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Rainfall intensity-duration-return period equations and nomographs for Tamil Nadu

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Abstract : Rainfall intensity-duration-return period equations and nomographs for various stations are required for designing soil conservation and runoff disposal structures and also for planning flood control projects. Such relationships and nomographs for the state of Tamil Nadu were developed during 1978 for few stations namely Madras (Chennai), Tiruchirapalli and Kodaikanal. Presently, long period self recording rainfall data for 18 stations of Tamil Nadu State have been obtained from Indian Meteorological Department, Pune. Based on the data, the intensity-duration-return period equations and nomographs for all the 18 stations have been developed and discussed along with the general equation and nomograph for the State of Tamil Nadu. *(Key Words :* Rainfall intensity, Return period, Recurrrence interval, Nomograph, Run-off disposal)

Rainfall is one of the most important factors responsible for soil erosion. The characteristics of rain storm amount, its intensity and duration play an important role in determining the rate of soil erosion. Greater is the intensity, greater is the kinetic energy. The kinetic energy of rainfall dislodges soil particles and splashes them in suspension in runoff. Among other factors, the amount of runoff is determined by rainfall intensity, duration and amount. A rainfall of longer duration reduces the infiltration capacity of soil. As a result a long duration rainstorm produces considerable runoff regardless of its intensity. The capacity of a runoff conveyance system is usually based on a certain depth of rainfall to be expected during a selected period of time. Farm terraces, culverts, bridges and flood control structures are thus designed.

The significance of rainfall intensity, duration and frequency analysis is also important from economic considerations. An over designed structure involves excessive cost while under - designed structure would be unsafe and also involves high recurrence expenditure on maintenance and replacement, etc. An intermediate design would provide a structure with reasonable initial and maintennce costs.

Information on rainfall intensity-duration-return period equations and nomographs are impressively required for design of soil conservation and also runoff disposal structures and for planning flood control projects. Such relationships and nomographs have been developed only for some stations (Gupta *et al,* 1968; Raghunath *et al,* 1969; Khullar *et al,* 1975 ; Senapati *et al,* 1976; and Ram Babu *et al,* 1980). No attempts have been made in the past to develop such a tool for a State as a whole.

In the present study, based on observed data of 18 representative stations, the intensity-duration-return period equations and nomographs for individual stations as well as one general equation and nomograph for the State of Tamil Nadu have been developed.

Materials and Methods

To derive prediction equations for intensitydurati frequency and for development of nomographs, the continuous recorded rainfall data for 18 stations situated in the State of Tamil Nadu were obtained from Indian Meteorological Department, Pune. Due to the non-availability of data for long period for all the stations under study, more than 15 years records for 14 stations and 10-12 years data for four stations (1974 to 1995) have been used. The locations of these stations are shown in Fig.1. The data for all the stations were tested for reliability using the procedure of Ogrosky and Mockus (1957) and it was observed that the length of record for all the stations were adequate and hence could be used for frequency analysis.

Analytical Procedure

Various formulae had been used for connecting the three parameters - rainfall intensity, duration and return period {Schwab *et al* (1955), Linsley *et al* (1949), Skurlow (1960), Nemec (1973), Gupta *et al* (1968), Raghunath *et al* (1969), Khullar *et al* (1975), Senapati *et al* (1976) and Ram Babu *et al* (1980)}. Formula is of the general form and given here under:

$$I = KT^a/(t+b)^d \quad \text{---------------(1)}$$

where, I = intensity of rainfall (cm/hr), T = return period (years, t = duration (hours); K, a, b and d are the constants.

Equation (1) was used for developing intensity-duration-frequency relationships. Looking into its simplicity in use and quickness, the nomographs were developed for field workers. The detailed methodology for developing intensity duration-return period equations and nomographs has been dealt by Ram Babu *et al* (1980).

Method of Frequency Analysis and Development of frequency Lines

Various methods had been proposed for frequency analysis and there are several theoretical interpretations or reasoning for the preference of one method over the other (Chow, 1964). Mathematical or graphical methods are generally used for frequency analysis. When the records are of short in duration, the sampling error would be large. A regid mathematical treatment needed data for more than 30 years (Dalrymple, 1960). The present data used for analysis are of short period of about 15 years, graphical methods have been employed. Gumbel extreme value technique was applied for computation of return period values and the frequency lines were plotted after computing the plotted points by 'computed methods' as suggested by Ogrosky and Mockus (1957). Frequency lines for 15 minutes, 30 minutes, one hour, 3 hours, 6 hours, 12 hours and 24 hours intensity were developed for Vellore and plotted on log-normal probability papr (Fig .2).

Deriving Equation for Intensity-Duration-Return Period

The intensity-duration-return period equation, (equation 1) can be expressed by taking logarithms on both sides as :

$$\log I = \log K + \log T - d \log (e+b) \quad \text{-------------(2)}$$

$$\text{or } \log I = \log K_1 - d \log (t+b) \quad \text{--------------(3)}$$

$$\text{where, } \log K_1 + \log K + a \log T \quad \text{--------------(4)}$$

In order to evaluate the co-efficients, a, b, d and K, the following steps were undertaken:

Step I: On log-log paper the values of rainfall intensity for each individual duration were plotted on the Y-axis and return period (or recurrence interval) in years on X-axis (Fig.3). Points were connected for each duration by dotted line giving more weight to the points from 10 year to 100 year return periods and extended the dotted line to cut out the Y-axis against year return period.

Step II: The intensity values, I_t at different values of t equal to 2, 5, 10, 25, 50 and 100 years recurrence intervals for each duration were read from Fig. 3. The mathematical relationship between T and various I_t values of I_t could be given by

$$\text{Log } I_t = m \log T + C \quad \text{--------------(5)}$$

where, I_t = maximum intensity for duration t, T = recurrence interval, m = frequency factor for each line (i.e., slope of the frequency line) and C = intercept on Y-axis at T + I. These interval equations define the intensity-frequency relationship for any selected duration.

Step III: The slope (m) of eq. (g) for each duration was determined and then its geometric mean (m) was computed. The slope of line (m) represents the exponent 'a' in equation (1). The geometric mean slope m thus determined represented actually T^a in equation (1).

Step IV: A line representing geometric mean slope (m) was drawn (Fig.3) at the base through origin; so lines parallel to this mean slope were drawn to have the lines as close as possisble to points between 10 to 100 years periods extending them to cut the Y-axis. Rainfall intensities against one-year return period for all selected duration were then read on Y-axis.

Step V: Intensity for one-year recurrence interval was plotted on the Y-axis with selected duration (t) on the X-axis on log-log paper (Fig.4). Since the points so plotted did not fall on a straight line, a suitable constant was added (b) to time 't'. Thus, the equation become:

$$I = K/(t+b)^d \quad \text{--------------(6)}$$

It was done by trial and error method in such a way that the deviatiions were minimum (Fig .4).

Step VI: The equation (3) written in its logarithmic form is :

$$\log I = \log K - d \log (t+b) \quad \text{----------(7)}$$

$$\text{or } \log I - \log K + d \log (r+b) = 0 \quad \text{----------(8)}$$

The constants K and d in equation (8) were then solved by the method of least squares. They can also be obtained by solving the equation (9) and (10).

$$\log K = \frac{\Sigma \log I . \Sigma [\log (t+b)]^2 - [(\log I . \log (t+b)] . \Sigma \log (t+b)}{N\Sigma [\log (r+b)]^2 - [\Sigma \text{ kig } (t+b)]^2} \quad \text{-----(9)}$$

$$\text{and } d = \log (r+b)] \; \frac{\Sigma \log I . \Sigma \log (t+b) - N\Sigma [\log I.}{N\Sigma [\log (t+b)]^2 - [\Sigma \log (t+b)]^2} \quad \text{----(10)}$$

Thus all the parameters 'a' (step III), 'b' (step V) and 'k' & 'd' (step VI) became known for equation (I).

Step VII: At this stage, frquency factor T^a obtained in step III above was included to arrive the intensity-duration-frequency or return period formula.

$$I = \text{---------}\ Ta \qquad 11)$$

Development of Nomograph

A nomograph is an alignment chart consisting of a set of parallel scales, which are suitably graduated. In the present study, there were only three variables and thus the alignment chart had three parallel scales so graduated that a line which joins values on two scales will intersect the third scale at a value which satisfies the given equation. In order to design alignment charts the following was used.

$$F_1(u) + f_2(v) = f_3(w), \frac{K}{(t+b)^d} \qquad \text{------------------}(12)$$

The graduation of scales, which are marked with the values of the variable and on which the distances to the graduations are laid off the proportion to the corresponding values of the function of the variables, and the determination of spacing of the parallel scale.

The scale equation for determining functional modulus (m), commonly defined as a proportionality multiplier used to bring a range of values of particular function with a selected length for a scale, which is given as :

$$m = L/\{f(u_2) - f(u_1)\} \qquad \text{------------------}(13)$$

where, m=calculated functional modulus, L=length of the scale chosen, $f(u_1)$ and $f(u_2)$ = lower and upper limit respectively of the function.

The unknown functional modulus m_w was calculated by

$$mw = m_u.m_v/(m_u - m_v) \qquad \text{-------------}(14)$$

where, m_u and m_v were the calculated functionla moduli

Scale spacing ratio = m_u / m_v was determined with the help of the equation (11). The limiting values of intensity were determined on the basis of conditions laid down on t and T.

Results and Discussion

Mathematical Equations

Following the procedure as discussed earlier, the intensity-duration-frequency relationships for 18 stations of Tamil Nadu were developed and are presented in Table1. The prescision of these equations could be recognized only after verifying the reliability of anyone of the station equation. For this purpose, the equation was applied to Vellore station. The maximum per cent deviation between the rainfall intensity values obtained from developed equation ($I = 7.9848T^{0.1276} / (t+0.50)^{1.1060}$) and the observed values obtained from frequency lines from primary data (i.e. probability chart) for various duration and 10, 25 and 50 years frequency ranged from -10.6 to +6.1 per cent (Tabale-2) while for Tamil Nadu State as a whole it ranged from -11.6 to +7.3 per cent, on the basis of general equation developed for the State ($I = 7.9328T^{0.1811} / (t+0.75)^{1.0710}$) from the 18 stations. This deviation was quite low. Notwithstanding the inherent weakness of an average equation, the developed equation seems to be reliable and may be used with confidence.

From the equations of individual station, the intensity for any desired duration and frequency (or return period, or recurrence interval) can be determined for that location and the general equation may be used for any location falling in the State.

Nomograph

On the basis of intensity-duration-frequency relationships developed for 18 stations located in Tamil Nadu (Table1), nomographs were prepared for all these stations. A nomograpah of Vellore station is shown in Fig.5. From this nomograph, the rainfall intensity for any desired duration between 10 to 100 year frequency (or return period) could be directly read for a particular location. General nomogrph for the State of Tamil Nadu (Fig .6) was also developed which may be used in determining intensity for any duration and recurrence internal for any location falling in the State.

Comparison of Mathematical and Nomographic Solutions

Per cent deviation of rainfall intensity observed from nomograph and those calculated from corresponding mathematical equation of Vellore and the State of Tamil Nadu for various duration and 10, 25 and 50 years frequencies showed that maximum deviation between nomographc solutions and mathematical equations (i.e. σ_{nomo}) ranges from -11.6 to +7.6 and -13.1 to +8.2 per cent respectively.

The deviations for other 17 stations were also still less.

On comparing the rainfall intensity at various duration and frequencies obtained from the developed equations and observed values obtained from the probability charts. It is observed that the maximum deviation ranges from -24.0 to 20.3 per cent for Cuddalore. Thus, in general, the variations lie around the acceptable limit (±20%). On further scrutiny, it is observed that the nomographic solutions are more precise for predicting rainfall intensity of various duration and frequencies. Looking into simplicity in use, quickness and precision in results obtained, nomographs appear to be the most handy tool for field workers.

When the rainfall intensity of 15, 30 minutes, one hour and 3 hours duration for 10, 25 and 50 years frequency obtained for the Tamil Nadu State equation and comparing with individual stations, it appears in general, that the per cent deviations of calculated and nomographic intensities of individual station with respect to State, occurs between ±25 per cent for all the locations except Coimbtore and Tirupattur. This indicates the limitation of the State equation. It is, therefore, suggested that the State equation is best suited for locations where intermediate intensity rainfal is received which is always true for any equation or nomograph developed for a State or a region.

Conclusions

Rainfall intensity-duration-frequency relationship and nomographs were developed for 18 stations of Tamil Nadu and State as a whole. These equations and nomographic solution are quite reliable due to their closeness among observed, calculated and nomographic values. Nomograph is a handy tool due to its simplicity, quickness and preciseness for predicting intensity for desired duration and return period.

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Table1 : Intensity-Duration-Return period relationships of various stations in Tamil Nadu

Station	Equation	Station	Equation
Coimbatore	$I = \frac{7.7061\,T^{0.3210}}{(t+0.75)^{1.1145}}$	Cuddalore	$I = \frac{8.4570\,T^{0.1676}}{(t+0.70)^{1.1250}}$
Kalklakurchi	$I = \frac{6.3297\,T^{0.1745}}{(t+0.80)^{2.4456}}$	Kodaikanal	$I = \frac{6.6652\,T^{0.1382}}{(t+0.90)^{1.0972}}$
Kovilpatti	$I = \frac{11.1387\,T^{0.1956}}{(t+1.30)^{1.1443}}$	Kanyakumari	$I = \frac{6.7327\,T^{0.2165}}{(t+1.00)^{1.1774}}$
Karur	$I = \frac{9.1002\,T^{0.1537}}{(t+1.00)^{1.1522}}$	Tirupattur	$I = \frac{6.5520\,T^{0.2563}}{(t+0.60)^{0.8335}}$
Madurai	$I = \frac{7.0165\,T^{0.1598}}{(t+0.50)^{1.0770}}$	Minambakkam	$I = \frac{11.3674\,T^{0.1474}}{(t+1.00)^{1.1598}}$
Nagapatinam	$I = \frac{10.4709\,T^{0.1580}}{(t+0.75)^{[illegible]}}$	Nungambakkam	$I = \frac{6.0886\,T^{0.1883}}{(t+0.50)^{0.9907}}$
Palani	$I = \frac{7.0627\,T^{0.1567}}{(t+0.70)^{1.1356}}$	Pampan	$I = \frac{8.1725\,T^{0.1579}}{(t+0.60)^{0.7852}}$
Salem	$I = \frac{8.1285\,T^{0.1638}}{(t+0.85)^{1.0726}}$	Tiruchirapalli	$I = \frac{7.0848\,T^{0.1279}}{(t+0.50)^{1.0826}}$
Tuticorin	$I = \frac{7.0328\,T^{0.1811}}{(t+0.75)^{1.0770}}$	Vellore	$I = \frac{7.0328\,T^{[illegible]}}{(t+0.75)^{[illegible]}}$
General: Tamil Nadu State	$I = \frac{6.3297\,T^{0.1745}}{(t+0.80)^{2.4456}}$		

{I = intensity (cm/hr); T = return period (year); and t = duration (hour)}

Table-2 : Comparison among calculated, nomographic and observed intensities of rainfall (cm/hr) and their present deviation.

Duration	i_{cal}			i_{noma}			i_{obs}			σ_1			σ_{noma}		
Mins;hrs	Frequency (years)			Frequency (years)			Frequency (years).			Frequency (years)			Frequency (years)		
	10	25	50	10	25	50	10	25	50	10	25	50	10	25	50
Station : Vellore															
15 mins.	14.72	16.55	18.08	14.50	17.00	18.00	15.00	16.80	18.00	-1.9	-1.5	0.4	-3.3	1.2	0.0
30 mins.	10.71	12.04	13.15	10.50	12.00	13.00	11.00	12.20	13.00	-2.6	-1.3	1.2	-4.5	-1.6	0.0
1 hr.	6.84	7.69	8.40	6.80	7.60	8.50	7.60	8.60	9.40	-10.0	-10.6	-10.6	-10.5	-11.6	-9.6
3 hrs.	2.68	3.01	3.29	2.70	3.00	3.30	2.70	2.90	3.10	-0.7	3.8	6.1	0.0	3.4	6.5
6 hrs	1.35	1.52	1.66	1.30	1.50	1.70	1.35	1.50	1.58	0.0	1.3	5.1	-3.7	0.0	7.6
General : Tamil Nadu State															
15 mins.	12.04	14.21	16.11	12.00	14.10	16.20	12.59	14.77	16.36	-4.4	-3.8	-1.5	-4.7	-4.5	-1.0
30 mins.	9.48	11.19	12.69	9.50	11.20	12.80	9.41	10.82	11.83	0.7	3.4	7.3	1.0	3.5	8.2
1 hr.	6.61	7.80	8.85	6.50	7.90	9.00	7.48	8.73	9.61	-11.6	-10.7	-7.9	-13.1	-9.5	-6.3
3 hrs.	2.92	3.45	3.91	2.290	3.50	3.90	3.03	3.40	3.67	-3.6	1.5	6.5	-4.3	2.9	6.3
6 hrs.	1.56	1.84	2.08	1.60	1.80	2.10	1.60	1.86	2.05	-2.5	-1.1	1.5	0.0	-3.2	2.4

i_{cal} = Calculated intensity ofg rainfall (cm/hr) from developed equation;

i_{noma} = Observed intensity of rainfall (cm/hr) from nomographs of the particular station;

i_{obs} = Observed intensity of rainfall (cm/hr) from the frequency lines from primary data; and

σ_1 = Per cent deviation of observed valus from the frequency lines to those calculated with the developed equation.

σ_{noma} = Per cent deviation of nomographic values from those calculated with the developed equation

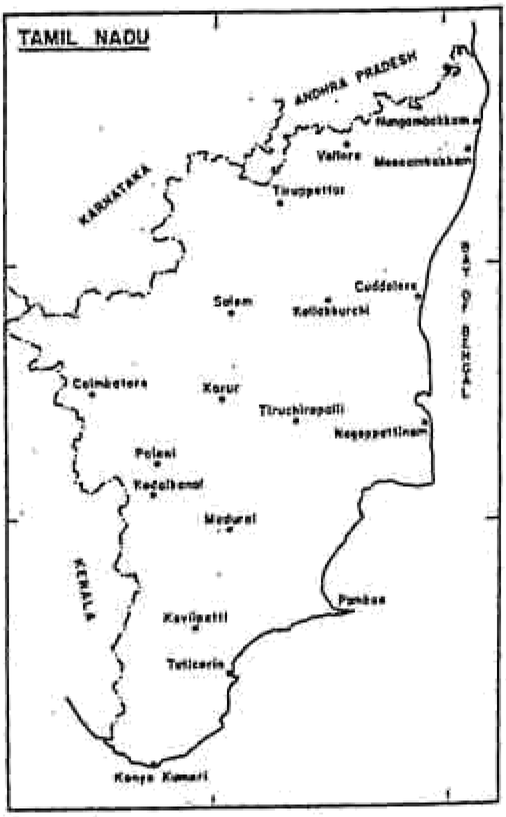


Fig 1 : Map Showing locations of recording rain-guage stations in Tamil Nadu

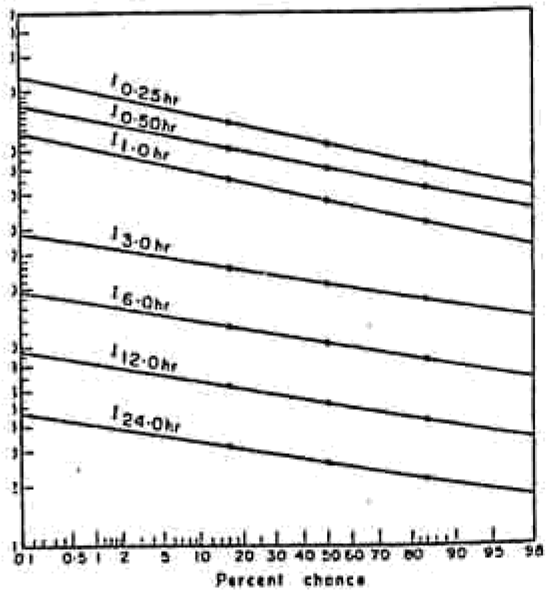


Fig 2 : Frequency distribution of rainfann intensities for various duration - Vellore

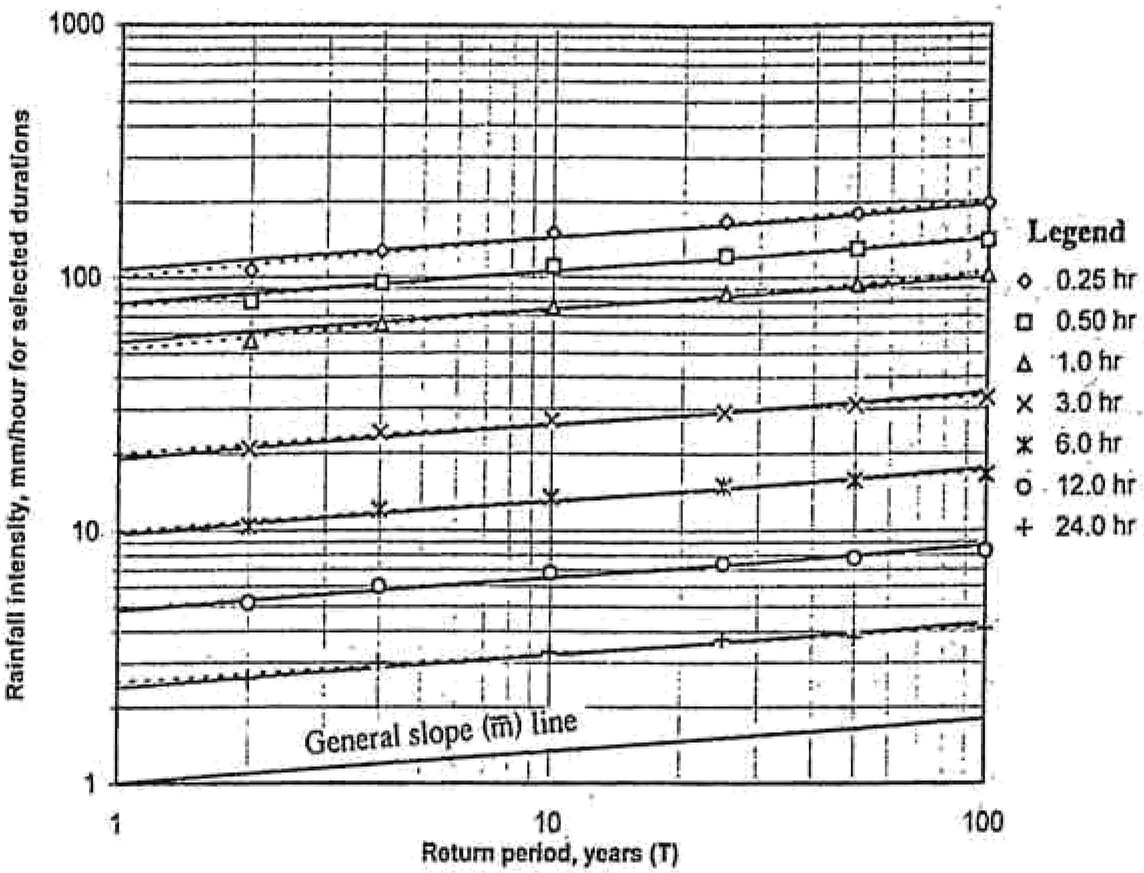
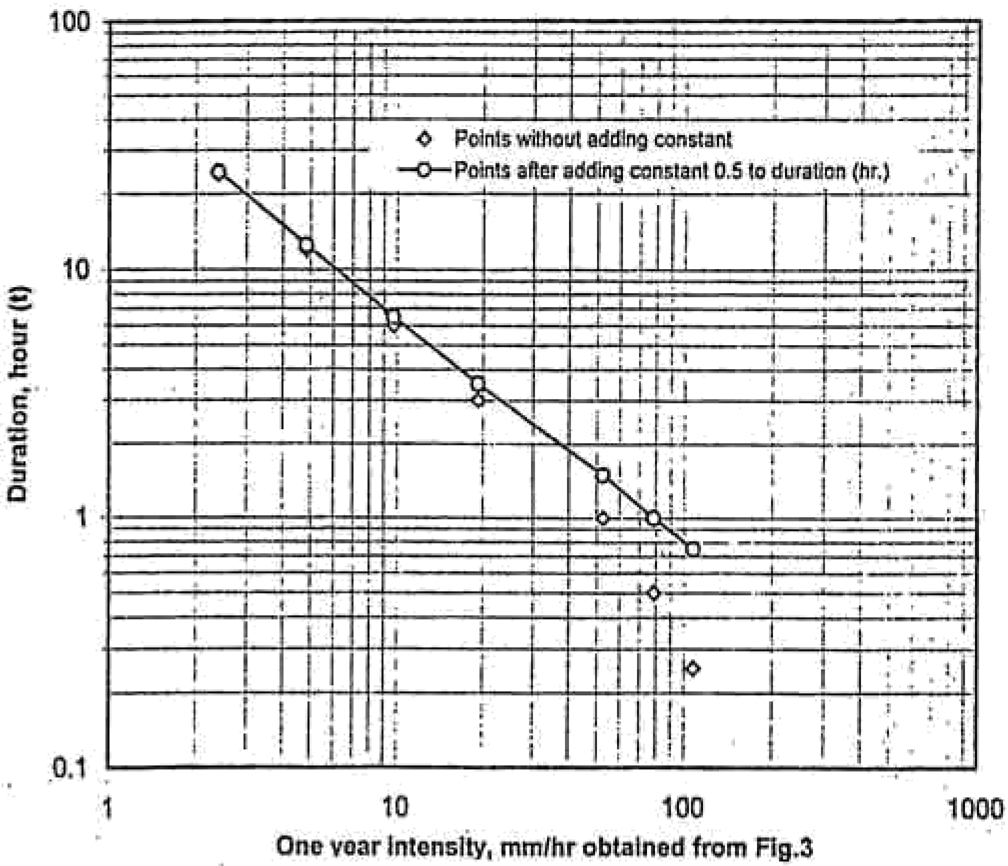


Fig. 3. Rainfall intensities for selected durations and return periods - Vellore



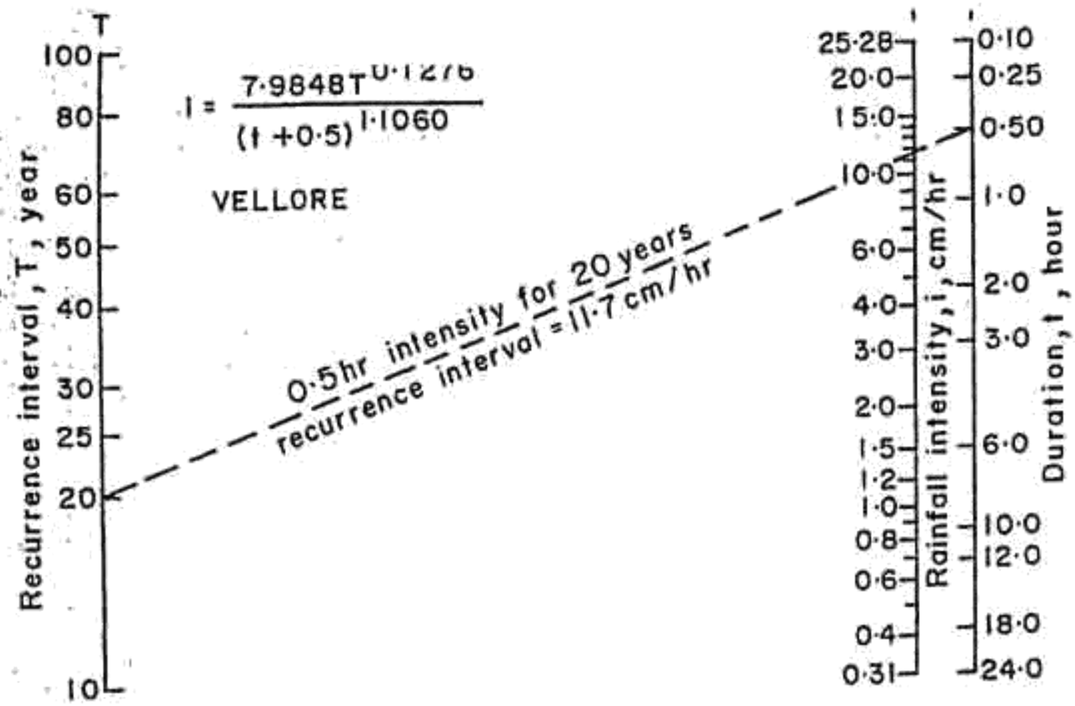


Fig. 5. Nomograph for solving intensity-duration-return period (or recurrence interval) equation – Vellore.

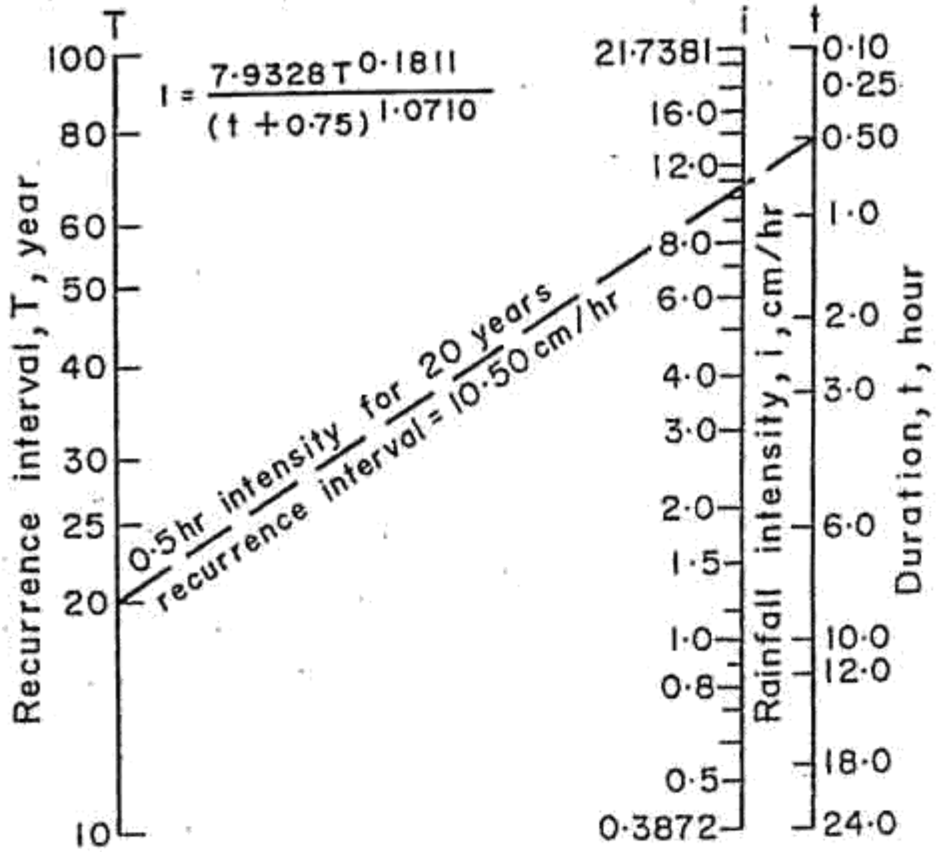


Fig. 6. Nomograph for solving intensity-duration-return period (or recurrence interval) equation – Tamil Nadu.

References

Chow, V.T. (1964). Handbook of Applied Hydrology. McGraw Hill, New York. 1453 pp.

Dalrymple, T. (1960). Flood-frequency analysis. U.S. Feol. Survey Water Supply-Paper 1543-A, U.S. Dept. Interior. 80 pp.

Gupta, S.K., Dalal, S.S. and Ram Babu (1968). Analysis of point rainfall data of Dehradun. Irrig. Power *J. 25* : 291-330.

Khullar, A.K., Das, D.C. and Ram Babu (1975). Station nomograph and one hour rainfall for intensity duration return period computation in India. *Soil Cons. Digest 3* : 1-9.

Linsley, R.K., Kohler, M.A. and Paulhus, J.L.H. (1949). Applied Hydrology. McGraw Hill, New York. 689 pp.

Nemec, J. (1973). Engineering Hydrology. Tata McGraw Hill Pub. Co. Lrd., New Delhi. 316 pp.

Ogrosky, H.O. and Mockus, V. (1957). National Engineering Handbook. Sec. 4. Hydrology Supp. A. 18-11 to 14. Soil Cons. Serv., U.S. Dept. Agric.

Ranghunath, B., Das, D.C., Srinivas and Lakshmanan V. (1969). Rainfall intensity-duration-returr period analysis and simplified methodology *The Harvester 11* : 86-92.

Ram Babu, Tejwani, K.G., Agarwal, M.C. and Bhushan L.S. (1980). Rainfall intnsity-duration-return period equations and nomographs of India. Statistical Climatology. Developments in Atmospheric science, 13. Elsevier Scientific Pub. Co., Amsterdam : 359-374.

Schwab, G.P., Frevert, R.K., Edminster, T.W. and Barnes, K.K. (1955). Soil and Water Conservation Engineering. John Wiley and Sons, New York. 525 pp.

Senapati, P.C., Shakya, S.K. and Nema, J.P. (1976). Nomograph of intensity, duration and recurrence interval of rainfall at Bombay (Colaba). *Irrig. and Power J. 33* : 525-528.

Skurlow, J. (1960). A nomograph for estimation of rainfalal intensity and runoff. *J. Soil Cons Serv. New South Wales 16* : 126-136.

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Effect of ferrogypsum on yield, nutrient uptake and quality in groundnut

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Abstract : The present investigation was undertaken to study the efficacy of ferrogypsum on yield, quality and nutrient uptake in groundnut. Ferrogypsum is a byproduct from the titanium industry and it contains gypsum (52.63%) and iron (10.24% as Fe_2O_3). Field experiment was conducted on a calcareous red soil with groundnut to evaluate the efficacy of ferrogypsum in comparison with gypsum + $FeSO_4$ (as soil application and foliar spray). The results revealed that application of ferrogypsum in amounts equivalent to recommended dose (400 kg/ha) of gypsum significantly increased the pod and haulm yield, quality, nutrient content and uptake in groundnut. This beneficial effect was similar to those obtained with the application of gypsum + $FeSO_4$ (FeSO4 as either soil applicztion of foliar spray). Thus the results of the present study indicated that ferrogypsum was as effective as gypsum in increasing pod, haulm yield and oil and protein content and nutrient uptake in groundnut crop grown on a calcareous soil. (*Key words : ferrogypsum, Iron nutrition, Sulphur source*)

Groundnut is one of the most important oil seed crops grown in India. It accounts for about 50% of the 13 m t annual oil seed production in the country. But at present, it's average productivity is only 1,155 kg ha^{-1} against the potential of 3000 kg ha^{-1}. Higher yield of groundnut was contributed by optimum nutrient composition and it's uptake from soil. Among the different constraints in groundnut production, lime induced iron chlorosis is the major one especially in calcareous soils where HCO_3 ions hinder the uptake and translocation of Fe in the plant (Patel *et al.*, 1993). This lime induced iron chlorosis can be managed by