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, Recurrence 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 run-off. Among other factors, the amount of run-off 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 run-off regardless of its intensity. The capacity of a run-off 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 maintenance 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 intensity-duration 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 Orosky 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), Skurow (1960), Nemenz (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:
\[ I = KT^a(t+b)^d \]  \hspace{1cm} (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 rigid mathematical treatment needed data for more than 30 years (Dahlymple, 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 Ogresky 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 paper (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:

\[ \log I = \log K + \log T - d \log (t+b) \]  \hspace{1cm} (2)

or \[ \log I = \log K_1 - d \log (t+b) \]  \hspace{1cm} (3)

where, \( \log K_1 + \log K + a \log T \)  \hspace{1cm} (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, \( I \), 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 \( I \) values of \( I \) could be given by:

\[ \log I = m \log T + C \]  \hspace{1cm} (5)

where, \( I = \) 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 \( T + 1 \). These interval equations define the intensity-frequency relationship for any selected duration.

**Step III:** The slope (m) of eq. (5) 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 thus determined represented actually \( T \) 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 cut the lines as close as possible to points between 10 and 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:

\[ I = K/(t+b)^d \]  \hspace{1cm} (6)

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

**Step VI:** The equation (2) written in its logarithmic form is:

\[ \log I = \log K - d \log (t+b) \]  \hspace{1cm} (7)

or \[ \log I - \log K + d \log (t+b) = 0 \]  \hspace{1cm} (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 equations (9) and (10).

\[
\log K = \frac{\log I \Sigma [\log (t+b)]^2 - [\log I \cdot \Sigma \log (t+b)]}{N \Sigma [\log (t+b)]^2 - [\Sigma \log (t+b)]^2} \quad (9)
\]

and \( d = \log t \cdot \Sigma \log (t+b) - N \Sigma [\log I \cdot \Sigma \log (t+b)]}{N \Sigma [\log (t+b)]^2 - [\Sigma \log (t+b)]^2} \quad (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, frequency factor $T^n$ obtained in 
step III above was included to arrive the intensity-
duration-frequency or return period formula.

$$I = \frac{T_a}{11}$$

**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.

$$F_1(u) + F_2(v) = F_3(w) / (1+b)^d$$  \hspace{1cm} (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 :

$$m = L / \{f(u_u) - f(u_l)\}$$  \hspace{1cm} (13)

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

The unknown functional modulus $m_w$ was calculated by

$$m_w = m_o \cdot m / (m_o - m)$$  \hspace{1cm} (14)

where, $m_o$ and $m_w$ were the calculated functiona moduli.

Scale spacing ratio $= m_w / m_o$ was determined 
with the help of the equation (11). The limiting values of 
intensity were determined on the basis of conditions 
laid down on $T_a$ 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 Table 1. The precision 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 
inensity values obtained from developed equation ($I = 7.9848 + 0.227 / (T+0.50) + 0.460$) 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 
(Table-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 ($I = 7.9328 + 0.611 / (T+0.75) + 0.270$) from the 18 stations. This 
development 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 (Table 1), nomographs were prepared for all these 
stations. A nomograph 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 nomograph for the State of Tamil Nadu 
(Fig. 6) was also developed which may be used in 
determining intensity for any duration and recurrence 
interval 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 
nomographs solutions and mathematical equations (i.e. 
$\sigma_{nom}$) 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 
development ranges from -24.0 to 20.5 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 percent deviations of calculated and nomographic intensities of individual station with respect to State, occurs between ±25 per cent for all the locations except Coimbatore 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 rainfall 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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<table>
<thead>
<tr>
<th>Station</th>
<th>Equation</th>
<th>Station</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coimbatore</td>
<td>$2.7061T^{0.1270}$</td>
<td>Cuddalore</td>
<td>$8.4570T^{0.1578}$</td>
</tr>
<tr>
<td>Kalkaluruli</td>
<td>$6.3297T^{0.2750}$</td>
<td>Kodaikanal</td>
<td>$6.6532T^{0.2328}$</td>
</tr>
<tr>
<td>Kovilpatti</td>
<td>$11.1511T^{0.2290}$</td>
<td>Kanyakumari</td>
<td>$6.7327T^{0.2142}$</td>
</tr>
<tr>
<td>Karur</td>
<td>$10.1002T^{0.158}$</td>
<td>Tirupattur</td>
<td>$6.5520T^{0.2165}$</td>
</tr>
<tr>
<td>Madurai</td>
<td>$7.0165T^{0.1495}$</td>
<td>Minambakkam</td>
<td>$11.5674T^{0.1792}$</td>
</tr>
<tr>
<td>Nagapattinam</td>
<td>$10.4709T^{0.2820}$</td>
<td>Nungambakkam</td>
<td>$6.0886T^{0.2302}$</td>
</tr>
<tr>
<td>Palani</td>
<td>$7.0627T^{0.158}$</td>
<td>Pamban</td>
<td>$8.1725T^{0.2177}$</td>
</tr>
<tr>
<td>Salem</td>
<td>$8.1285T^{0.2185}$</td>
<td>Tiruchirapalli</td>
<td>$7.9884T^{0.2080}$</td>
</tr>
<tr>
<td>Tuticorin</td>
<td>$7.0228T^{0.1421}$</td>
<td>Vellore</td>
<td>$7.9228T^{0.2101}$</td>
</tr>
<tr>
<td>Tamil Nadu State</td>
<td>$6.5597T^{0.208}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$I =$ 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.

<table>
<thead>
<tr>
<th>Duration</th>
<th>(i_{cal})</th>
<th>(i_{nom})</th>
<th>(i_{obs})</th>
<th>(\sigma_i)</th>
<th>(\sigma_{nom})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mins/hrs</td>
<td>Frequency (years)</td>
<td>Frequency (years)</td>
<td>Frequency (years)</td>
<td>Frequency (years)</td>
<td>Frequency (years)</td>
</tr>
<tr>
<td>10</td>
<td>25</td>
<td>50</td>
<td>10</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>15 mins.</td>
<td>14.72</td>
<td>16.55</td>
<td>18.08</td>
<td>14.50</td>
<td>17.00</td>
</tr>
<tr>
<td>30 mins.</td>
<td>10.71</td>
<td>12.04</td>
<td>13.15</td>
<td>10.50</td>
<td>12.00</td>
</tr>
<tr>
<td>1 hr.</td>
<td>6.84</td>
<td>7.69</td>
<td>8.40</td>
<td>6.80</td>
<td>7.60</td>
</tr>
<tr>
<td>3 hrs.</td>
<td>2.68</td>
<td>3.01</td>
<td>3.29</td>
<td>2.70</td>
<td>3.00</td>
</tr>
<tr>
<td>6 hrs.</td>
<td>1.35</td>
<td>1.52</td>
<td>1.56</td>
<td>1.30</td>
<td>1.50</td>
</tr>
</tbody>
</table>

**Station: Vellore**

**General: Tamil Nadu State**

- \(i_{cal}\) = Calculated intensity of rainfall (cm/hr) from developed equation;
- \(i_{nom}\) = 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
- \(\sigma_i\) = Per cent deviation of observed values from the frequency lines to those calculated with the developed equation.
- \(\sigma_{nom}\) = Per cent deviation of nomographic values from those calculated with the developed equation.

Fig 1: Map showing locations of recording rain-gauge stations in Tamil Nadu

Fig 2: Frequency distribution of rainfall intensities for various duration - Vellore
Fig. 3. Rainfall intensities for selected durations and return periods - Vellore
Rainfall Intensity-Duration-Return Period Equations and Nomographs for Tamil Nadu

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.
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 Fe₂O₃). Field experiment was conducted on a calcareous red soil with groundnut to evaluate the efficacy of ferrogypsum in comparison with gypsum + FeSO₄ (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 + FeSO₄ (FeSO₄ as either soil application or 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 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 5000 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 HCO₃ ions hinder the uptake and translocation of Fe in the plant (Patel et al., 1993). This lime induced iron chlorosis can be managed by...