JNSF 1-2-

Journal of the National Science Council of Sri Lanka, **1** (1973), 167—181

Groundwater Recharge at Yala

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(Accepted for publication: November 9, 1973)

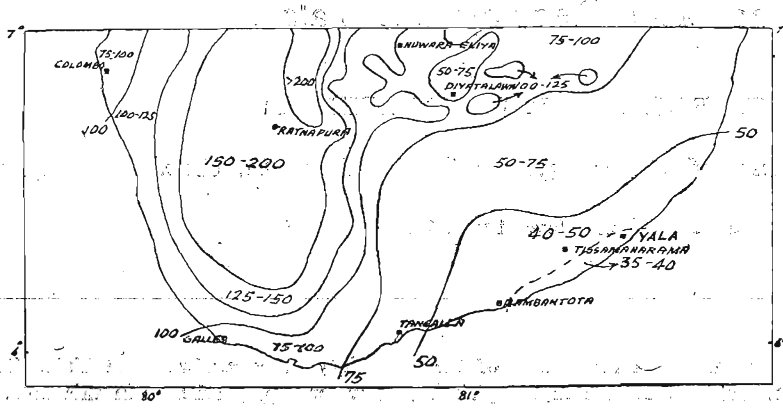
Abstract . A preliminary study of the availibility of groundwater at Yala. The results could be utilized in the planning of water supply schemes in this area.

Groundwater recharge is often computed as a constant percentage of the annual rainfall. Due to the wide seasonal variation of the soil moisture regime at Yala, a more detailed analysis is necessary in order to evaluate the groundwater recharge. There are three well defined rainfall seasons at Yala, a $3\frac{1}{2}$ month wet season from mid-October to January, with a mean monthly rainfall of 6.4 in., a 4 month intermediate season from February to May, with a mean monthly rainfall of 2 in. and a dry season from June to mid-October, with a mean monthly rainfall of 1.2 in. The mean monthly free water evaporation being 4, 5 and 7 in. respectively during the above seasons, there is surplus water during the wet season, a moderate moisture deficit during the intermediate season and a severe moisture deficit during the dry season. Thus the water balance in the root zone fluctuates violently during the course of the year and groundwater recharge, therefore, cannot be a constant percentage of the annual rainfall.

In this study, the annual as well as the wet season rainfall, when analysed statistically, was found to be normally distributed. The variations of the different parameters of the hydrologic equation expressing the water balance of the root zone were computed, making certain necessary assumptions regarding water consumption by dry zone vegetation. The groundwater recharge which is the residual of rainfall was then computed.

It was found that the long-term mean annual groundwater recharge was approximately 8 in. There is a 16% probability that no recharge will occur in any one year and a $2\frac{1}{2}$% probability that no recharge will occur in two consecutive years.

SOUTHERN PART OF SRI LANKA SHOWING ANNUAL AVERAGE RAINFALL IN INCHES



Rainfall Distribution

Yala, situated in the south eastern sector of Sri Lanka is in the Dry Zone. The mean annual rainfall at Yala is 37.4 in., calculated for the period 1923 to 1971. The maximum and minimum recorded during this period were 62.9 in. and 21.6 in. respectively. The standard deviation was 9.1 in. (*Appendix* 1.) The values of rainfall **R** corresponding to a deviation of one standard deviation from the mean are 28.3 in. and 46.5 in. Of the 42 years of accepted annual totals, the rainfall was less than 28.3 in. during 8 years, between 28.3 in. and 46.5 in. during 26 years and greater than 46.5 in. during 8 years. These correspond to relative frequencies of 19%, 62% and 19%. If the annual rainfall was normally distributed, the expected relative frequencies would be 16%, 68% and 16%. The agreement seems reasonable, considering the fact that in a period as short as 42 years, the standard deviation derived from the sample distribution may deviate slightly from the corresponding statistics for the population. In order to test further the validity of the assumption that rainfall is normally distributed, the *Chi-Square test* was performed on the sample distribution. *Appendix* 3 gives the details of the computation. The observed and theoretically expected frequencies for different class intervals of **R** are shown in columns (7) and (6).

There is a marked seasonal variation of rainfall with the rainy season beginning in October and ending in January. The real dry season occurs during the Southwest Monsoon, mid-May to the end of September, while during the $3\frac{1}{2}$ months from February to mid-May the moisture conditions are intermediate between those of the dry and wet seasons. Further analysis of rainfall during the months of October and January by dividing each month into two halves shows that the wet season commences around the middle of October and ends at the end of January.

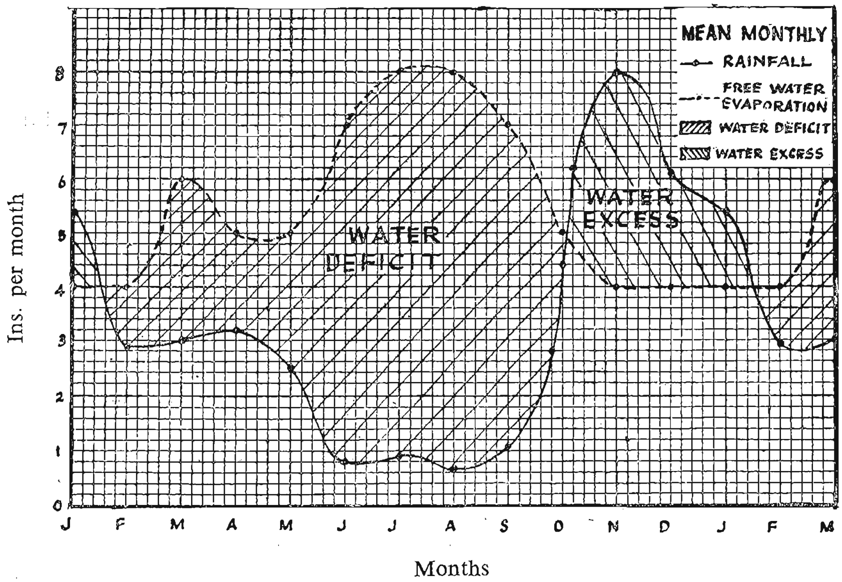


Figure 1. Mean monthly rainfall and free water evaporation at Yala

Mean Seasonal Moisture Balance

Figure 1 shows the mean monthly rainfall and assumed free water evaporation at Yala. In the absence of evaporation data at Yala itself, the adopted values are an interpolation of those at Ridiyagama and Inginiyagala and are in agreement with the saturation deficit variations at Hambantota and Batticaloa meteorological stations. The potential annual loss of water from a free water surface at Yala is approx. 67 in. while the mean rainfall is only 37 in., giving a moisture deficit of about 30 in. per year. However, due to the marked seasonal variation of rainfall, a moisture surplus of 8.3 in. exists during the wet season mid-October to end of January. This amounts to an average surplus of 2.3 in. per month during the wet season. During the intermediate period from February to May there is a total moisture deficit of 8.4 in. which amounts to an average of 2.1 in. per month. Very dry conditions prevail at Yala during the period June to end of September with a mean monthly rainfall of less than 1 in and a potential evaporation of over 7 in. The moisture deficit for this period up to mid-October is 27.6 in. and amounts to 6.1 in. per month. Thus the climate at Yala can be broadly divided into three seasons from the point of view of moisture availability.

Table 1

	Wet Season	Intermediate Season	Dry Season
Period	Mid-October to January	February to May	June to mid-October
Duration	$3\frac{1}{2}$ months	4 months	$4\frac{1}{2}$ months
Mean Rainfall per month	6.4 in.	2.0 in.	1.2 in.
Potential evaporation per month	4 in.	5 in.	7.5 in.
Moisture balance	Surplus 2.4 in. per month	Deficit 2.1 in. per month	Deficit 6.1 in. per month

In view of the above evidence of extreme seasonal variation in the moisture regime at Yala, it appears incorrect to assume the groundwater recharge to be either a constant percentage or the excess over a certain minimum of the total annual rainfall. If data of streamflow from a neighbouring catchment or the water levels of a well in the locality were available it would have been possible to assess the groundwater recharge by the normal hydrological methods. No such data is available for Yala. The method outlined below is approximate but in view of the lack of data required for more accurate analysis, the results may be of some value in estimating the availability of groundwater.

This investigation was primarily directed at estimating the groundwater recharge in the Maha Seelawa area within the Yala National Park. Since no well defined surface drainage system exists in the area, it may be assumed that no surface run off normally occurs and the infiltration capacity of the soil is greater than the rainfall intensities normally experienced.

Effective Rainfall

We may therefore assume that out of an amount of rainfall **R** received in a given period of time, all water, except that intercepted by all wetted surfaces including vegetation and held by surface tension forces, will infiltrate into the root zone of the soil whatever the rainfall intensity. The water held by wet surfaces is rapidly lost by evaporation at a rate greater than the rate of free water evaporation. For purposes of computation here, we assume this to be constant throughout the year and equal to 0.20 in. per day. The daily falls of less than 0.20 in. are thus ineffective in adding moisture to the soil and are lost by re-evaporation. The effective rainfall $\mathbf{R_e}$ in a given period can be expressed as :

$$\mathbf{R_e = R - (r + 0.2n)}$$

where **r** is the sum of all falls less than 0.20 in. and **n** is the number of days on which the rainfall was greater than 0.20 in. The gross, ineffective and effective total rainfall for the three seasons defined earlier and their monthly and daily means are given below:

Table 2

	Wet Season	Inter. Season	Dry Season
	in.	in.	in.
R	22.35	11.00	4.65
r	1.42	0.92	0.80
0.2n	5.20	3.20	2.40
r+0.2n	6.62	4.12	3.20
R_e	15.73	6.88	1.45
R_e per month	4.50	1.72	0.32
R_e per day	0.15	0.06	0.01

Infiltration

We now assume that all excess rainfall **R** enters the root zone of the soil through infiltration. While excess rainfall adds moisture to this store, evapo-transpiration losses cause depletion. This zone has a certain maximum water holding capacity S, determined by the soil type and the depth of the root system of vegetation. This represents the amount of water held in the root zone between the wilting point of vegetation and the field capacity of the soil. Any infiltration of rainwater occuring after this zone reaches field capacity, must pass beyond it into the deeper layers of the soil and finally into the groundwater reservoir. The root zone, therefore, regulates the flow of water into the groundwater reservoir so that an assessment of groundwater recharge is possible only through a detailed study of the water balance of this zone.

The water balance of the root zone layer during a given period of time can be expressed by the hydrologic equation :

$$\mathbf{R - r - E_T - I - \Delta S = 0.}$$

where **R**, **r**, $\mathbf{E_T}$ **I**, and ΔS are respectively, the gross rainfall, ineffective rainfall, evapo-transpiration, deep infiltration and increase in the soil moisture storage within the root zone. The above equation is valid over any period of time.

If we apply it for a complete climatic cycle (i.e. one year)

$$\Delta S = 0$$

Hence $\mathbf{I} = \mathbf{R_e} - \mathbf{E_T}$ *where* $\mathbf{R_e} = \mathbf{R} - \mathbf{r}$ is the effective rainfall.

Since the effective rainfall $\mathbf{R_e}$ is known, it would be possible to evaluate $\mathbf{I}$ if $\mathbf{E_T}$ were known. The problem therefore, reduces to the estimation of water consumption $\mathbf{E_T}$ by the vegetation.

Evapotranspiration from vegetation growing under saturated soil moisture conditions is proportional to free water evaporation $\mathbf{E_0}$

$$\text{i.e.} \quad \mathbf{E_T} = \mathbf{f.E_0}$$

where **f** is known as the crop factor and depends on the type and density of vegetation. *Fig.* 1 shows the mean monthly rainfall and free water evaporation $\mathbf{E_0}$ at Yala and may be considered to represent the water budget of a crop for which $\mathbf{f} = \mathbf{1}$. It is obvious that such a crop cannot survive here as the water deficit far exceeds the water surplus over the year. If the ordinates of the evaporation curve are halved, it lies below the rainfall curve for the period October through January to May and above the rainfall curve for the period May to October. This represents the water budget of a crop for which $\mathbf{f{=}0.5}$ throughout the year. There is moisture deficiency for such a crop only during the period May to October. Under such conditions of limited soil moisture, evapotranspiration loss is a percentage of the soil moisture content. If we assume the root zone of the soil to be 3 ft. deep and the soil to have a moisture holding capacity of 1.3 in. per ft., this zone will have a field capacity of approximately 4 ft. Thus an average of approximately 1 in. of water is available per month during the dry season.

Appendix 4 gives the mean monthly values of the gross and effective rainfalls, free water evaporation and evapotranspiration loss for the finally adopted value of crop factor $\mathbf{f} = \mathbf{0.4}$. Rows **8, 9** and **10** give the derived values of $(\mathbf{R_e} - \mathbf{E_T})$, Δ S and **I.** Soil moisture depletion occurs from June to October and the amounts lost in successive months are 2.0, 1.0, 0.5 and 0.25 in. Soil moisture recharge occurs in the months October and November, the amounts being 1.8 and 2.0 in. respectively. The residual, groundwater recharge **I**, occurs in November, December and January. The amounts are 3.1, 3.2 and 2.3 in.

Thus in a year of average rainfall, out of the gross rainfall of 22.35 in. occurring during the $3\frac{1}{2}$ month wet season from mid-October to the end of January, an amount 6.62 in. is ineffective and is lost as re-evaporation. (*Table* 2) The balance 15.73 in. is effective in infiltrating into the root zone and beyond. Of this amount, 3.80 in is stored up in the root zone which had dried up during the preceding dry season and an amount 3.70 in. is consumed by vegetation for the evapotranspiration process during this period. The residual (15.73 - 7.50) = 8.23 in. represents the ground water recharge and must infiltrate beyond the root zone layer into the groundwater reservoir.

Variation of Groundwater Recharge

Since groundwater recharge is only a residual, in an average year when the gross rainfall is 22.35 in., its value is 8.23 in. In an year when the wet season gross rainfall is **R** in. groundwater recharge must be equal to **R**—14 in. approximately, since the net loss is 6.62 + 3.80 + 3.70 in. The wet season rainfall **R** shows wide variation from year to year and the data at Yala for a period of 47 years is shown in *Appendix* 3. Since this may be too short a period to be representative of the long term average pattern of variation, an attempt is made to fit the observed series to a theoretical statistical distribution. The *Chi-Square test* applied to the 47 year statistical series shows that **R** is normally distributed at least for the higher 90% of the values. The rainfall during the drier 10% of the years does not seem to follow the normal distribution, but this will not affect the results as no infiltration occurs during such dry years. Assuming normality, we deduce from the normal distribution, the rainfall values that are likely to be equalled or exceeded with stated probabilities in any given year (*Appendix* 6).

The results are given below

Prob.(P)	95%	90%	75%	50%	40%	30%	20%	10%	5%	2%
$\frac{R - \mu}{\sigma}$	-1.64	-1.28	-0.68	0	0.25	0.52	0.84	1.28	1.65	2.0
$R - \mu$	-13.6	-10.8	-5.6	0	2.1	4.3	7.0	10.0	13.7	16.6
Rainfall(R)	8.8	11.6	16.8	22.4	24.5	26.7	29.4	33.2	36.1	39.0
Groundwater recharge (I)	0	0	2.8	8.4	10.5	12.7	15.4	19.2	22.1	25.0

Where **R** = rainfall in in. μ = mean rainfall σ = standard deviation

Conclusion

The above investigation shows that the hydroclimate at Yala can be divided into 3 distinct seasons, from the point of view of the moisture balance of the soil. During the greater part of the year, the rainfall is insufficient to meet the moisture demands of evaporation and evapotranspiration. However, during the $3\frac{1}{2}$ month wet season from mid-October to January, rainfall is in excess of the evaporative demands and there is a surplus of moisture. Groundwater recharge, therefore, occurs only during the wet season.

It was found that the long-term mean annual groundwater recharge is approx. 8 in. or about 100 million gallons per sq. mile. There is a 84% probability that some recharge will occur in any given year, a 75% probability that this recharge would be greater than 3 in., a 50% probability that this recharge would be greater than 8 in. and a 25% probability that this recharge would be greater than 14 in. The probability that no recharge will occur in any one year is approx. 16%, in two consecutive years $2\frac{1}{2}$%, while the risk that no recharge will occur in three consecutive years is $\frac{1}{2}$%.

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Appendix 1

Annual Rainfall at Yala

Year	Total in In.	Deviation from Mean	Square of Deviation
1957	62.92	+25.53	651.60
1944	51.11	+13.75	189.10
1961	49.66	+12.27	150.50
1936	48.91	+11.52	132.70
1942	48.30	+10.91	119.10
1925	48.10	+10.71	114.80
1951	47.97	+10.58	111.90
1954	46.92	+ 9.53	98.15
1941	45.70	+ 8.31	69.05
1927	45.23	+ 7.79	60.67
1924	44.86	+ 7.47	55.80
1931	44.13	+ 6.74	45.43
1955	42.35	+ 4.96	24.60
1960	41.18	+ 3.77	14.21
1949	39.54	+ 2.17	4.71
1940	39.27	+ 1.88	3.53
1923	39.23	+ 1.84	3.38
1943	38.47	+ 1.08	1.16
1935	38.03	+ 0.64	0.41
1947	37.07	— 0.32	0.10
1926	36.98	— 0.41	0.17
1938	36.59	— 0.80	0.64
1933	36.34	— 1.05	1.10
1959	36.05	— 1.34	1.80
1953	35.70	— 1.65	2.72
1930	35.47	— 1.92	3.69
1971	35.40	— 1.99	3.96
1939	33.75	— 3.64	13.25
1946	33.40	— 3.99	15.92
1965	33.16	— 4.23	17.80
1962	29.98	— 7.41	54.91
1948	29.84	— 7.55	56.99
1937	28.89	— 8.50	72.24
1958	28.72	— 8.67	75.16
1956	28.24	— 9.15	83.71
1952	27.93	— 9.46	89.50
1928	27.88	— 9.51	90.44
1945	25.16	—12.23	149.60
1950	24.04	—13.35	178.20
1932	23.84	—13.55	183.50
1968	22.47	—14.92	222.60
1934	21.60	—15.79	249.40
Total	1570.38		3418.20
Mean	37.39		83.35

$\sigma^2 = 83.35$

Standard deviation $\sigma = 9.131$

Accepted annual rainfall totals have been arranged in descending order of magnitude. The mean annual rainfall of 37.39 in. is in agreement with the mean annual rainfall of 37.40 in. for the standard 30 year period (1931—60).

Appendix 2

Rainfall at Yala for the 3½ Month Wet Season Period
16 October to 31 January

Year	Total in Inches	Deviation from Mean	Square of Deviation
1957	51.60	+29.25	855.56
1951	38.76	+16.41	269.29
1931	37.30	+14.95	223.50
1929	32.15	+ 9.80	96.04
1936	31.90	+ 9.55	91.20
1969	31.62	+ 9.27	85.93
1923	29.76	+ 7.61	57.91
1963	29.74	+ 7.39	54.61
1941	29.73	+ 7.38	54.46
1961	28.16	+ 5.81	33.76
1933	28.00	+ 5.65	31.92
1955	26.58	+ 4.23	17.89
1966	26.15	+ 3.80	14.44
1944	25.96	+ 3.61	13.03
1940	25.77	+ 3.42	11.70
1959	25.26	+ 2.90	8.41
1948	25.03	+ 2.68	7.18
1926	24.74	+ 2.39	5.71
1924	23.69	+ 1.34	1.79
1954	23.65	+ 1.28	1.64
1942	22.50	+ 0.15	0.02
1935	22.32	— 0.03	0
1953	22.17	— 0.18	0.03
1943	21.66	— 0.69	0.48
1965	21.43	— 0.92	0.85
1925	21.33	— 1.02	1.04
1956	21.04	— 1.31	1.72
1937	20.09	— 2.26	5.11
1949	19.75	— 2.60	6.76
1960	19.51	— 2.84	8.07
1952	19.26	— 3.09	9.55
1971	18.56	— 3.79	14.36
1962	18.44	— 3.91	15.29
1938	18.31	— 4.04	16.33
1927	17.98	— 4.37	19.10
1946	17.90	— 4.45	19.80
1928	15.80	— 6.55	42.90
1939	14.02	— 8.33	69.39
1958	13.56	— 8.79	77.26
1950	13.14	— 9.21	84.82
1930	11.74	—10.61	112.57
1964	11.67	—10.68	114.06
1945	11.45	—10.90	118.81
1934	11.23	—11.12	123.65
1932	10.72	—11.63	135.26
1968	9.62	—12.73	162.05
1947	9.54	—12.81	164.10
Total	1050.26		3174.53
Mean	22.35		69.01
	Std. deviation	σ =	8.32

Appendix 3

Chi-Square Test of Total Annual Rainfall — Yala

1 Order of Magnitude	2 Deviation from Mean	3 $\frac{R-\bar{R}}{\sigma}$	4 Prob. (P)	5 1000-P	6 Expected Freq.e	7 Observed Freq.o	8 |e-o|	9 |e-o|^2
1	+25.53	2.8	997.4	2.6	0		—	—
5	+10.91	1.2	885	115	2.3	5	3	9
10	+ 7.79	0.855	805	195	8.4	10	2	4
15	+ 2.17	0.238	595	405	17	15	2	4
20	— 0.32	—0.035	488	512	21	20	1	1
25	— 1.65	—0.181	429	571	24	25	1	1
30	— 4.23	—0.462	323	677	28	30	2	4
35	— 9.15	—1.00	159	841	35	35	0	0
40	—13.55	—1.48	69	931	39	40	1	1
42	—15.79	—1.73	42	958	41		—	—
								24

$$\chi^2 = \frac{24}{5} = 4.8$$

No. of degrees of freedom $\nu = 8 - 3 = 5$

From χ^2 Tables, $\chi^2_{50\%} = 4.35$; $\chi^2_{90\%} = 1.61$

For $\nu = 5$, the value of $\chi^2 = 4.8$ corresponds to a probability of approximately 50% Hence departure is not significant *i.e.* assumption of normality is not incorrect.

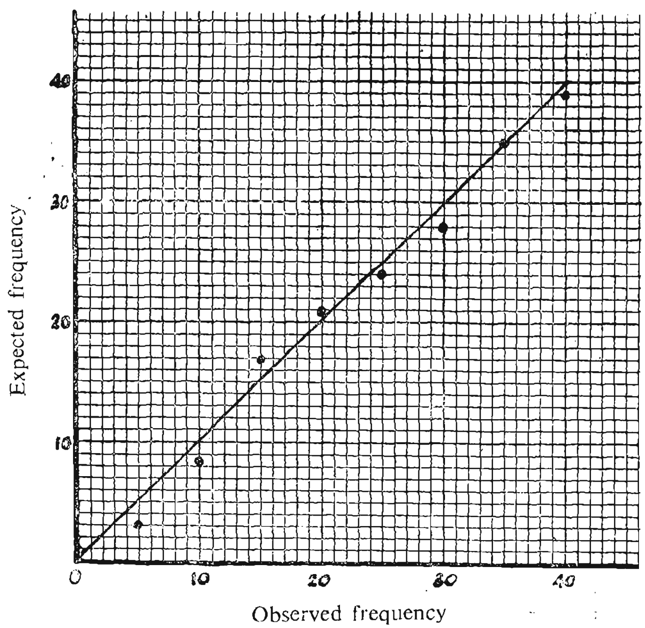
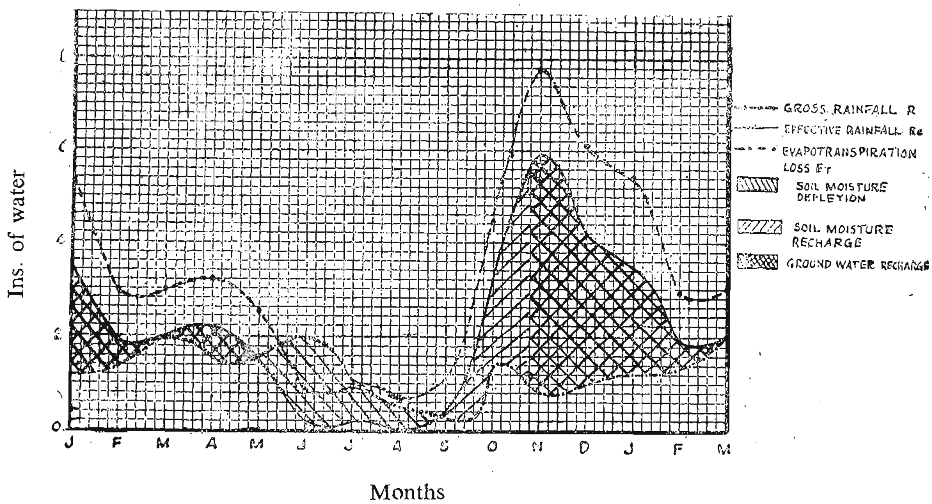


Figure 2. Observed vs expected frequency on assumption of normality

Appendix 4

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Gross rainfall (R) (in.)	5.4	2.9	3.0	3.2	2.5	0.8	0.9	0.7	1.1	4.4	7.8	6.1
Effective rainfall (R_e) (in.)	3.5	1.9	2.0	2.2	1.5	0.1	0.2	0	0.4	3.2	5.9	4.2
No. of raindays	8	5	5	6	6	3	2	3	3	9	14	11
No. of dry days (n)	23	23	26	24	25	27	29	28	27	22	16	20
E_o per day (in.)	0.13	0.14	0.19	0.17	0.16	0.23	0.26	0.26	0.23	0.16	0.13	0.13
$E_o n$ (in.)	3.0	3.2	4.9	4.1	4.0	6.2	7.5	7.3	6.2	3.5	2.1	2.6
$E_T = 0.4E\ n$ (in.)	1.2	1.3	2.0	1.6	1.6	2.5	3.0	2.9	2.5	1.4	0.8	1.0
$R_e - E_T$ (in.)	+2.3	+0.6	0	+0.6	−0.1	−2.4	−2.8	−2.9	−2.1	+1.8	+5.1	+3.2
$\triangle S$ (in.)	0	0	0	0	0	−2.0	−1.0	−0.5	−0.3	+1.8	+2.0	0
I (in.)	2.3	0.6	0	0.6	0	0	0	0	0	0	3.1	3.2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GROSS RAINFALL R
EFFECTIVE RAINFALL Re
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SOIL MOISTURE DEPLETION
SOIL MOISTURE RECHARGE
GROUND WATER RECHARGE
Months

Figure 3.

Appendix 5.

Chi-Square Test on Wet Season Rainfall — Yala

1	2	3	4	5	6	7	8
Order of Magnitude m	Deviation from Mean	$\frac{R-\bar{R}}{\sigma}$	Prob. (P) %	Expected Freq.(e)	Observed Freq. o	$\lvert e-o \rvert$	$\lvert e-o \rvert^2$
1	29.25	—	—	—	—	—	—
5	9.55	1.15	12.5	5.6	5	1	1
10	5.81	0.70	24.2	10.8	10	1	1
15	3.42	0.37	35.6	16	15	1	1
20	1.28	0.15	43.8	20	20	0	0
25	— 0.92	—0.11	54.4	25	25	0	0
30	— 2.84	—0.34	63.3	29	30	1	1
35	— 4.37	—0.53	70.2	32	35	3	9
40	— 9.21	—1.11	86.7	39	40	1	1
45	—11.63	—1.40	91.9	41	45	4	16
							30

$$\chi^2 = \frac{30}{5} = 6. \quad \text{for } m = 45$$

$$\chi^2 = \frac{14}{5} = 2.8 \quad \text{for } m = 40$$

From χ^2 Tables, $\nu = 9 - 3 = 6$

$$\chi^2_{50\%} = 5.35 \,; \quad \chi^2_{10\%} = 10.65$$

i.e. $\chi^2 = 6$ can be equalled or exceeded with a probability of about 45%. Hence departure is not significant *i.e.* assumption of normality is not incorrect.

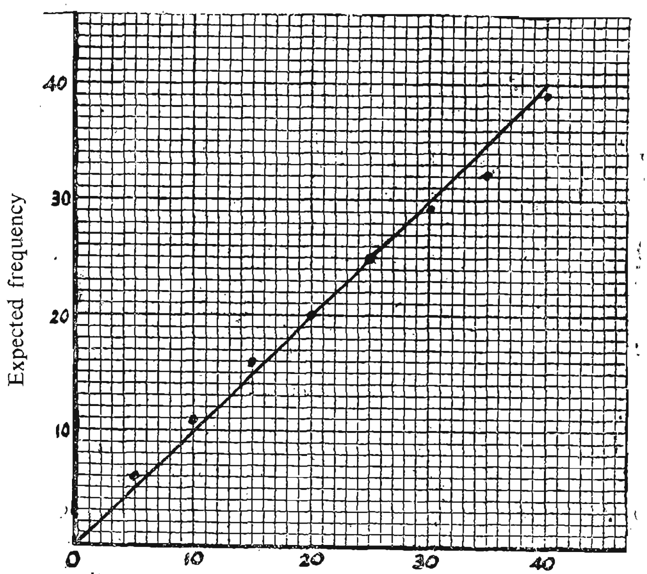

Figure 4. Observed vs expected frequency on the assumption of normality

Appendix 6.

Percent Probability(P)	95	90	75	50	40	30	20	10	5	2
Average Return Period(T) years			1⅓	2	2½	3⅓	5	10	20	50
Gross Rainfall (in.)	8.8	11.6	16.8	22.4	24.5	26.7	29.4	33.2	36.1	39.0
Groundwater recharge (in.)	0	0	2.8	8.4	10.5	12.7	15.4	19.2	22.1	25.0

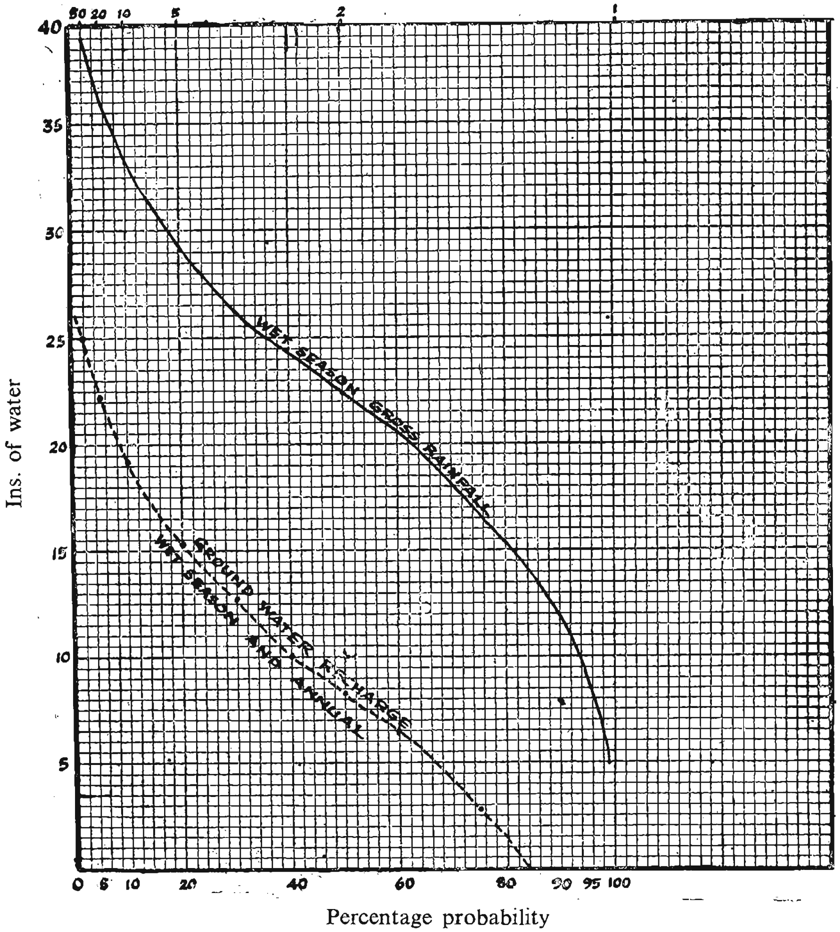

Figure 5. October to January — Yala

Rainfall and groundwater recharge likely to be equalled or exceeded with the stated probability in any one year