Vol. 49, No. 1, pp 72-76, 2021
Indian Journal of Soil Conservation

Rainfall intensity–duration–frequency curves for Ballowal Saunkhri in the *Shivalik* foot–hills of Punjab

Kiran Sharma, Anil Bhardwaj and Sanjay Satpute*

Department of Soil and Water Engineering, Panjab Agricultural University, Ludhiana − 141 004, Punjab.

**Corresponding author:*
E-mail: sanjay4471@pau.edu (Sanjay Satpute)

ARTICLE INFO

DOI : 10.59797/ijsc.v49.i1.212

Article history:
Received : March, 2021
Revised : April, 2021
Accepted : April, 2021

Key words:
Duration
Frequency
IDF curves
Rainfall intensity
Return period

ABSTRACT

Rainfall is the result of complex atmospheric phenomena and it is a complicated temporal and spatial structure. Rainfall intensity–duration–frequency (IDF) relationship and nomographs are required for design of soil and water conservation structures. In this study, the rainfall IDF relationships were determined for *Shivalik* foothills. The raingauge charts of 11 years (2000 to 2010) analysed to get rainfall depth and rainfall intensities for different durations (15, 30, 45 and 60 min). The maximum rainfall intensities for 15, 30, 45 and 60 min duration for 5, 10, 15, 20 and 25 year return periods were found to be 122.5 mm hr^{-1} to 178.9 mm hr^{-1} for 15 min, 98.8 mm hr^{-1} to 151.5 mm hr^{-1} for 30 min, 87.16 mm hr^{-1} to 137.4 mm hr^{-1} for 45 min and 79.7 mm hr^{-1} to 128.3 mm hr^{-1} for 60 min duration. The coefficient of determination (R^2) varies between 0.90 to 0.95 which showed good relation between maximum rainfall intensity and the return period.

1. INTRODUCTION

Rainfall is the principal form of precipitation in India. Rainfall per unit of time that occurs at a place determines the quantity of rainwater which goes as runoff over the land surface. The quantity of runoff produced by a storm would depend upon whether rain falls as gentle showers or as cloud bursts, whether in wet spells, much of it coming after the ground is already soaked, or as well distributed showers, heavy enough to soak the previously dry soil but not fast enough to cause much runoff. It is generally observed that more intense the rainfall, greater would be the runoff per unit of rain. When gentle rains occur, there is ordinarily little or no runoff, except from almost impervious surfaces. However, intense storm cause high runoff from even moderate slopes on forest or grass covered areas. Data on rainfall intensity are significant to those interested in soil erosion control, groundwater recharge and management, drainage and maintenance of transportation or other services across or along the runoff channels. Prospects of rains of various intensities are important for engineers in order to provide structures large enough to accommodate the runoff. Agriculturists would like to know the expectancy of rains in each season, the percentage of the rain that falls in light and in heavy showers and the fraction likely to be available for plant growth. In short, the rainfall intensity is one of the most important parameter in hydrology and is of critical importance in planning and design of hydrologic projects.

The duration for which rainfall intensity lasts at a particular rate is also important in hydrologic studies. The intensity is an important characteristic of rainfall because, other things being equal, more runoff and hence more soil erosion is caused by one rainstorm of high intensity than by several storms of low intensity. The rainfall depths derived from the intensity duration frequency relationship and trend analysis is being used to benefit water resource planning and management decisions (Karl *et al.*, 1995; Angel and Huff, 1997; Guo, 2006; Elsebaie, 2012; Dourte *et al.,* 2013; Zope *et al.,* 2016; Kumar and Singh, 2016; Dabral *et al.,* 2016). By analyzing past rainfall events, statistics about rainfall re–occurrence can be determined for various standard return periods, typically 2, 5, 10, 25, 50 and 100 year return periods are shown on IDF curves. Dupont and Allen (2000) defined rainfall IDF relationship as graphical representation of the amount of water that falls within a given period of time. These graphs are used to determine when an area will be flooded and when a certain rainfall rate or a specified volume of flow will re–occur in future. In Rational formula for estimation of peak rate of runoff, the factor 'I', which is defined as maximum rainfall intensity for duration at least equal to time of concentration and for a specified recurrence interval, is also derived from IDF analysis.

Shivalik foot−hills which are locally known as *Kandi* area is one of the eight most degraded zones of the country. The area comprises of denuded steep slopes having light soils. High intensity and short durations storms are very common in the area that result into high runoff (35–45%), soil erosion and flash floods in the downstream areas. Many watershed management programmes are in operation in the region and huge sum of money is being spent to take up conservation measures to tackle the problem. However, IDF curves which are essential for designing the capacity of conservation structures are not available for this region. Accurate estimates of maximum rainfall intensities for different durations and return periods should therefore be readily available to design conservation structures in the area. Keeping in view of the rationale, the study was conducted to develop the rainfall IDF curves for Ballowal Saunkhri, district Shaheed Bhagat Singh Nagar in *Shiwalik* foot−hills.

2. MATERIALS AND METHODS

A study was undertaken at the Department of Soil and Water Engineering, Punjab Agricultural University (PAU), Ludhiana to develop the IDF curves for the *Shivalik* foot−hills. The daily rain gauge charts for the period from the year 2000 to 2010 *i.e.* 11 years were collected from the PAU−Regional Research Station for *Kandi* area, Ballowal Saunkhri located at latitude 31°06'05"N and longitude 76°23'26"E at an altitude of 355 m. The rain gauge charts were analyzed to get rainfall depth for different durations, daily rainfall depth and rainfall intensities for different durations.

The standard methodology was followed to determine the intensity of rainfall occurring for any selected time interval. The rainfall intensity was determined by plotting the graphs of cumulative rainfall (mm) *vs* cumulative time (minutes). Cumulative curves for rainfall and time were plotted for each storm for the study period. The mass curves were obtained which have different slopes depending upon the intensity of rainfall during the duration of the storm. The values of maximum rainfall intensity (mm hr^{-1}) for duration of 15, 30, 45 and 60 min during each storm were computed by selecting maximum slope of the curve for the selected durations. The maximum rainfall intensity was computed using the following relationship:

$$I_t = \frac{R_2 - R_1}{T_2 - T_1} X\ 60 \qquad ...(1)$$

Where, I_t = maximum rainfall intensity (mm hr^{-1}) for duration of t minutes, R_2 = final rainfall (mm), R_1 = initial rainfall (mm), T_2 = final time (minutes), T_1 = initial time (minutes), and t = 15, 30, 45 and 60 min = ($T_2 - T_1$) min.

Rainfall intensity values for durations 15, 30, 45 and 60 min durations for all the storms occurred during each year for the study period were obtained / computed and tabulated. From these tabulated values, maximum 15, 30, 45 and 60 min rainfall intensities designated as I_{15}, I_{30}, I_{45} and I_{60} were selected. Hence, one value each of I_{15}, I_{30}, I_{45} and I_{60} was available for every year, which constituted annual time series.

In this study, the annual series, *i.e.* the maximum rainfall intensity for 15, 30, 45 and 60 min duration for each year was selected for the analysis. Thus, for 11 years, 11 values for each time duration were analyzed. While selecting the data, care was taken that the values must satisfy two important criteria namely:

(i) that the events be independent of a previous or subsequent event.

(ii) that the data for the period of record for analysis must be the representative of the long time period.

Maximum rainfall IDF analysis seeks to define the events with a probability of being equalled or exceeded in any year. Weibull's equation (1951) for plotting position was used in the study to determine the probability (P) and return period (T_r).

The data series were obtained as annual maximum rainfall intensity series using the methodology suggested by Subramanya, 1984; Okonkwo and Mbajiorgu, 2010.

3. RESULTS AND DISCUSSION

The results showed the IDF curves developed for the study area.

Rainfall Depth and Number of Rainy Days

The annual rainfall depth and number of rainy days that has occurred at Ballowal Saunkhri during the years 2000−2010, is shown in Fig. 1. The mean annual rainfall during the study period was 779.9 mm, out which 54% occurred during the monsoon season (July to September) and 46% during rest of year. The annual rainfall varied from 564.9−1409.2 mm for the study period. The mean annual number of rainy days were 65, out of which 43% occurred during the monsoon season and 57% during the rest of year. The total number of rainy days varied from as low as 50 to as high as 75 (Fig. 1).

Maximum Rainfall Intensity

The data have been analyzed as an annual series consisting of maximum rainfall intensity for various duration of 15, 30, 45 and 60 min for each year from the year 2000 to 2010. The observed maximum and mean values of maximum rainfall intensities for different durations are shown in the Fig's 2 and 3. The observed maximum rainfall intensity varied from 70 mm hr^{-1} to 160 mm hr^{-1} for 15 min, 33.4 mm hr^{-1} to 130 mm hr^{-1} for 30 min, 22.7 mm hr^{-1} to 117.34 mm hr^{-1} for 45 min and 19.5 mm hr^{-1} to 108 mm hr^{-1} for 60 min duration (Fig. 2). The mean maximum rainfall intensities for 15, 30, 45 and 60 min were recorded to be 94.47, 76.30, 64.56 and 55.54 mm hr^{-1}, respectively during the period 2000−10 (Fig. 3).

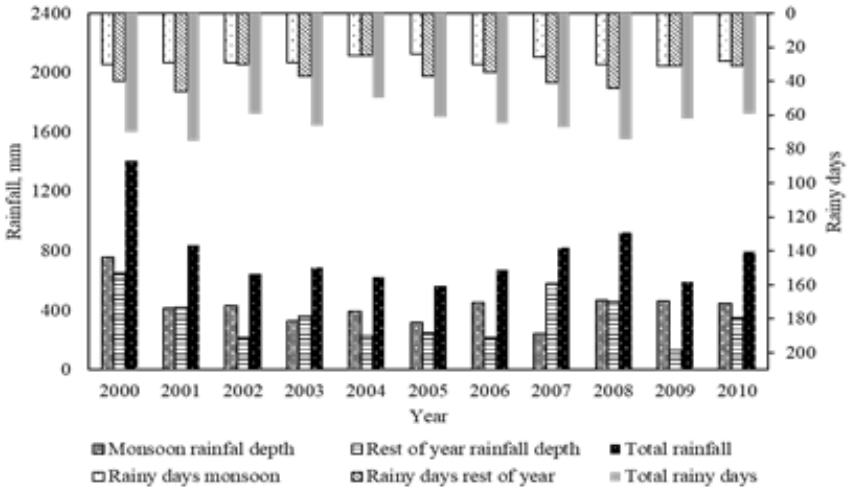

Fig. 1. Annual rainfall depth and number of rainy days at Ballowal Saunkhri, district SBS Nagar (2000−2010)

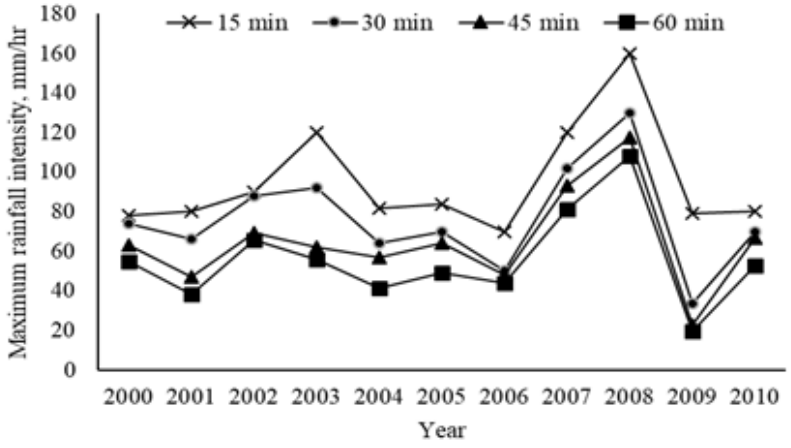

Fig. 2. Observed maximum rainfall intensities for 15, 30, 45, 60 min durations at Ballowal Saunkhri, district SBS Nagar (2000−2010)

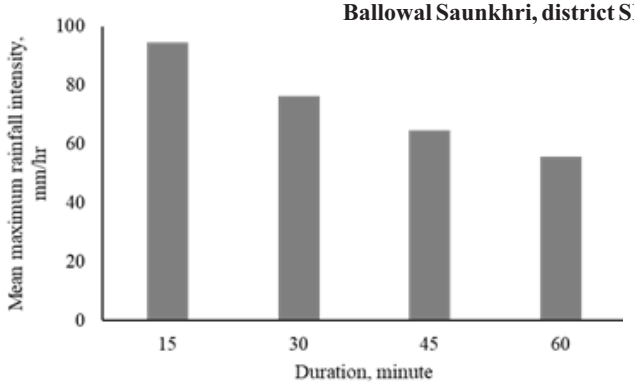

Fig. 3. Mean maximum rainfall intensities for various durations at Ballowal Saunkhri, district SBS Nagar (2000−2010)

It is evident from the Fig's 2 and 3 that rainfall intensity decreases with the increase in duration *i.e.* shorter the duration, higher is the maximum rainfall intensity. That means rainfall intensity is inversely proportional to the duration of the storm. This corroborates the fact that high intensity rainstorms last for short duration.

IDF Analysis

The plotting positions using the Weibull's formula have been calculated and the results have been summarized and shown in Fig. 4. The regression analysis was carried out and the following equations in the form of linear models for different durations were obtained:

(i) For duration D = 15 min

$I_{15} = 34.88 \ln(T) + 62.90$; $R^2 = 0.925$ ...(2)

(ii) For duration D = 30 min

$I_{30} = 33.22 \ln(T) + 46.90$; $R^2 = 0.933$ ...(3)

(iii) For duration D = 45 min

$I_{45} = 30.71 \ln(T) + 36.79$; $R^2 = 0.900$ ...(4)

(iv) For duration D = 60 min

$I_{60} = 34.41 \ln(T) + 28.33$; $R^2 = 0.946$ ...(5)

Where, I_{max} = Maximum rainfall intensity, mm hr^{-1}, and T = Return period, years.

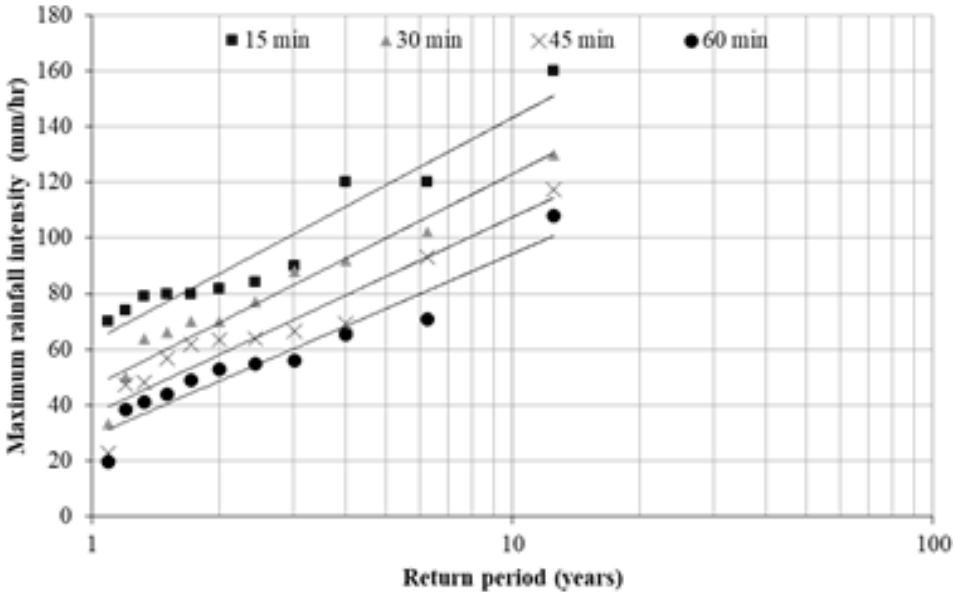

Fig. 4. Maximum rainfall intensity−frequency curve for 15, 30, 45 and 60 min duration

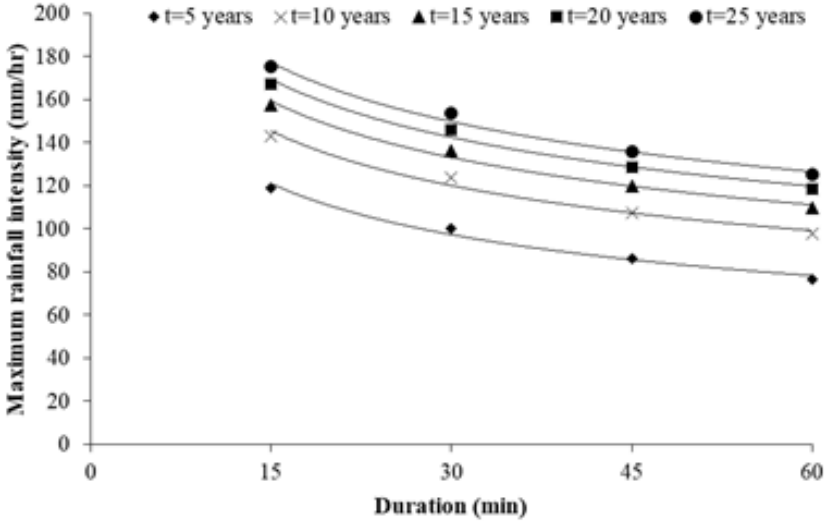

Fig. 5. Maximum rainfall−intensity−duration−frequency curves for *Kandi* area

The value of coefficient of determination (R^2) in case of these regressed linear models varies between 0.90 to 0.95. It is maximum for the equation regressed for duration of 60 minutes and minimum for duration of 45 min. High values of r (0.90−0.95) indicate good correlation between maximum rainfall intensity and the return period.

IDF Curves

The maximum rainfall IDF curves were developed using the linear regression models and Weibull's plotting positions and are shown in Fig. 5. The developed curves indicate that the intensity of storm decrease with the increase in storm duration. Further, a storm of any given duration will have a larger intensity if its return period is large *i.e.* for a storm of given duration, storms of higher intensity in that duration are rarer than storms of smaller intensity. The IDF curve is shown in Fig. 5. The equations obtained through the regression analysis for different return periods are of the following form:

(i) For return period T = 5 years

$$I_{max} = 283.7D^{-0.31} \qquad R^2 = 0.982 \qquad ...(6)$$

(ii) For return period T = 10 years

$$I_{max} = 306.3D^{-0.27} \qquad R^2 = 0.986 \qquad ...(7)$$

(iii) For return period T = 15 years

$$I_{max} = 322.1D^{-0.26} \qquad R^2 = 0.984 \qquad ...(8)$$

(iv) For return period T = 20 years

$$I_{max} = 333.6D^{-0.25} \qquad R^2 = 0.984 \qquad ...(9)$$

(v) For return period T = 25 years

$$I_{max} = 342.7D^{-0.24} \qquad R^2 = 0.984 \qquad ...(10)$$

Where, I_{max} = Maximum rainfall intensity, mm hr^{-1}, and D = Duration, minutes.

High values of coefficient of determination (R^2 = 0.982 −0.986) indicate that the above regression power models represent well the relationship between the maximum rainfall intensity and duration for different recurrence intervals. The maximum rainfall intensity values for selected duration and recurrence intervals for *Kandi* area have also been tabulated (Table 1). The maximum rainfall intensity having probabilities of occurrences of 20%, 10%, 6.67%, 5% and 4% have been found to vary from 122.5 mm hr^{-1}, 147.5 mm hr^{-1}, 159.3 mm hr^{-1}, 169.5 mm hr^{-1} and 178.9 mm hr^{-1} for a duration of 15 min 79.7 mm hr^{-1}, 101.4 mm hr^{-1}, 111.0 mm hr^{-1}, 119.8 mm hr^{-1} and 128.3 mm hr^{-1} for 60 min duration, with return period of T = 5 yrs, 10 yrs, 15 yrs, 20 yrs and 25 yrs, respectively.

4. CONCLUSIONS

The IDF curves were developed from the plotting position using Weibull's formula, and the regression models were developed. The following specific conclusions have been drawn:

(i) The maximum rainfall IDF curves for Ballowal Saunkhri in Shivalik foot−hills have been developed.

(ii) The maximum rainfall intensities for 15 min, 30 min, 45 min and 60 min duration for 5 yrs, 10 yrs, 15 yrs, 20 yrs and 25 yrs return periods were found to be 122.5 mm hr^{-1} to 178.9 mm hr^{-1} for 15 min, 98.8 mm hr^{-1} to 151.5 mm hr^{-1} for 30 min, 87.16 mm hr^{-1} to 137.4 mm hr^{-1} for 45 min and 79.7 mm hr^{-1} to 128.3 mm hr^{-1} for 60 min duration.

The coefficient of determination (R^2) varies between 0.90 to 0.95 which showed good relation between maximum rainfall intensity and the return period.

Table 1: Maximum rainfall intensity for various durations and recurrence intervals for Ballowal Saunkhri

Recurrence interval, T (years)	Maximum rainfall frequency intensity (mm hr^{-1})			
	15 min	30 min	45 min	60 min
5	122.5	98.8	87.2	79.7
10	147.5	122.3	109.5	101.4
15	159.3	133.0	119.7	111.0
20	169.5	142.5	128.8	119.8
25	178.9	151.5	137.4	128.3

REFERENCES

Angel, J.R. and Huff, H.A. 1997. Changes in heavy rainfall in the mid−western United States. *J. Water Resour. Plann. Manage*., 123(4): 246–249.

Dabral, P.P., Choudhury, K. and Debbarma, S. 2016. Probability analysis of 5−day antecedent rainfall at different return periods and seasons for Doimukh (Itanagar), Arunachal Pradesh. *Indian J. Soil Cons.,* 44(3): 332−335.

Dourte, D., Shukla, S., Singh, P. and Haman, D. 2012. Rainfall intensity−duration−frequency relationships for Andhra Pradesh, India: Changing rainfall patterns and implications for runoff and groundwater recharge. *J. Hydrol. Eng.*, 18(3): 324–330.

Dupont, B.S. and Allen, D.L. 2000. Revision of the rainfall intensity duration curves for the commonwealth of Kentucky. Kentucky Transportation Centre, College of Engineering, University of Kentucky, Lexington.

Elsebaie, I.H. 2012. Developing rainfall intensity–duration–frequency relationship for two regions in Saudi Arabia. *J. King Saudi University–Engg. Sci.*, 24(2): 131−140.

Guo, Y. 2006. Updating rainfall IDF relationships to maintain urban drainage design standards. *J. Hydrol. Eng.,* 11(5): 506–509.

Karl, T.R., Knight, R.W. and Plummer, N. 1995. Trends in high−frequency climate variability in the twentieth century. *Nature,* 377(6546): 217–220.

Okonkwo, G.I. and Mbajiorgu, C.C. 2010. Rainfall intensity−duration−frequency analysis for south−eastern Nigeria. *Agric. Engg. Int. CIGR J.,* 12(1): 22−30.

Singh, S. and Kumar, S. 2016. Trend analysis of rainfall of Sagar district, Madhya Pradesh. *Indian J. Soil Cons.,* 44(1): 44−49.

Subramanya, K. 1984. Engineering hydrology. Tata McGraw−Hill Inc, New Delhi, pp 40−45.

Weibull, W. 1951. A statistical distribution function of wide applicability. *J. Appl. Mech.,* 18: 293–297.

Zope, P.E., Eldho, T.I. and Jothiprakash, V. 2016. Development of rainfall intensity duration frequency curves for Mumbai city, India. *J. Water Resour. Prot.,* 8: 756−765.