-\theta_r}\right]} = \frac{w}{(\tilde{\theta}-\theta_r)(\theta^* - \theta_i^*)} \tag{4}$$

When the wetting front reaches water table $Z_f = D$ where D is the depth to water table.

$$\text{Hence} \quad D = \frac{w}{(\tilde{\theta}-\theta_r)(\theta^* - \theta_i^*)} \tag{5}$$

From equation (5), θ^* is known when wetting front reaches the water table.

4.4 Time Taken By Wetting Front To Reach Water Table After Rainfall Stops

If q is the drainage rate, then

$$\frac{d\theta}{dt} = -\frac{q}{Z_f}$$

and

$$\frac{d\theta^*}{dt} = -\frac{q}{Z_f(\tilde{\theta}-\theta_r)} \tag{6}$$

Elimination of Z_f between equations (4) and (6) gives

$$\frac{d\theta^*}{dt} = -\frac{q}{w}(\theta^* - \theta_i^*) \tag{7}$$

Darcy's law for flow in unsaturated soil if capillary effects are neglected reduces to the form

$$q = \tilde{K}\, k_{rw}(\theta) \tag{8}$$

where $\tilde{K}$ is hydraulic conductivity at natural saturation. Expressing $k_{rw}(\theta)$ as a power function of θ^* of exponent n, equation (8) becomes

$$q = \tilde{K}\,(\theta^*)^n \tag{9}$$

Hence $\frac{d\theta^*}{dt} = - \frac{\tilde{K}}{w}(\theta^*)^n(\theta^* - \theta_i^*)$ (10)

For first rainfall, $\theta_i = \theta_r$ and $\theta_i^* = 0$, hence equation (10) reduces to

$$\frac{d\theta^*}{dt} = - \frac{\tilde{K}}{w}(\theta^*)^{n+1} \quad (11)$$

Integrating equations (10) and (11) from time t=0 when rain stops to time when wetting front reaches the water table, and taking $\theta^* = \theta_1^* = 1$ at time t=0, yields for n=4:

$$t = \frac{W}{\tilde{K}} [\frac{1}{(\theta_i^*)^4} \log \frac{\theta^*(1-\theta_i^*)}{\theta^* - \theta_i^*} + \frac{1}{(\theta_i^*)^3} (1- \frac{1}{\theta^*}) + \frac{1}{2(\theta_i^*)^2} (1- \frac{1}{(\theta^*)^2}) + \frac{1}{3\theta_i^*}(1- \frac{1}{(\theta^*)^3})] \quad (12)$$

and $t = \frac{w}{4\tilde{K}}[(\frac{1}{\theta^*})^4 - 1)]$ (13)

respectively.

From equations (12) and (13) time for wetting front to reach the water table can be calculated.

4.5 Recharge When Wetting Front Reaches Water Table

Equation (9) gives the recharge rate when the wetting front reaches the water table. A value of n=4 is typical of a sand. The smaller the value of n, the coarser will be the soil.

Once the wetting front reaches the water table recharge starts. The rate of recharge is given by

$$R = \frac{q}{[1+ \frac{(n-1)\tilde{K}t}{D(\tilde{\theta}-\theta_i)} (\frac{q}{\tilde{K}})^{\frac{n-1}{n}}]^{\frac{n}{n-1}}} \quad (14)$$

where D is the water table position, q is recharge rate when recharge starts, and t is measured from beginning of recharge.

Using the above equation, recharge to the water table has been calculated for five days. At the end of five days, the rate of recharge becomes quite small. The amount of water left in soil, and the soil moisture content are calculated at the end of five days and this value of soil moisture content has been used as θ_i for next rainfall.

4.6 Hantush solution

The rise in water table at the centre of a large square area of dimensions 2a, is given by the expression

$$h^2 = h_0^2 + \frac{w\bar{h}t}{2s}\, 4F\left[\frac{a}{2\sqrt{(Tt/s)}}, \frac{a}{2\sqrt{(Tt/s)}}\right] \quad (15)$$

where

- w – constant rate of percolation
- $\bar{h}$ – weighted mean depth of saturation during the period of flow
- h – height of water table above the base of aquifer
- h_0 – initial depth of saturation of the aquifer
- T – transmissivity of aquifer
- t – time since the incidence of recharge
- s – specific yield of aquifer

and

$$F(p,q) = \int_0^1 \operatorname{erf}(p/\sqrt{\tau}).\operatorname{erf}(q/\sqrt{\tau})\,d\tau \quad (16)$$

From eqn.(15) we have

$$h^2 - h_0^2 = \frac{w\bar{h}t}{2s}\, 4F\left[\frac{a}{2\sqrt{(Tt/s)}}, \frac{a}{2\sqrt{(Tt/s)}}\right]$$

Therefore

$$(h-h_0)(h+h_0) = \frac{w\bar{h}t}{2s}\, 4F\left[\frac{a}{2\sqrt{(Tt/s)}}, \frac{a}{2\sqrt{(Tt/s)}}\right]$$

writing $K(t) = h-h_0$ = rise in water table and $\bar{h} = \frac{h+h_0}{2}$

$$K(t) = \frac{wt}{s} F[\frac{a}{2\sqrt{(Tt/s)}}, \frac{a}{2\sqrt{(Tt/s)}}]$$

Therefore

$$K(t) = \frac{t}{s}\int_0^1 (\text{erf} \frac{a}{2\sqrt{(Tt/s)}\sqrt{\tau}})^2 d\tau$$

$$\partial(n) = K(n) - K(n-1)$$

$$\partial(1) = K(1)$$

The water table position $s(m)$ at m^{th} day is given by

$$s(m) = \sum_{\gamma=1}^{m} \delta(m-\gamma+1)R(\gamma) \qquad (17)$$

4.7 A statistical method

Vishwanathan has developed a linear model which estimates the daily water level in the bore hole given the rainfall on the same day and upto eight days before by the relation

$$s_t^* = \lambda_t s_{t-1} + a_{0,t}R_t + a_{1,t}R_{t-1} + a_{2,t}R_{t-2} + \cdots\cdots + a_{8,t}R_{t-8} + b_t \qquad (18)$$

and $s_t = s_t^* + e_t \qquad (19)$

where

s_t^* = estimated water level rise in the bore hole above certain datum level(m),

s_t = measured water level in the bore hole (m),

R_t = rainfall (m),

e_t = error between estimated and actual water table level (m),

Subscript t indicates day "t", and

$\lambda_t, a_{0,t}, a_{1,t} \cdots\cdots\cdots a_{8,t}, b_t$ are model parameters.

Using the above analysis and assuming the parameters to be independent of time one can write

$$s(8) = \lambda s(7)+a_1P(8)+a_2P(7)+a_3P(6)+........+a_8P(1)$$

$$s(9) = \lambda s(8)+a_1P(9)+a_2P(8)+a_3P(7)+........+a_8P(2)$$

.

.

.

$$s(i) = \lambda s(i-1)+a_1P(i)+a_2P(i-1)+a_3P(i-2)+......+a_8P(i-7)$$

.

.

.

$$s(n) = \lambda s(n-1)+a_1P(n)+a_2P(n-1)+a_3P(n-2)+......+a_8P(n-7)$$

where s(8), s(9).......s(i)......have already been calculated by Hantush's solution and P(1), P(2).......are the daily precipitation values. The model parameters λ, a_1, a_2......a_8 can be found in the following way:

Writing the above equations in matrix notation

$$\begin{bmatrix} s(7) & P(8) & P(7).....P(3) & P(2) & P(1) \\ s(8) & P(9) & P(8).....P(4) & P(3) & P(2) \\ \cdot & & & & \\ \cdot & & & & \\ s(i-1) & P(i) & P(i-1)...P(i-5) & P(i-6) & P(i-7) \\ \cdot & & & & \\ \cdot & & & & \\ s(n-1) & P(n) & P(n-1)...P(n-5) & P(n-6) & P(n-7) \end{bmatrix} \cdot \begin{bmatrix} \lambda \\ a_1 \\ a_2 \\ \cdot \\ \cdot \\ a_6 \\ a_7 \\ a_8 \end{bmatrix} = \begin{bmatrix} s(8) \\ s(9) \\ \cdot \\ \cdot \\ \cdot \\ s(i) \\ \cdot \\ \cdot \\ \cdot \\ s(n) \end{bmatrix}$$

or

$$[H][\phi] = [Y] \qquad (20)$$

where

[H] is the left hand matrix

[ϕ] is left hand column matrix

and [Y] is righthand column matrix

Multiplying equation (20) by $[H^T]$

$$[H^T][H][\phi] = [H^T][Y]$$

$$\{[H^T][H]\}^{-1}\{[H^T][H]\}[\phi] = \{[H^T][H]\}^{-1}[H^T][Y]$$

$$[\phi] = \{[H^T][H]\}^{-1}[H^T][Y] \tag{21}$$

Equation (21) gives the model parameters.

5.0 DATA USED IN THE STUDY

The soil moisture characteristics required for estimation of infiltration rate have been obtained from the experimental results of Sonu (1973). The variation of capillary pressure (h_c) with the volumetric soil moisture content (θ) and relation of capillary pressure with relative permeability $k_{rw}(\theta)$ for touchet silt loam soil are shown in Figure 3 and 4 respectively.

1. The initial soil moisture content θ_r and saturation moisture content $\tilde{\theta}$ are taken to be 0.2425 and 0.485 respectively for this study.
2. The value of $\tilde{K}$ for touchet silt loam was taken as 0.02088 m/hour.
3. The value of H_f for θ_i=0.2425 was found to be 0.7711 m.
4. The rainfall data and depth to water table have been taken arbitrarily.

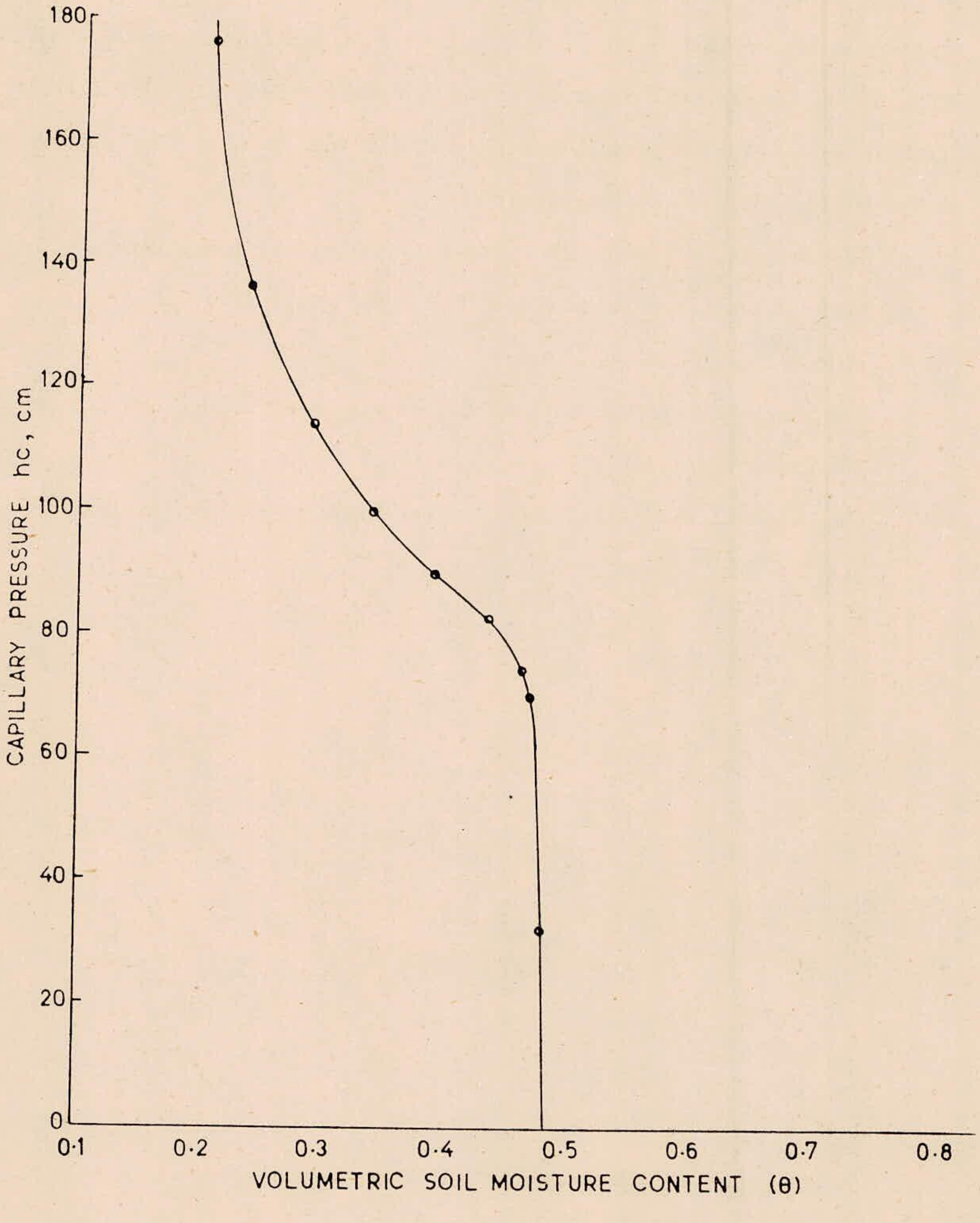

Fig.3: Variation of capillary pressure (h_c) with volumetric soil moisture content (θ) for touchet silt loam

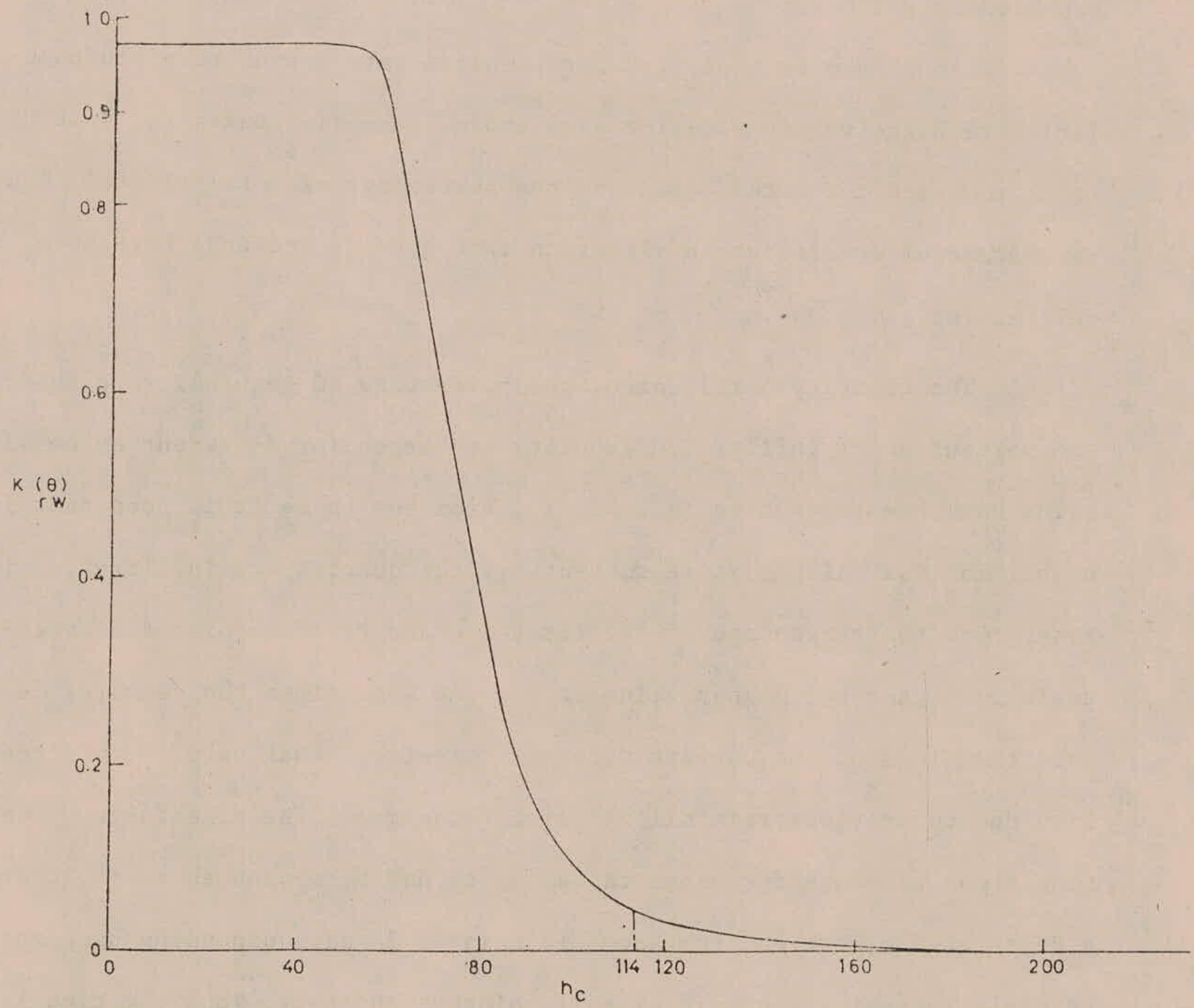

Fig.4: Variation of $K_{rw}(\theta)$ with h_c for touchet silt loam

6.0 RESULTS AND DISCUSSION

Results have been obtained for three cases of different types of storms. The storms taken are arbitrary. In the first case, four different storms of variable rainfall rate have been taken.

In the second case, a single storm of variable rainfall rate has been repeated four times.

In the third case, a storm of constant rainfall rate has been repeated four times.

Graphs have been plotted for recharge rate versus time and cumulative recharge versus time for each storm. The time taken for wetting front to reach the water table and the percentage of total rainfall and percentage of cumulative infiltration that goes as recharge have been calculated for each case.

The quantity infiltrated, the percentage of rainfall recharged, and percentage of infiltrated quantity recharged for different successive rains have been presented in Table I. From the table it is seen that for higher initial soil moisture content θ_i, the quantity of infiltration is less. But the percentage of infiltrated quantity that joins the water table is higher for higher value of θ_i. At some times the recharge is more than 100% of the current rainfall, meaning that part of infiltration due to previous rainfall is being recharged. The time taken by wetting front to reach the water table, which has been assumed to exist at a depth of 5 m, varies from about 12 days to 24 days depending upon the rainfall intensity and initial soil moisture content. Thus the time lag between rainfall and water table rise would vary considerably depending on the intial soil moisture content. Table II gives the recharge values at the end of each day due to each storm.

Figures 5 to 10 show the variation of recharge rate with time and cumulative recharge versus time for the three cases of storms considered. Time has been measured from the onset of recharge after each storm. Figures 11 to 13 show continuous variation of recharge rate with time since the occurrence of recharge due to first storm.

The daily recharge values have been used to calculate water table rise using Hantush's solution, at the centre of a square area of dimension 1000 m and for a value of $T = 1000\ m^2/day$ and storage coefficient 0.2425.

The water table rise has also been calculated using the statistical method as described in section 4.7. As there will be a time lag between the occurrence of rainfall and consequent recharge equation (18) has been modified to

$$s_t^* = \lambda s_{t-1} + a_1 R_{t-3} + a_2 R_{t-4} + \ldots\ldots + a_8 R_{t-10}$$

The values of the parameters $\lambda, a_1, a_2 \ldots\ldots a_8$ have been calculated.

Table III gives the comparative values of water table rise obtained by the two methods with time starting from day of second rainfall. Table IV gives the values of the parameters $\lambda, a_1, a_2 \ldots\ldots a_8$.

The increase in water table rise due to rainfall recharge on any day would be $h_i - \lambda h_{i-1}$. Therefore recharge rate would be $(h_i - \lambda h_{i-1})\phi$. The contribution towards this recharge in the i^{th} day by previous rainfall would be determined by the parameters $a_1, a_2 \ldots\ldots$etc.

Table - I

Percentage of total rainfall and cumulative infiltration that goes as recharge and time to reach water table

Case	Storm No.	Initial soil Moisture Content (θ_i)	Total Rain (m)	Quantity Infiltrated (m)	% of rainfall recharged	% of infiltration recharged	Time to reach water table (hrs.)
I	1	.2425	.42	.3528	1.36	1.62	585.31
	2	.3119	.43	.3326	18.14	23.45	64.27
	3	.3628	.175	.1696	73.83	76.18	33.04
	4	.3015	.175	.1750	10.17	10.17	190.87
II	1	.2425	.42	.3528	1.36	1.62	585.31
	2	.3119	.42	.3253	17.79	22.96	66.44
	3	.3620	.42	.3030	57.21	79.31	20.54
	4	.3746	.42	.3015	74.52	103.81	14.79
III	1	.2425	.48	.4350	2.73	3.01	309.09
	2	.3269	.48	.4012	34.96	41.82	32.34
	3	.3736	.48	.3750	85.85	109.89	10.14
	4	.3661	.48	.3797	75.46	95.39	12.55

Case I - Different storms of varying rainfall rate

Case II - Same storm of varying rainfall rate repeated

Case III - Same storm of constant rainfall rate repeated

Table - II

Total recharge at the end of each day

Case	Storm No.	Recharge at the end of				
		1st day	2nd day	3rd day	4th day	5th day
I	1	.0023	.0013	.0009	.0007	.0006
	2	.0317	.0174	.0121	.0093	.0075
	3	.0525	.0289	.0200	.0153	.0124
	4	.0073	.0040	.0028	.0021	.0017
II	1	.0023	.0013	.0009	.0007	.0006
	2	.0304	.0167	.0116	.0089	.0072
	3	.0977	.0537	.0372	.0285	.0231
	4	.1273	.0699	.0485	.0372	.0302
III	1	.0053	.0029	.0020	.0016	.0013
	2	.0682	.0375	.0260	.0199	.0162
	3	.1676	.0920	.0639	.0490	.0397
	4	.1473	.0809	.0561	.0430	.0349

Table III

Comparison of water rise evaluated using actual ground water recharge and Hantush's solution and evaluated by statistical method

Time (hrs.)	Case I Hantush solution	Case I Statistical method	Case II Hantush solution	Case II Statistical method	Case III Hantush solution	Case III Statistical method
1	.0231	.0209	.0231	.0207	.0534	.0469
2	.0248	.0230	.0248	.0228	.0572	.0516
3	.0260	.0246	.0260	.0244	.0601	.0553
4	.0270	.0956	.0270	.1714	.3404	.2618
5	.1571	.1635	.1516	.1260	.4936	.5357
6	.2283	.2366	.2197	.2615	.5990	.6749
7	.2772	.2838	.2666	.3022	.6778	.7432
8	.3139	.3186	.3016	.3300	.7383	.7948
9	.3420	.3451	.3285	.5024	.7849	.9969
10	.3637	.3682	.3493	.3952	1.4632	1.0920
11	.3802	.3713	.7465	.5231	1.8267	1.7473
12	.5895	.4061	.9607	.8823	2.0707	1.9720
13	.6999	.6412	1.1055	1.0473	2.2479	2.1989
14	.7726	.7280	1.2116	1.2026	2.3793	2.3367
15	.8244	.7907	1.2912	1.2810	2.4761	2.4390
16	.8618	.8365	1.3506	1.3410	3.0342	2.6762
17	.8884	.8696	1.8499	1.5374	3.3113	3.4693
18	.9067	.8941	2.1081	2.0420	3.4798	3.5363
19	.9183	.9330	2.2741	2.3579	3.5874	3.5606
20	.9246	.9677	2.3885	2.3557	3.6539	3.6311
21	.9270	.9512	2.4676	2.4421	3.6900	3.6707
22	.9263	.9440	2.5204	2.5017	3.7032	3.8492
23	.9239	.9377	2.5530	2.6916	3.6988	3.9120
24	.9200	.9313	2.5698	2.5900	3.6810	3.7040
25	.9240	.9254	2.5744	2.7140	3.6533	3.5572
26	.9147	.9219	2.5695	2.5401		
27	.9005	.9086				
28	.8840	.8945				
29	.8661	.8781				
30	.8476	.8603				
31	.8287	.8419				
32	.8098	.8232				
33	.7911	.8044				
34	.7728	.7859				

Table IV

Parameters of the statistical method

Parameter	Case I	Case II	Case III
λ	.9933	.9867	.9663
a_1	.1622	.3390	.4244
a_2	.3178	.2312	.4309
a_3	.1872	.2601	.4123
a_4	.1326	.1988	.3425
a_5	.1004	.1558	.2912
a_6	.0775	.4762	.5904
a_7	.0663	.1652	.6947
a_8	.0232	.4150	.2701

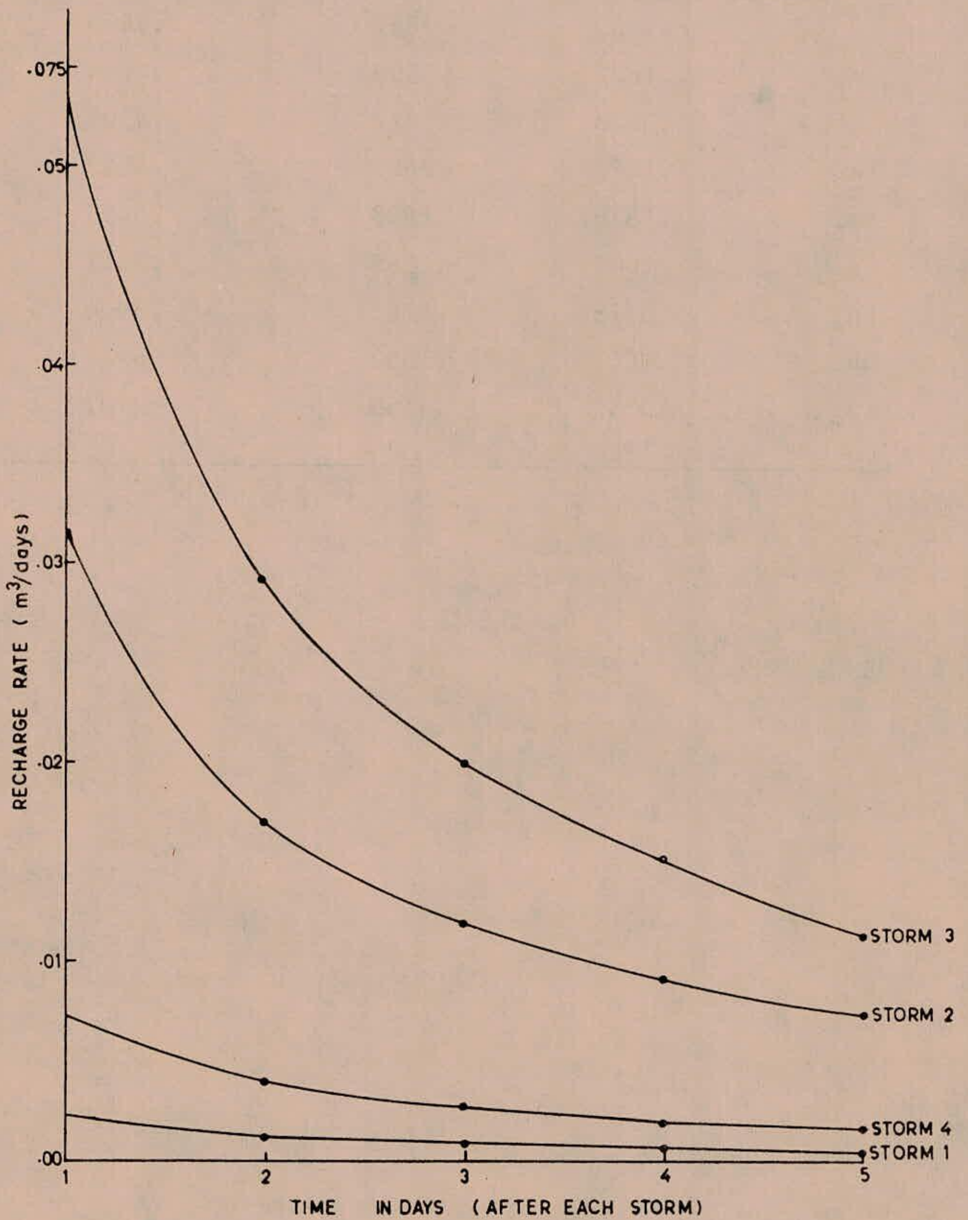

Fig.5: Ground water recharge due to rainfall predicted for storm of different intensity and duration

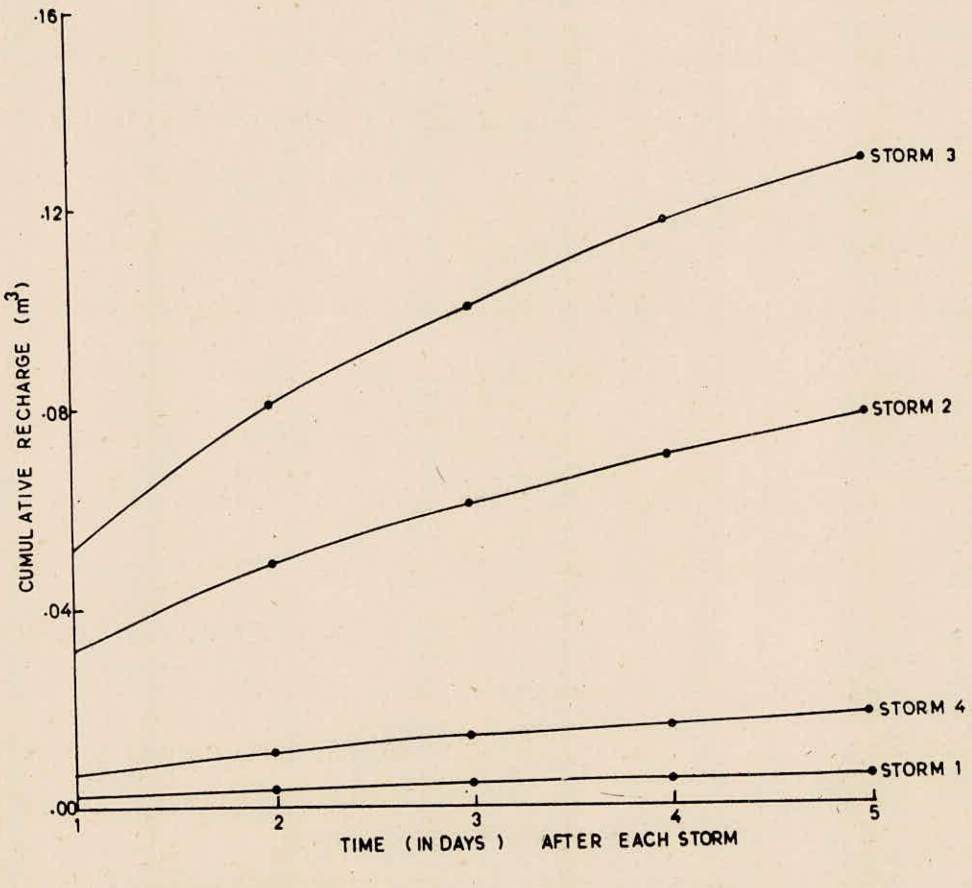

Fig.6: Cumulative Recharge due to storms of different intensity and duration

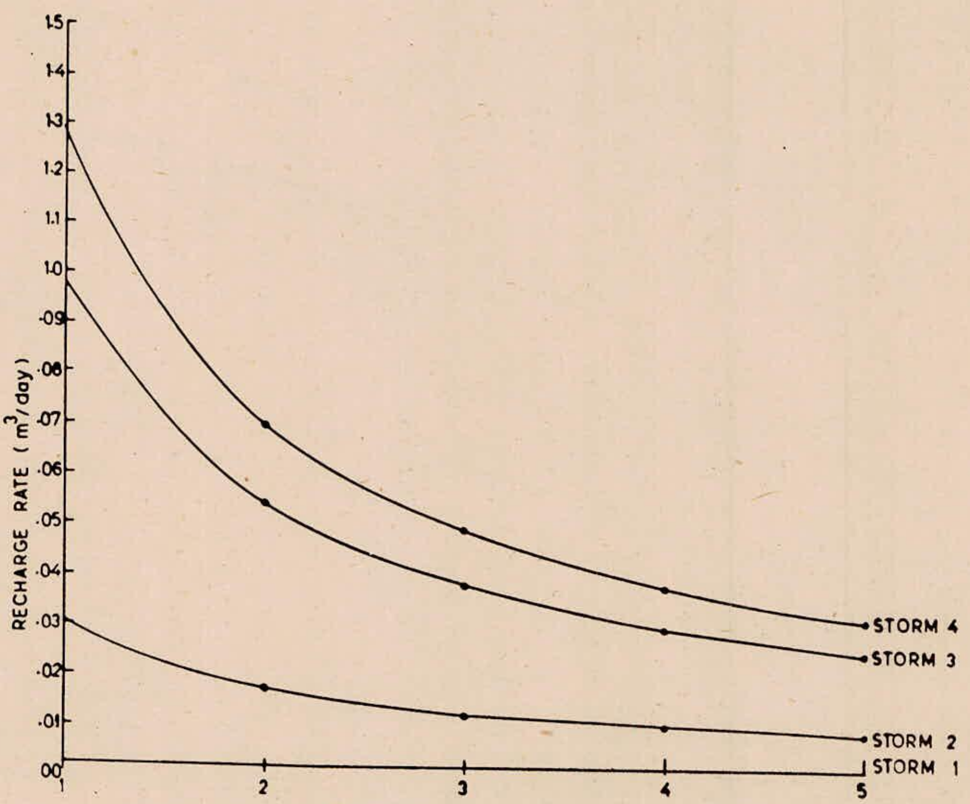

Fig.7: Ground water recharge due to rainfall, predicted for successive occur ence of same storm of variable intensity

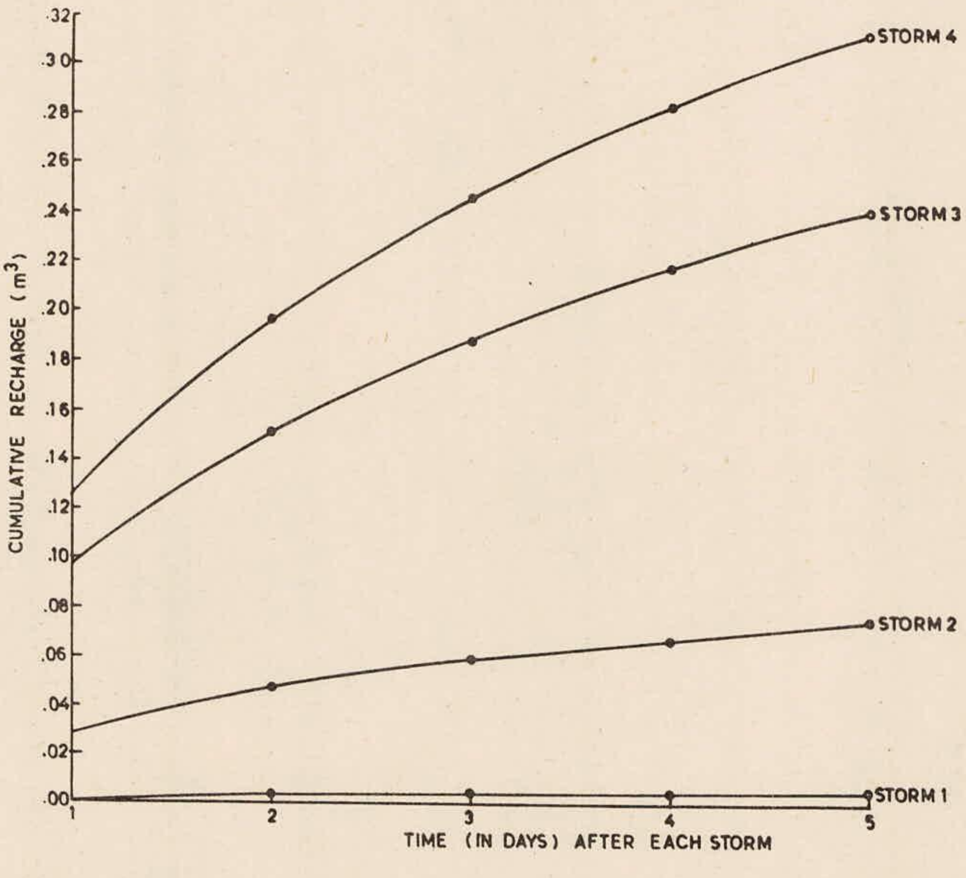

Fig.8: Cumulative Recharge due to successive occurrence of same storm of variable intensity

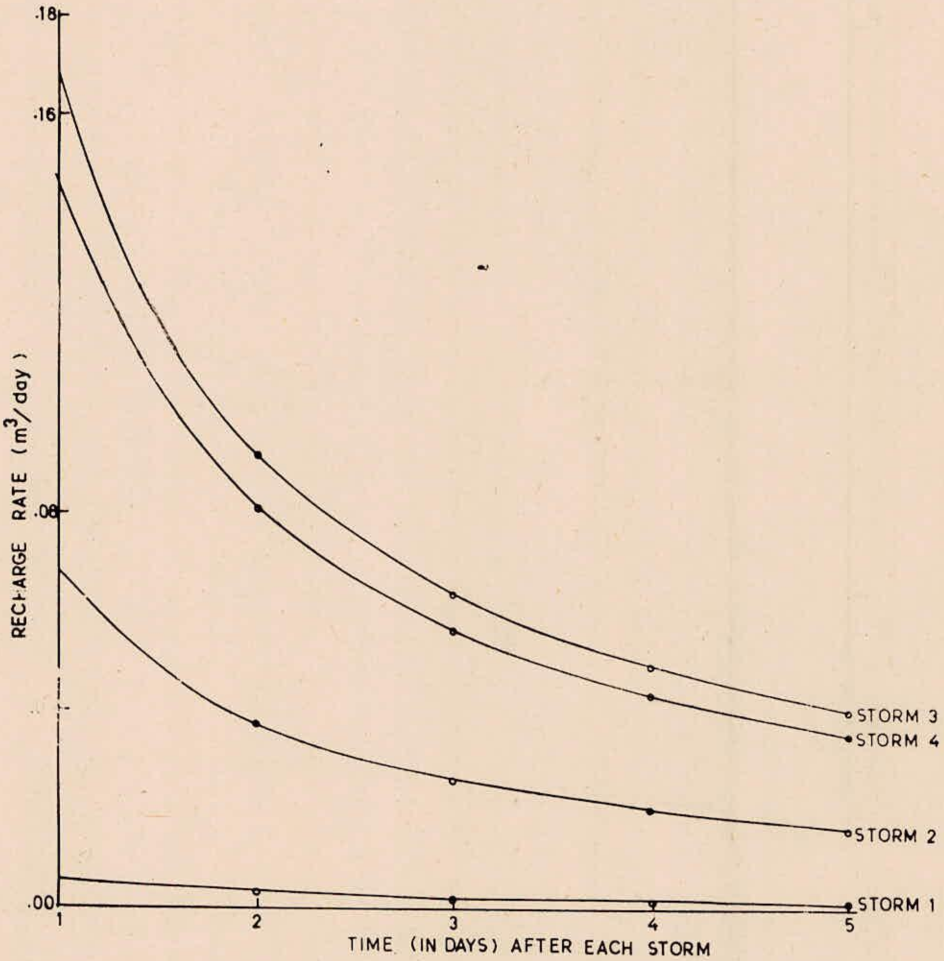

Fig.9 : Ground water recharge due to rainfall predicted for successive occurrence of same storm of constant intensity

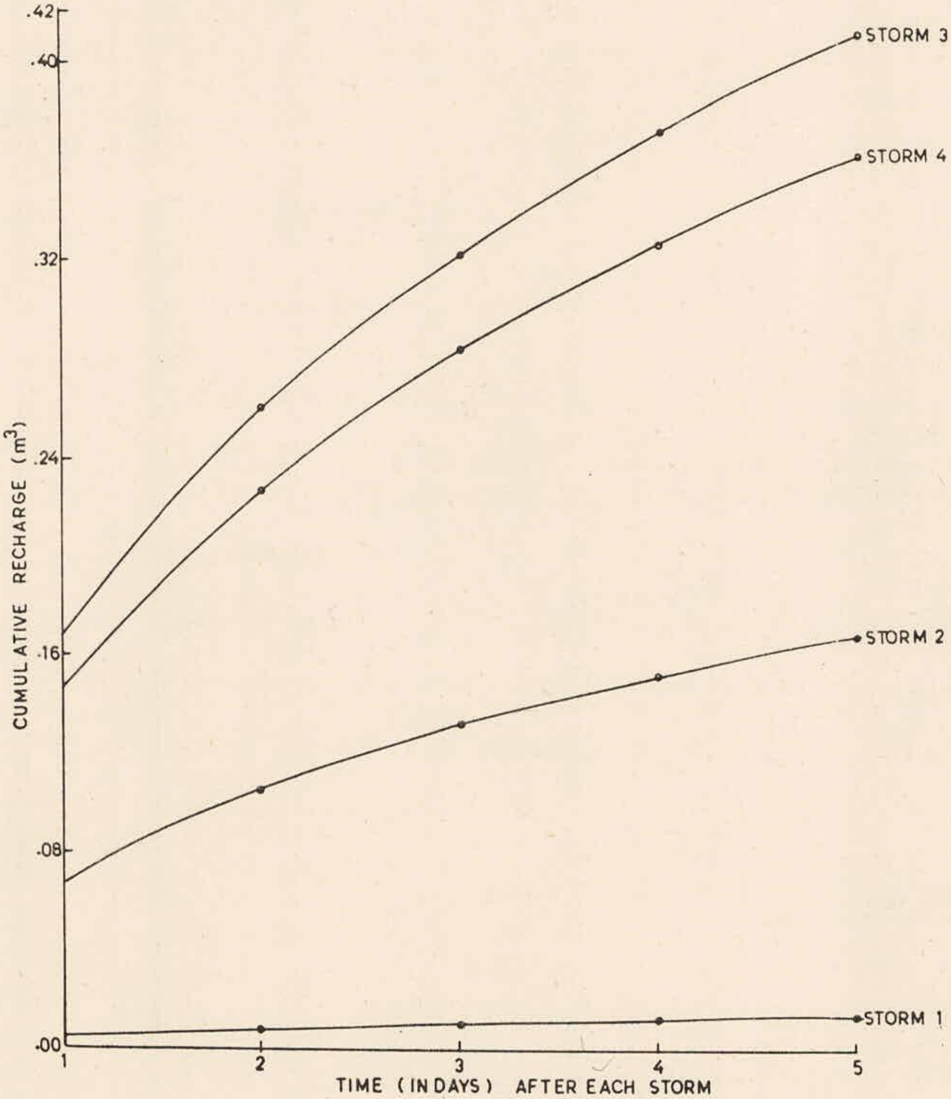

Fig.10: Cumulative recharge due to successive occurrence of same storm of constant intensity

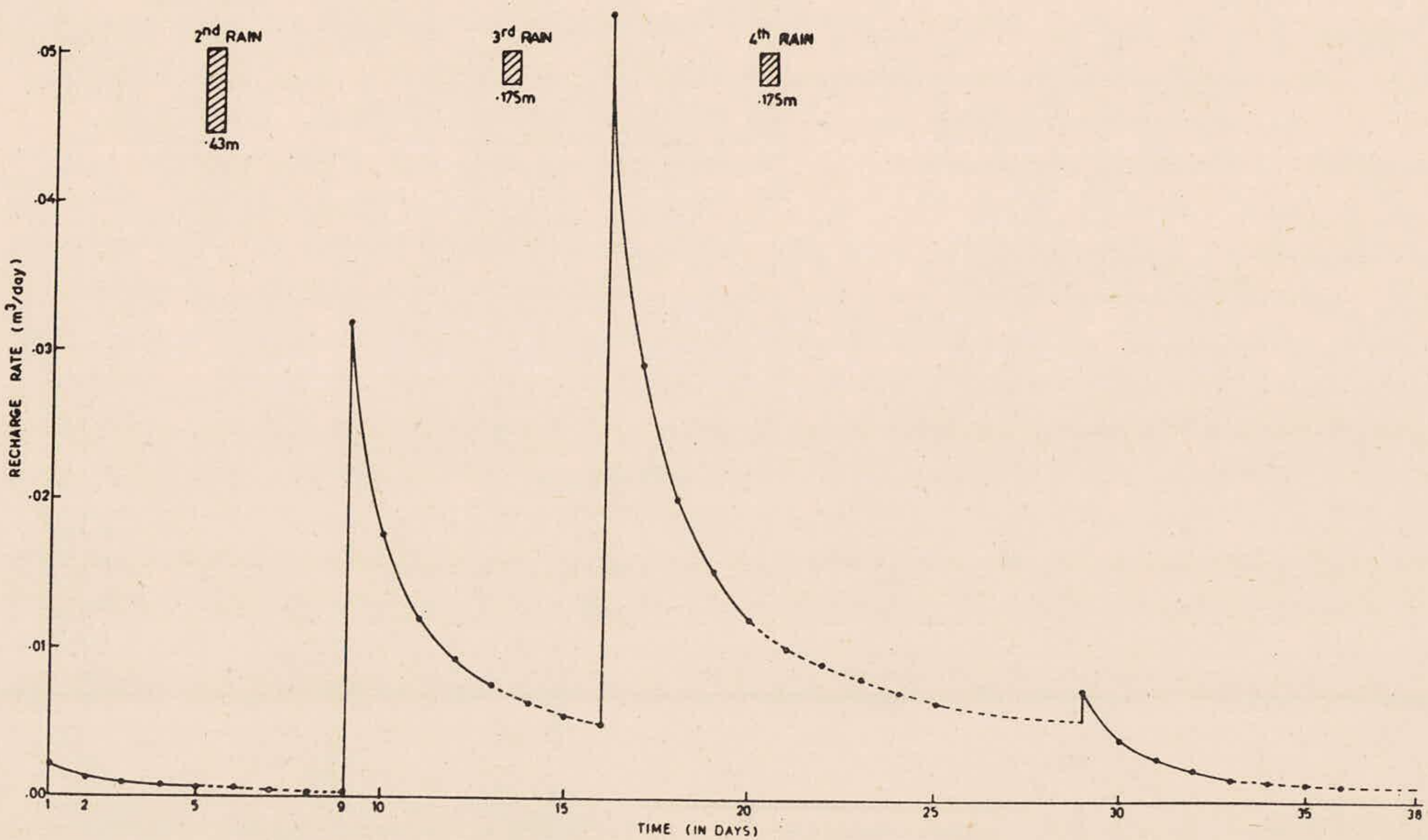

Fig.11: Variation of ground water recharge with time subsequent to occurrence of different storms of varying intensity and duration

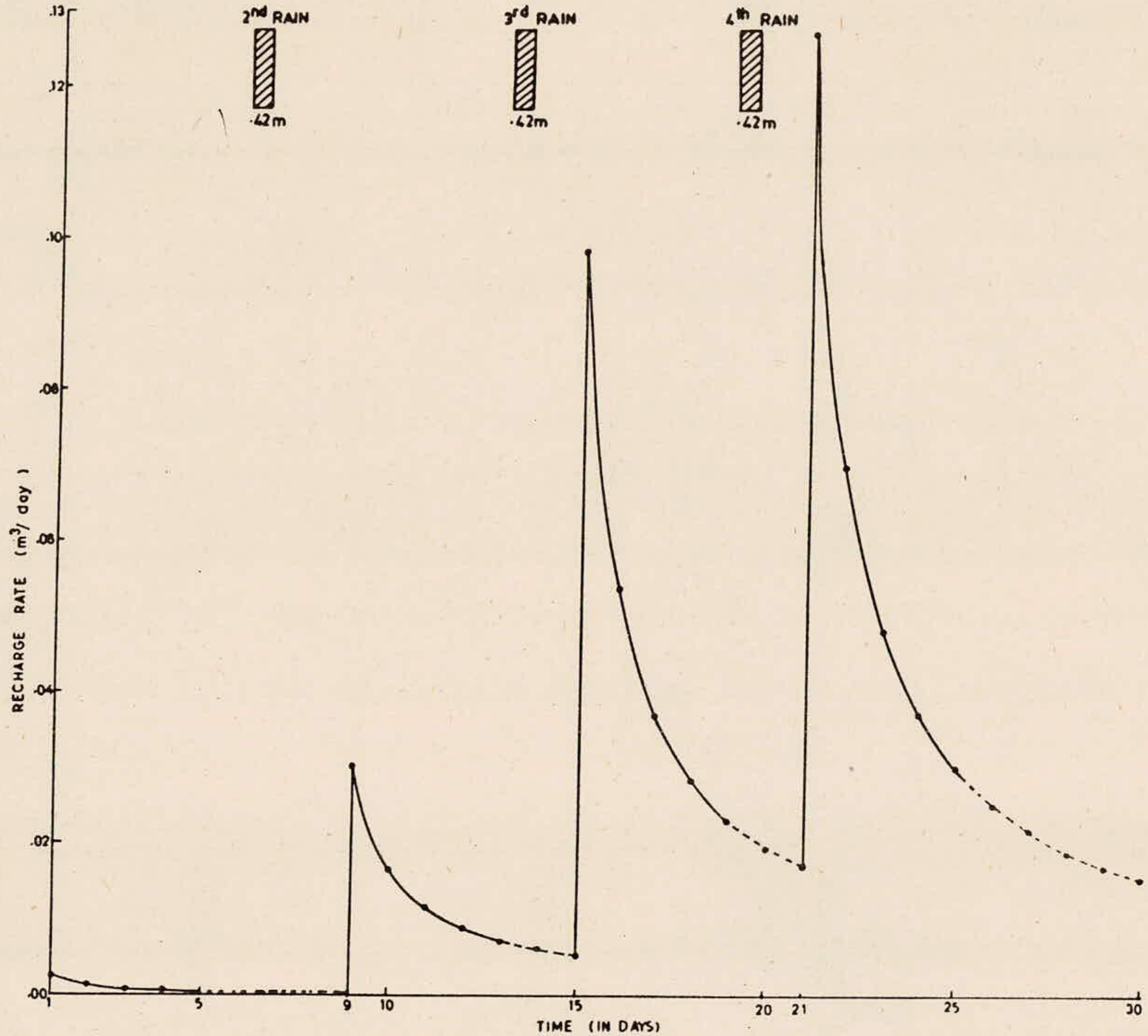

Fig.12: Variation of ground water recharge with time subsequent to occurrence of same storm of varying intensity

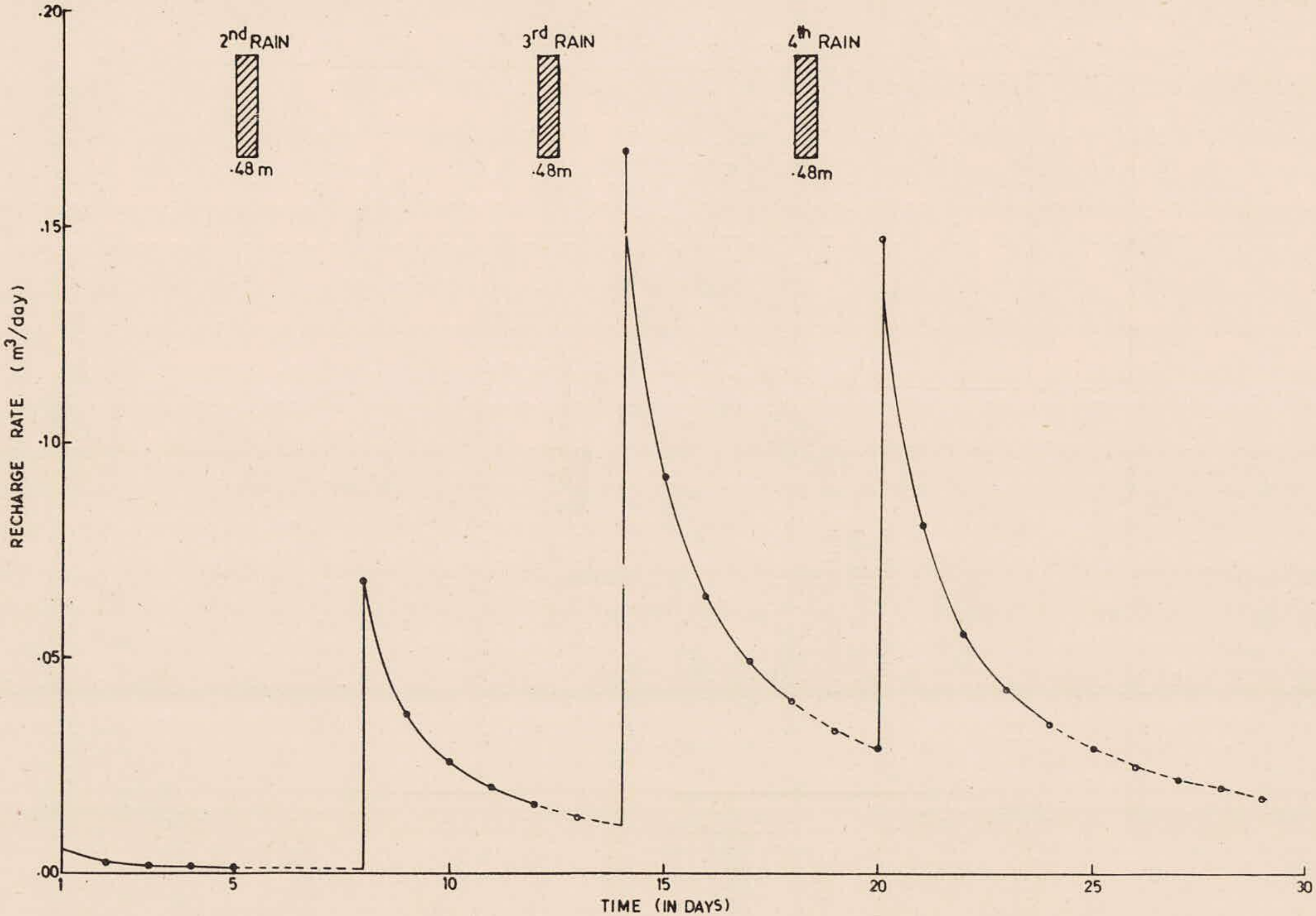

Fig.13: Variation of ground water recharge with time subsequent to occurrence of same storm of constant intensity

7.0 CONCLUSIONS

It is possible to estimate groundwater recharge by statistical approach, that makes use of water table data monitored in an observation well and the rainfall in the area. Statistical approach does not require the details of the soil moisture characteristics and the soil moisture accounting for estimation of rainfall recharge. In the analytical approach presented in this report, the recharge is to be estimated by Green and Ampt equation and it is to be verified by comparing the consequent water table rise computed by Hantush method with the actual observation.

From the study it is found that the infiltration that occurs during the earlier rainfalls satisfies the soil moisture deficiencies and the rainfall contributions to groundwater recharge is less than 18% of the precipitation. The later rainfalls contribute more to the groundwater recharge which is of the order of 57% of the precipitation. However these results are point recharge values predicted for a silty loam soil.

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