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Effect of discretisation on extreme rainfall analysis : A study of Jaipur city in India

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सार – वर्तमान अध्ययन में घंटावार वर्षा अभिलेखों का उपयोग करके अत्यधिक वर्षा के अनुमानों में विविक्तीकरण के प्रभाव कास्थान-आधारित मूल्यांकन किया गया है। इस विश्लेषण का उद्देश्य भारत के मेट्रो शहर, राजस्थान के जयपुर के लिए वर्षा संशोधन गुणक (RCF) का पता लगाने के लिए संशोधन मॉडल विकसित करना है। इसके अलावा, इस अध्ययन में पृथक-समय अंतराल में दर्ज की गई अत्यधिक वर्षा पर प्रति घंटे संशोधन गुणक (CHCF) के प्रभाव को दर्शाया गया और इसकी तुलना आईएस 5542:2003 द्वारा सुझाए गए संबंधित मान से की गई। सीएचसीएफ की गणना वार्षिक मैक्सिमा श्रृंखला (AMS) और पीक-ओवर-थ्रेशोल्ड (POT) दृष्टिकोणों का उपयोग करके वर्षा मूल्यों को प्राप्त करने के लिए की गई। 24 घंटे में अधिकतम वर्षा की गहराई के लिए स्लाइडिंग विंडो (SW) समुच्चय और फिक्स्ड विंडो (FW) प्रेक्षण का उपयोग करके मूल्यांकन किए गए चरम मानों में अंतर का मूल्यांकन करने के लिए प्रति घंटा वर्षा माप का उपयोग किया गया। चरम मानों का विश्लेषण किया गया और इसकी विश्वसनीयता के लिए मॉडल की जांच की गई। 24 घंटे और 1 घंटे की अवधि में हुई अत्यधिक वर्षा की गहराई को गहराई-अवधि-आवृत्ति वक्र पर प्लॉट किया गया। बाढ़ अनुमान रिपोर्ट (उप-क्षेत्र 1 बी) में दिए गए रूपांतरण गुणक का उपयोग करके 1 घंटे की अवधि की अधिकतम वर्षा की गणना 25-, 50- और 100-वर्षों की प्रत्यागमन अवधि के लिए की गई और वर्तमान अध्ययन के परिणामों से इसकी तुलना की गई। 1 घंटे और 24 घंटे की अवधि में अलग-अलग प्रत्यागमन काल में हुई अत्यधिक वर्षा पर काम किया गया, जो केंद्रीय सार्वजनिक स्वास्थ्य और पर्यावरण इंजीनियरिंग संगठन (CPHEEO, 2019) के नए दिशानिर्देशों के अनुसार डिजाइन तैयार करने में सहायक होगा।

ABSTRACT. A location-based evaluation of the effect of discretisation on extreme rainfall estimates has been reported in the current study using hourly rainfall records. This analysis aims to develop correction model to find rainfall correction factor (RCF) for the metro city, Jaipur, in Rajasthan, India. Further, the study addressed the effect of the clock hour correction factor (CHCF) on extreme rainfall recorded in the discrete-time interval and compared it with the corresponding value suggested by IS 5542:2003. The CHCF was computed using annual maxima series (AMS) and peak-over-threshold (POT) approaches in deriving the rainfall values. The hourly rainfall measurement was used to evaluate the differences in extremes evaluated using sliding window (SW) aggregation and fixed window (FW) observation for 24-hour maximum rainfall depth. The extreme value analysis was performed and the model was checked for its reliability. The peak rainfall depth-duration-frequency curve was plotted for observed 24-hr and 1-hr duration peak rainfall depth. The 1-hour duration peak rainfall was computed for 25-, 50- and 100-year return periods using the conversion factor given in the Flood estimation report (sub-zone 1b)and compared with the results of the current study. The peak rainfall for the different return periods for 1-hour and 24-hour duration was worked out, which will be helpful to the design engineer as per the recent guidelines of the Central Public Health and Environmental Engineering Organization (CPHEEO, 2019).

Key words – Extreme rainfall, Fixed window maxima, Sliding window maxima, RCF, CHCF, Extreme value analysis, Jaipur city.

1. Introduction

A reliable evaluation of hydrological extremes is crucial for the efficient planning and design of hydraulic structures. The extreme value theory provides a firm theoretical foundation for the statistical modelling of extreme hydrological events (Tabari, 2020). The extreme rainfall analysis without considering temporal aggregation may lead to under estimation (over estimation) of the peak discharge leading to infrastructure failures (increased infrastructure cost) (Papalexiou and Koutsoyiannis, 2013). The temporal aggregation of rainfall plays a significant role in estimating rainfall and, subsequently, developing peak intensity-duration-frequency (IDF) curves. For larger temporal aggregations, the error in the single rainfall value and a series of rainfall values can reach up to 50% and 17%, respectively (Morbidelli *et al*., 2017).

The extreme rainfall analysis using statistical distributions reported in the past studies, the effects of various extreme distributions and threshold selection remain unclear on a global scale (Madsen *et al*., 1997; Martins and Stedinger, 2000; Choulakian and Stephens, 2001; Solari *et al*., 2017; Wang *et al*., 2020) Recently, the extreme rainfall analysis over India using probabilistic methods is suggested by, the Central Public Health and Environmental Engineering Organization (CPHEEO, 2019) for the design of drainage system network.

The error due to discretisation/aggregation needs to be considered in the accurate assessment of extreme rainfall, The observed rainfall was often recorded in the discrete-time interval, leading to under estimating the design rainfall. The error of discretisation could be overcome using the clock hour correction factor (CHCF), which is the ratio of sliding window maxima (SW) to fixed window maxima (FW) of annual maximum rainfall. In India, the IS 5542 : 2003 recommends the CHCF as 1.15 uniform over the entire Indian region to convert 1-day observed maximum rainfall to the 24-hour true accumulation of rainfall. India is a country with an immense variation of rainfall at different locations with diverse climate regimes across the country (Attri and Tyagi, 2010). Llabrés-Brustenga *et al*. (2020) found that a single value of CHCF is commonly applied without considering the rainfall pattern (neither regional nor seasonal consideration) and resulted in the error in the computation of peak rainfall. Hence, it is always essential to study the location-based CHCF.

The investigation on CHCF was first carried out by Hershfield and Wilson (1957) as H-factor (1.13) for the Eastern United States of America. Later, the probabilistic model was developed assuming uniform rainfall over a period and reported the conversion factor (CF) as 1.143 (Weiss, 1964). Van Montfort (1990) reported CF as 1.137 for New Zealand using daily rainfall data. Dwyer and Reed (1994) reported CF for the United Kingdom using daily or hourly rainfall data was 1.167. However, the CF values of 1.16, 1.11, 1.035, 1.005 for 1, 2, 5 and 10-days respectively were worked out by Fowler *et al*. (2005) for the United Kingdom.

Young and McEnroe (2003) reported sampling adjustment factor (SAF) for the Kansas City area, United States of America and established the empirical relationship to convert FW maxima into SW maxima. In the recent past, the correction is suggested in the Weiss model by investigating the various temporal distribution of rainfall and its effect on the CF of rainfall by Yoo *et al*. (2015).

In India, the first study on CHCF was reported by Dhar and Ramachandran (1970). Later, the research was carried over the entire Indian region and on different parts of the country by Ayyar and Tripathi (1973); Deshpande (2010), PMP Atlas for the Ganga River basin including Yamuna (2015); Dauji (2019). To the best of the authors' knowledge, the study on the statistical modelling of extreme rainfall and the effect of CHCF was not reported for Jaipur city, India in recent past.

Keeping in view of the importance of the extreme rainfall analysis in the hydrologic design, the present study is carried out to fulfill the following objectives:

(*i*) To evaluate the performance of Generalised Extreme Value (GEV) distribution and Generalised Pareto Distribution (GPD) using hourly rainfall data of Jaipur City. (*ii*) To develop a Rainfall Correction Factor (RCF) model for the Jaipur city rain gauge station which can be useful to convert 1-day (1-hour) observed maximum rainfall depth to 24-hour (60-minute) actual accumulation of rainfall, (*iii*) To evaluate the CHCF for the present study using the Annual maxima series (AMS) and Peak-over-threshold (POT) approach and (*iv*) To estimate the effect of CHCF on extreme rainfall for various return periods with the most suitable statistical distribution for Jaipur city, India.

The CHCF derived in the present study is useful to the design engineers in designing and evaluating storm water drainage systems of Jaipur city, India. Further, the study's methodology to evaluate the effect of discretisation on extreme rainfall is generic and can be useful in the other part of India.

2. Study area

In the foothills of the Aravalli range, Jaipur city is surrounded by Jhalna hills in the east and Nahargarh in the north between latitude 26° 46' N to 27° 01' N and longitude 75° 37' E to 76°57' E. The Jaipur is the capital and the largest city in Rajasthan state, making it the 10th most populous city in the country (Census, 2011). The location map of the study area is presented in Fig. 1. The Ban Ganga and the Sabi rivers are the main rivers flowing through the city. The ephemeral streams flow from north

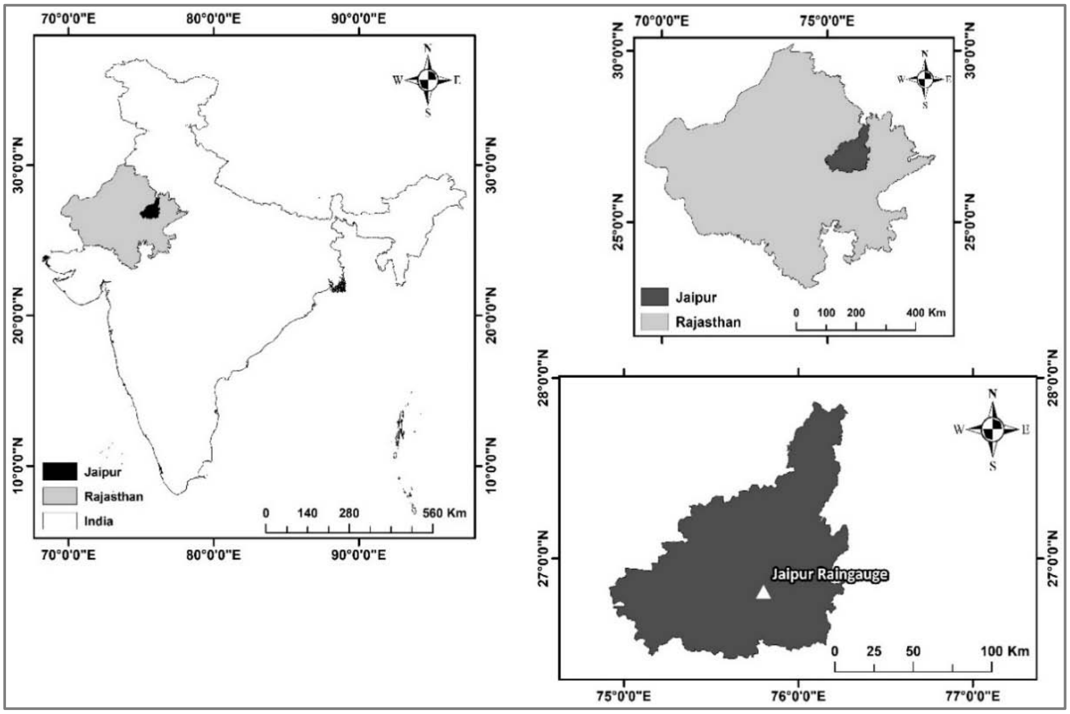


Fig. 1. Location map of the study area

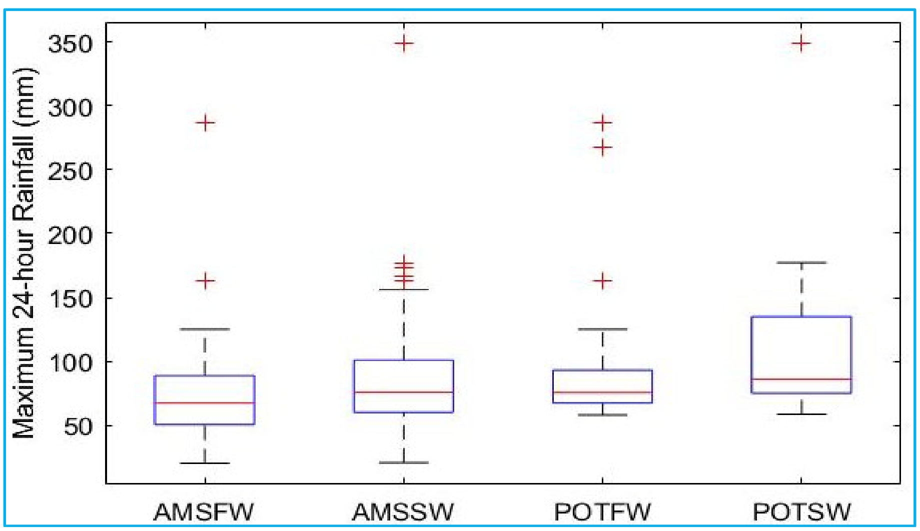


Fig. 2. Box whisker plot of the AMS and POT series

to south and afterwards to the south-east of the city. The city belongs to the semi-arid zone of India with high temperature, low precipitation and mellow winter. The Jaipur city's mean temperature is 36 °C varying from 18 °C in winter (January as the coldest month) to 40 °C in summer (June as the hottest month). The elevation of the city is about 390 m above mean sea level. The north-west monsoon showers contribute to the normal rainfall of the city as 600 mm. (JMC-Greater, http://jaipurmc.org/Jp_HomePagemain.aspx).

3. Data collection and analysis

3.1. *Data*

The self-recording rain gauge (SRRG) data with a temporal resolution of 1-hour was available from the India Meteorological Department (IMD) Pune, India. The rainfall data from the year 1970 to 2013 of Jaipur city rain gauge station having latitude 26°48' N and longitude 75°48' E was collected from IMD, Pune. The

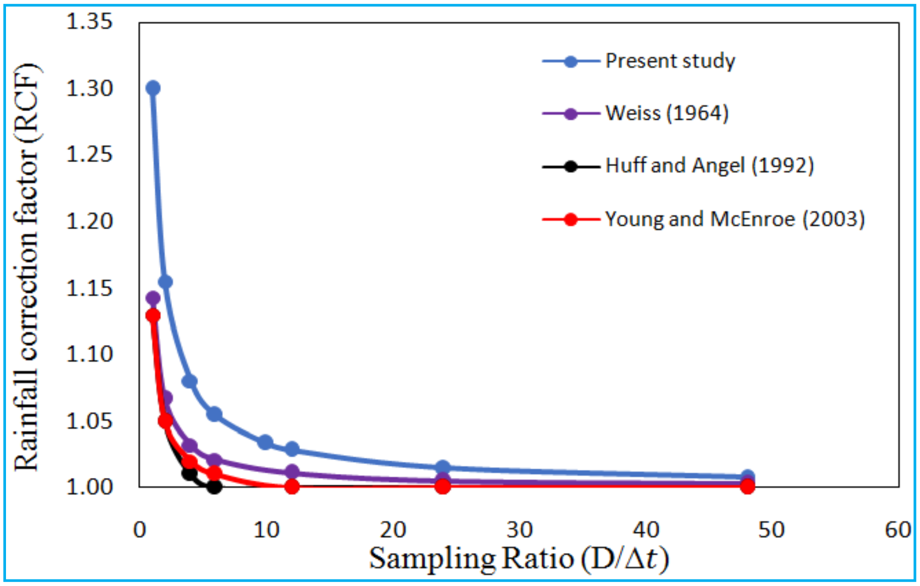


Fig. 3. RCF model developed in the present study and comparison with previous studies

obtained data was checked for its completeness and missing value analysis was performed as mentioned in the literature (Papalexiou *et al.*, 2016). The data for the years 1972, 1996, 2008 and 2011 are missing from the available data record, hence skipped from the analysis. The AMS and POT data series' descriptive statistics are presented at box whisker plots in Fig. 2. Further, details of the data variability, including high and low outliers, are included in section 4.

The two prevailing approaches for modelling extreme events are adopted, such as the AMS and POT. In the prior case, the maximum value from each calendar year was selected for statistical analysis; while the threshold of 58 mm was selected such that the value in the series was equal to the number of years of the record. The method for selection of threshold value for POT is described in Chow *et al.* (1988). The non-parametric Sen's innovative trend analysis (Sen, 2012; Dabanl *et al.*, 2016) and Modified Mann-Kendall (MMK) test (Hamed and Rao, 1998) were performed to check the trend of extremes over the region on the AMS and POT rainfall series.

3.2. *Development of RCF model*

The RCF was computed as per the methodology given in Young and McEnroe (2003). The aggregation of the rainfall data from 2-48 hours was carried out. The sampling ratio (ratio of the duration of interest, D to the observation time step, Δt was selected and RCF was computed. The computed empirical relationship aims to convert the 1-day (1-hour) observed maximum rainfall to 24-hour (60-minute) true accumulation rainfall.

3.3. *Statistical models for extreme rainfall*

Based on the extreme value theory, the AMS can be modelled by the Gumbel, Fréchet or Weibull distribution (Coles, 2001; Wang *et al.*, 2020). The family of distributions can be combined into a single parametric distribution of GEV.

$$G(z) = \exp\left\{-\left[1 + k\left(\frac{z-\mu}{\sigma}\right)\right]^{-1/k}\right\} \quad (1)$$

The Eqn. (1) describes the GEV modelas a three parameters distribution with a location parameter (μ), a scale parameter (σ) and a shape parameter (k). The shape parameter, $k = 0$, $k > 0$ and $k < 0$ correspond to Gumbel, Fréchet and Weibull, respectively (Coles, 2001).

The GPD was proposed by Pickands (1975) and adopted to model the POT data series with exceedances over a threshold. In many hydrological studies, GPD was fitted for gridded data using POT approach (Solari *et al.*, 2017; Tabari, 2020). For a selected threshold (u) the distribution function of (y-u), conditional on y>u, is approximately.

$$H(y) = 1 - \left(1 + \frac{ky}{\sigma}\right)^{-1/k} \quad (2)$$

TABLE 1

Comparison of RCF computed and reported in the literature

$\frac{D}{\Delta t}$	RCF Present study	Weiss (1964)	Huff and Angel (1992)	Young and McEnroe (2003)
1	1.30	1.143	1.13	1.13
2	1.16	1.067	1.05	1.05
4	1.08	1.032	1.01	1.02
6	1.05	1.021	1	1.01
12	1.03	1.011	1	1
24	1.01	1.005	1	1
48	1.01	1.003	1	1

The parameters of the GPD are same as GEV. If $k < 0$ the distribution of excesses has an upper bound of $u - \sigma / k$; if $k > 0$ the distribution has no upper bound and the distribution is unbounded if $k = 0$ (Coles, 2001). The method of maximum likelihood (MLE) gives the most efficient parameter estimates (Martins and Stedinger, 2000) and is adopted in the present study to fit GEV distribution and GPD. The reader can refer to Coles, (2001) for a detailed explanation of the distributions and MLE.

3.4. *Goodness of fit (GoF) test*

The extremes for various return periods were computed and compared. The Anderson-Darling (A-D) test (Abidin and Adam, 2014) and the Kolmogorov-Smirnov (K-S) test (Wang *et al.*, 2020) were used to verify the GoF of the fitted distribution. The fitted distribution model was tested using a probability plot, quantile plot and return level plot.

4. Results and discussion

4.1. *Development of RCF model*

As mentioned earlier, the rainfall data's temporal aggregation for durations of 3, 6, 12, 24 and 48-hour was carried out. The sampling ratio of 2, 4, 6, 8, 12, 24 and 48 was selected. The RCF was computed as per the methodology given by Young and McEnroe (2003). The sampling ratio wise RCF has been computed for Jaipur city and presented in the Fig. 3.

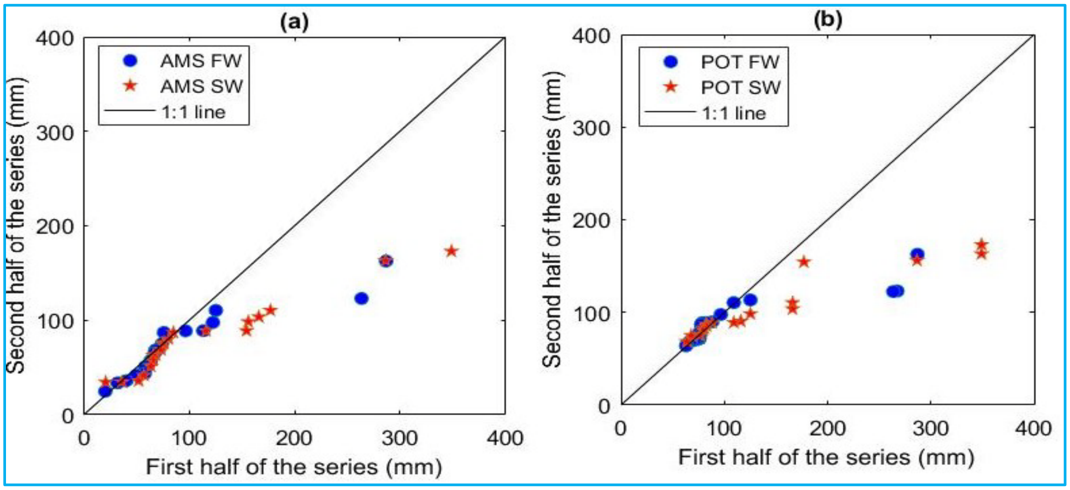
The empirical equation fitted to the present data and derived the relationship between sampling ratio and RCF as mentioned in Eqn. (3).

$$\mathrm{RCF} = 1 + 0.3\left(\frac{D}{\Delta t}\right)^{-0.95} \qquad (3)$$

The RCF computed in the present study is compared with the RCF of past studies. The comparison is tabulated in Table 1. The fitted relationship to the rainfall data of Jaipur city is useful in projecting the rainfall conversion factor to convert 1-day (1-hour) to 24-hour (60-minute) true accumulation. The present analysis showing the RCF as 1.30 for sampling ratio 1. The studies reported in the literature on the CF for various sampling ratio $\left(\frac{D}{\Delta t}\right)$ to convert FW to SW maxima are mentioned in Table 1. The RCF model's performance cannot be evaluated using 1-minute rainfall data due to the non-availability of the meta-data at the finer time scale. The evaluation of the developed RCF model for Jaipur city, India at a finer time scale can be treated as the future scope of the present work.

4.2. *Non-parametric trend analysis*

The non-parametric trend analysis was performed on the AMS and POT data series to assess the trend of rainfall extremes over a region. The innovative trend analysis (Sen, 2012; Dabanl *et al.*, 2016) results for AMS (FW and SW) and POT (FW and SW) is shown in Figs. 4(a&b) respectively which reveals the non-monotonic decreasein the extreme rainfall events. The said observations on the decreasing trend of extreme rainfall at Jaipur city are in line with Pingale *et al.* (2014) study. Additionally, the MMK test (Hamed and Rao, 1998) is also performed to verify the trend of rainfall extremes AMS (FW and SW) and POT (FW and SW).



Figs. 4(a&b). Innovative trend analysis (a) AMS (FW and SW) and (b) POT (FW and SW)

TABLE 2

MMK trend test results for extreme rainfall for Jaipur city at 5% significance level

Extreme rainfall data	Kendall score (S)	Variance (S)	Z statistics	Nature of trend
AMS (FW)	-26	7366	-0.291	Non-significant decreasing
AMS (SW)	-29	7365	-0.326	Non-significant decreasing
POT (FW)	52	7366	0.594	Non-significant increasing
POT (SW)	-13.7	7361	-0.139	Non-significant decreasing

TABLE 3

Testing of outliers in the AMS and POT data

Outliers	AMS (FW)	AMS (SW)	POT (FW)	POT (SW)
High outlier (mm)	262	336	225	327
Low outlier (mm)	18	18	32	30

The MMK test results tabulated in Table 2 indicate the non-significant decreasing trend in extreme rainfall at Jaipur city at 5% significance level for AMS (FW and SW) and POT (SW) whereas, the POT (FW) is showing non-significant increasing trend.

4.3. *Testing of outliers*

The testing for outliers is performed on the data and tabulated in Table 3. The maximum values from the data series of the AMS (FW) and POT (FW) are 287 mm, for AMS (SW) and POT (SW) is 349 mm whereas the minimum values AMS (FW), AMS (SW), POT (FW) and POT (SW) are 20.3 mm, 20.7 mm, 58.3 mm and 58.9 mm respectively. The results have shown that the maximum values of AMS (FW) and POT (FW) were falling under the high outlier's category. The high outliers were not eliminated from the present analysis as these extreme events were occurred over the study area and verified from the PMP atlas for Ganga River basin including Yamuna (2015).

4.4. *Statistical modelling for extreme rainfall*

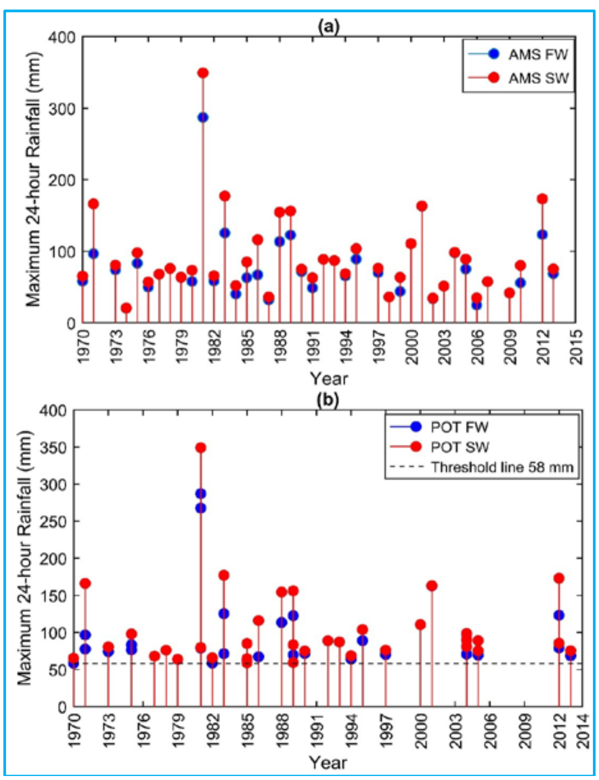
The extreme rainfall is analysed and modelled using GEV and GPD for AMS (FW and SW) and POT (FW and SW) and the result is explained in subsequent paragraphs.

TABLE 4

Comparative analysis of statistical parameters AMS (FW and SW), POT (FW and SW) and CHCF

Statistical parameters	AMS and POT (FW) extreme annual rainfall (mm)								AMS and POT (SW) extreme annual rainfall (mm)	
	CHCF = 1.00		CHCF = 1.167 (Deshpande 2010)		CHCF = 1.15 IS 5542:2003		CHCF (Obtained in the present study)			
							1.176	**1.212**		
Mean	76.5	**91.51**	89.3	**106.8**	88.0	**105.2**	90.0	**110.9**	148.17	**111.64**
Median	67.6	**75.6**	78.8	**88.2**	77.7	**86.9**	79.4	**91.6**	121.2	**86.25**
Standard Deviation	45.8	**48.69**	53.4	**56.8**	52.7	**56.0**	53.9	**59.0**	77.02	**66.36**
Minimum	20.3	**58.3**	23.7	**68.0**	23.3	**67.0**	23.9	**70.7**	55.8	**58.9**
Maximum	287.0	**287**	334.9	**334.9**	330.1	**330.1**	337.5	**347.8**	363.2	**349**
Coefficient of variation	0.6	**0.532**	0.7	**0.6**	0.7	**0.6**	0.7	**0.6**	0.520	**0.594**

Bold values represent POT values



Figs. 5(a&b). Annual maximum values (a) AMS (FW and SW) and (b) POT (FW and SW)

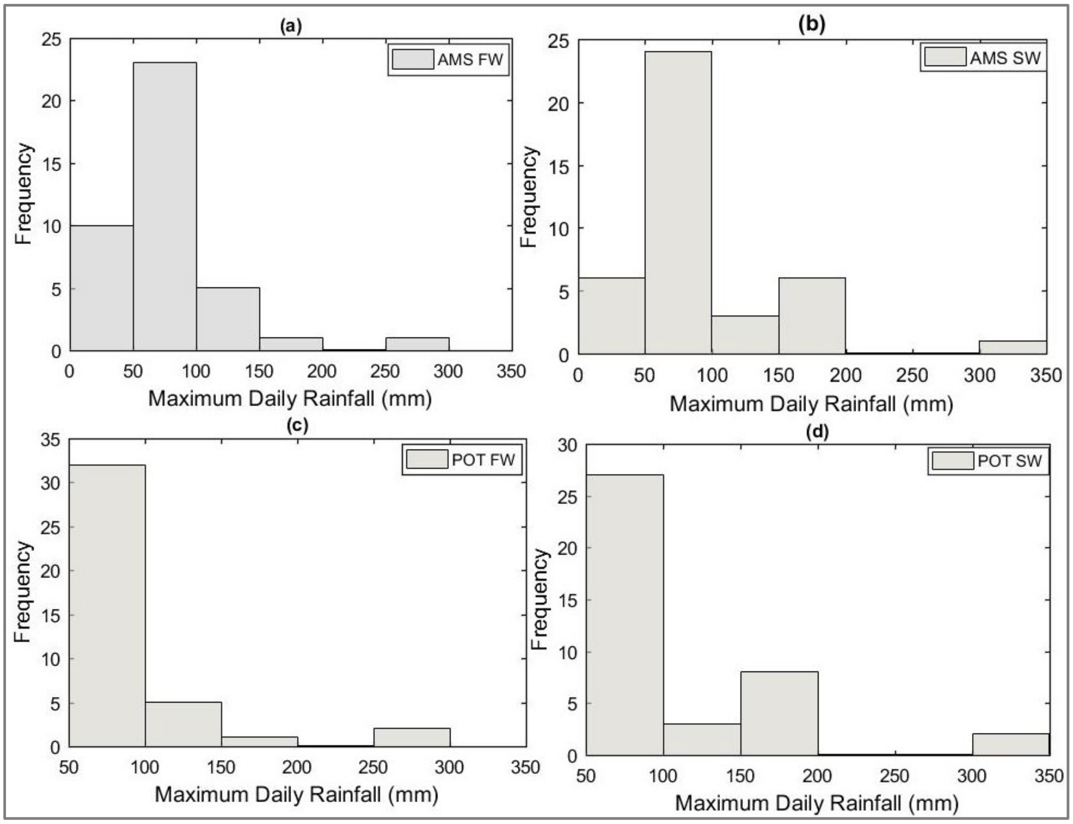
4.4.1. *Annual Maxima Series (AMS) and Peak-over-threshold (POT)*

In the AMS approach, the maximum value of each calendar year is considered. Fig. 5 (a) represents a graphical presentation of the Annual FW and SW maxima. The annual peak rainfall difference between FW and SW is due to the maximum value recorded with the discrete-time interval. In the POT series, one threshold is fixed and extremes above the fixed threshold are considered for analysis. The 24-hour maximum rainfall is selected such as the total values above the threshold should be equal to the number of years of the data record (*i.e.*, 40 values) as shown in Fig. 5 (b), above the threshold of 58 mm for POT (FW and SW) and considered for further analysis.

4.4.2. *Descriptive statistics and frequency histogram*

The statistical parameters of AMS and POT (FW and SW) are tabulated in Table 4. The CHCF computed for AMS and POT as1.176 and 1.212 respectively and compared with the CHCF reported in past studies and with SW maxima of AMS and POT. The maximum rainfall value is higher in AMS (SW) when compared with other values. The present analysis shows higher CHCF than the mean reported for the Indian subcontinent, 1.167 (Deshpande, 2010) and 1.15 recommended by IS 5542: 2003. The non-consideration of rainfall pattern at regional scale and seasonal scales (Llabrés-Brustenga *et al*., 2020) in the earlier studies for the area under consideration can be attributed as a reason for the higher values of CHCF and RCF for Jaipur city in the current study.

The effect of discretisation on the frequency of the extreme rainfall events is presented and the frequency histogram for AMS and POT data series is plotted and shown in Fig. 6. The difference in the FW and SW observation are visible in Figs. 6(a&b), the frequency



Figs 6(a-d). Frequency Histogram of (a)AMS (FW), (b) AMS (SW), (c) POT (FW) and (d) POT (SW)

of 300-350 mm rainfall is missed in AMS (FW). The extremes recorded in between intervals 150-200 mm are less in FW as compared to SW. The histogram shows that few events get excluded due to the fixed recording of the rainfall. The POT data series are represented in Figs. 6(c&d) it is observed that the frequency of 150-200 mm rainfall is less in FW than SW. The frequency of 300-350 mm is missed in FW, which is recorded in the SW histogram. Hence, The SW maxima series over the FW maxima series can be adopted for frequency analysis of extreme rainfall

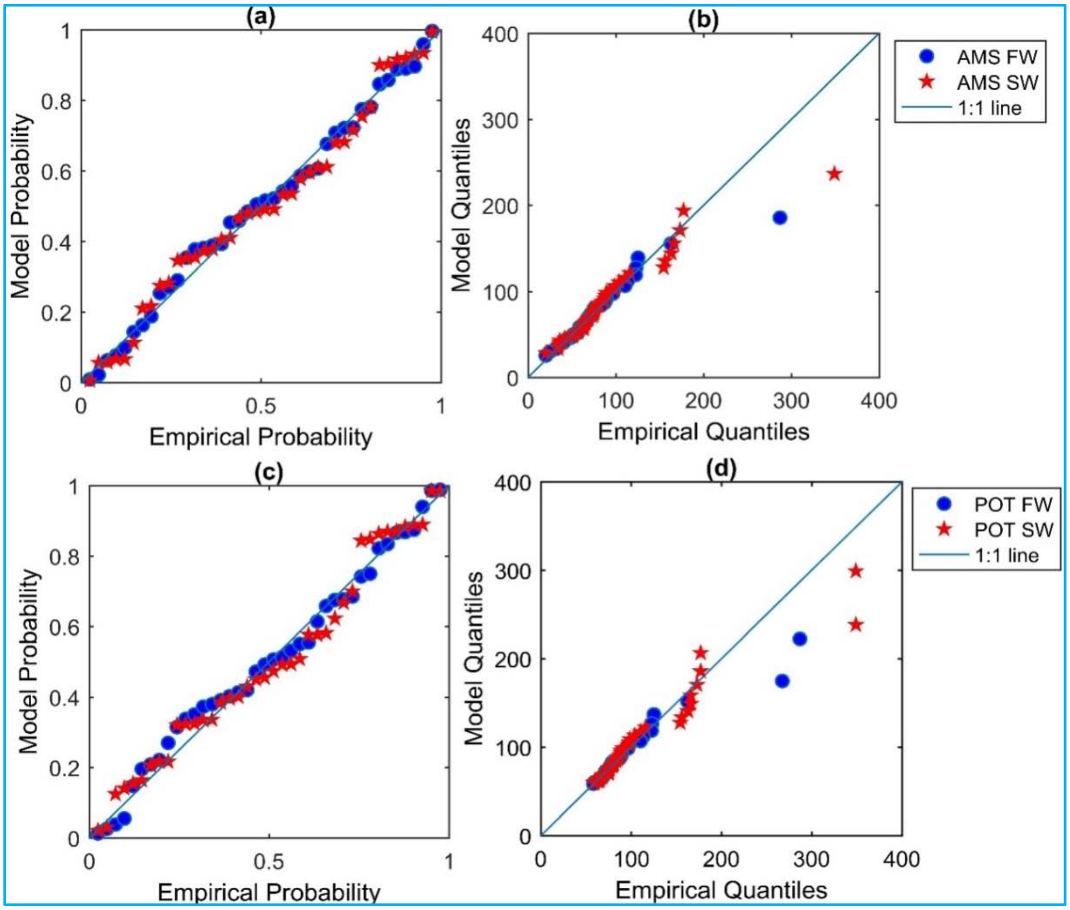
TABLE 5

Critical values for A-D test statistics for GEV distribution (Type II) at 0.05 significance level

A-D test		
Number of samples	k = 0.1	k = 0.2
40	0.5	0.474
50	0.496	0.472

4.4.3. *Statistical modelling of rainfall extremes and Goodness of fit*

The GEV distribution is fitted to the annual maximum rainfall data (1970-2013) for FW maxima and SW maxima. The parameters of the fitted distribution indicate that $k > 0$ and data is following the Type II distribution, *i.e*., Fréchet family of distribution. The goodness of fit test (GoF) is carried out for the distributions fitted; the Anderson-Darling (A-D) test and Kolmogorov-Smirnov (K-S) testis adopted for AMS. The AD test's critical value at the 5% significance level is represented in Table 5 for GEV Type II distribution (Abidin and Adam, 2014). The test statistics for AMS (FW) and AMS (SW) are 0.238 and 0.415 respectively and are below the critical value and hence the distribution is acceptable. The K-S test parameters (p and ksstat) at a 5% significance level used to determine the reliability of the data to the fitted probability distribution. If $p > 0.05$, it is inferred that the probability distribution is showing a better fit to the observed data series. The K-S test statistics (ksstat) value represents the maximum difference between two probabilities and thus the smaller value of ksstat indicates a better model fit (Wang *et al*., 2020). The ksstat for AMS (FW and SW) is 0.0789 and 0.0955 which shows the satisfactory fitting of the distribution.



Figs. 7(a-d). (a) Probability plots AMS (FW and SW), (b) Quantile plot AMS (FW and SW), (c) Probability plots POT (FW and SW) and (d) Quantile plot POT (FW and SW)

The parameters of the fitted distribution indicate POT (FW and SW) is following the Fréchet (Type-II) family of distribution as $k > 0$. The GoF for POT is evaluated using the A-D test, which is a modification of Cramer-von Mises (CM) test assigning more weightage to the observations in the tails of the distribution, which helps to detect outliers (Choulakian and Stephens, 2001). The critical values are mentioned in Table 6, reproduced from Stephens (1974). The A-D test statistics for POT (FW) and POT (SW) are 0.337 and 0.503 at 5% significance level indicates the distribution is acceptable.

4.4.4. *Reliability of the fitted model*

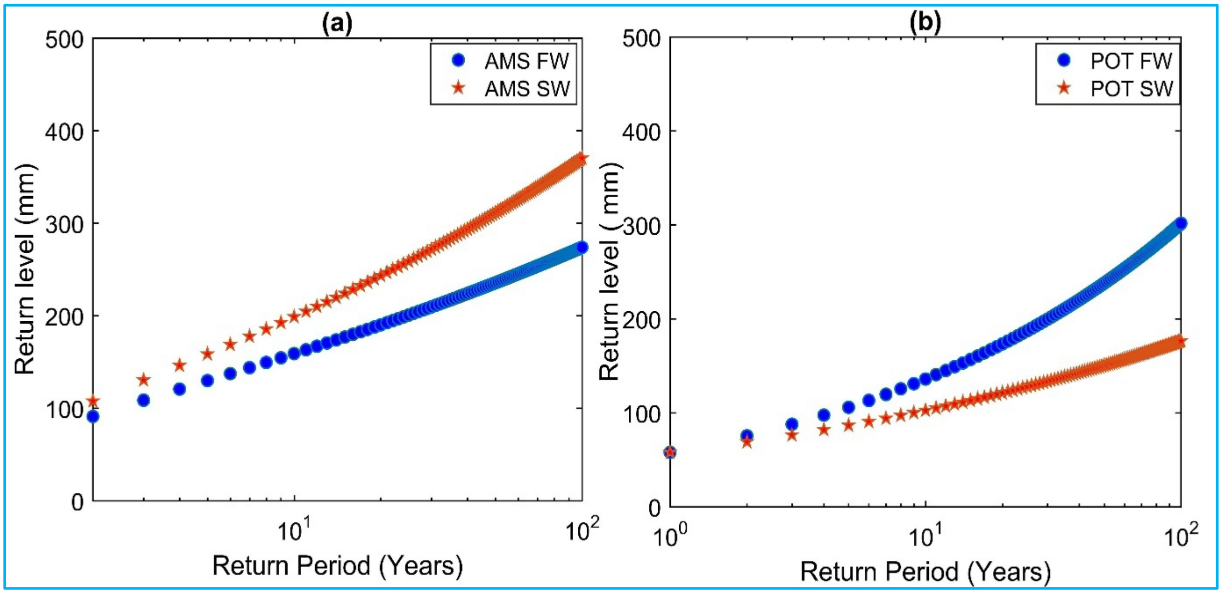
The fitted model is checked for its reliability using a probability plot, quantile plot and, return level plot. The Figs. 7(a-d) are showing the probability and quantile plot for AMS (FW and SW) and POT (FW and SW). In the quantile plot of AMS (FW and SW), the observed value of AMS (FW and SW) is 287 mm and 349 mm respectively and the model predicted value for the same is 186 mm and 237 mm respectively. In POT, the maximum empirical value of POT (FW and SW) is 287 mm and 349 mm respectively and the model projected value is 223 mm and 299 mm respectively. The quantile plot is showing deviation of a single event observed as 349 mm maximum rainfall depth in 24-hours in the year 1981.

TABLE 6

Critical values for A-D test statistics for GPD distribution

	Significance level				
Test statistics	0.15	0.10	0.05	0.025	0.01
A-D test	1.610	1.933	2.492	3.070	3.857

The model checking for return level for AMS (FW and SW) and POT (FW and SW) are plotted in Figs. 8 (a&b) respectively. As the $k > 0$, return level plots are concave with no finite bounds can be observed in the



Figs. 8(a&b). Return level plot (a) AMS (FW and SW) and (b) POT (FW and SW)

TABLE 7

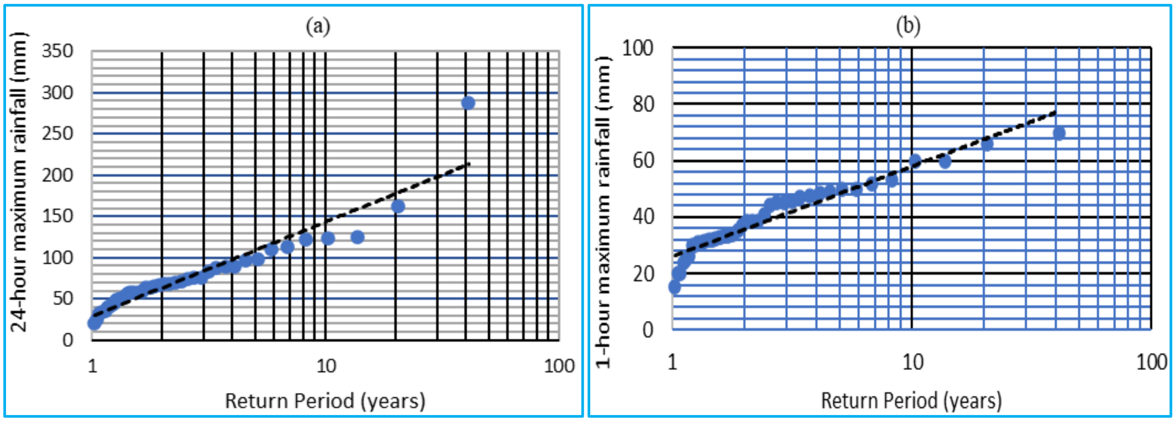
Extreme daily rainfall for various return periods (AMS)

Return Period (year)	AMS (FW) extreme annual rainfall (mm)					AMS (SW) Extreme rainfall (mm)
	CHCF 1.00	CHCF 1.167 (Deshpande 2010)	CHCF 1.15IS 5542-2003	CHCF 1.176 (Present study)	RCF Model 1.30 (Present study)	
2	66.7	77.8	76.7	78.4	86.7	76.9
5	100.8	117.6	115.9	118.5	131	120.1
10	126.7	147.8	145.7	149.0	164.7	154.4
25	163.7	191.0	188.2	192.5	212.8	205.5
50	194.6	227.1	223.8	228.8	253	249.9
100	228.6	266.7	262.8	268.8	297.1	300.3

TABLE 8

Extreme daily rainfall for various return periods (POT)

Return Period (Year)	POT (FW) extreme annual rainfall (mm)					POT (SW) Extreme rainfall (mm)
	CHCF 1.00	CHCF 1.167 (Deshpande, 2010)	CHCF 1.15IS 5542-2003	CHCF 1.212 (Present study)	RCF Model 1.30 (Present study)	
2	75.6	88.2	87.0	91.7	98.3	89.6
5	106.0	123.7	121.9	128.5	137.8	139.4
10	135.9	158.6	156.3	164.7	176.7	184.1
25	187.4	218.7	215.5	227.1	243.6	254.7
50	238.0	277.8	273.7	288.5	309.4	318.2
100	301.6	352.0	346.8	365.5	392.1	392.0



Figs. 9 (a&b). Rainfall depth frequency curve (a) 24-hour maximum rainfall depth and (b) 1-hour maximum rainfall depth

TABLE 9

Comparison with Maximum rainfall for various return period given in flood estimation report

Return Period (year)	Flood estimation report (sub-zone 1b)	GEV (AMS Extreme value)		GPD (POT Extreme value)	
		FW	SW	FW	SW
		Maximum 24-hour rainfall in mm			
25	180	163.7	205.5	187.4	254.7
50	200	194.6	249.9	238.0	318.2
100	240	228.6	300.3	301.6	392.0

figures. The model can be useful in computation of the extreme rainfall different return period described in the subsequent paragraphs.

4.4.5. *Extremes for various return periods using fitted statistical models*

The extreme daily rainfall for various return levels is tabulated in Tables 7&8 using the fitted statistical model's parameters. Table 7 represents the extremes for AMS using parameters of the GEV model. The extremes were compared with the CHCF reported in the literature and computed in the current study. The extremes using RCF model are higher for all return period except 100-year compared with other CHCF and AMS (SW).The CHCF and RCF computed in the present study project higher extremes than the IS 5542:2003 and Deshpande *et al*. (2010).

The extremes for POT are evaluated using the fitted GPD model parameters and presented in Table 8. The POT (SW) and the RCF model extreme rainfall is almost the same for the 100-year return period. The POT (SW) is higher for all the return period except 2-year. The CHCF evaluated in the presents study as 1.212 is higher than the CHCF reported in the literature.

The extremes evaluated using the statistical model parameters are compared with the flood estimation report for Chambal subzone 1(b) of Central Water Commission, India (CWC, 1988) as the Jaipur city is part of the said subzone. The 24-hour maximum rainfall for 25-, 50- and, the 100-year return period was given in the said report which can be used to compute corresponding return period design discharge. The extremes are tabulated in Table 9, indicating that the extreme rainfall is higher as compared to the CWC report (1988) estimate. It can be seen that GPD (FW) extreme rainfall for different return period are reasonable for the Jaipur city, India.

The 1-hour maximum depth for various return periods is evaluated using the conversion factors reported in CWC (1988), Flood estimation report (sub-zone 1b) are tabulated in Table 10. The table is a ready reference for the designer in the computation of 1-hour duration different return period peak discharge. The peak rainfall

TABLE 10

Estimation of 1-hour storm for various return period 24-hour maximum rainfall depth given in flood estimation report

Return Period (year)	Conversion factor CWC (1988)	Flood estimation report (sub-zone 1b)	GEV (AMS Extreme value)		GPD (POT Extreme value)	
			FW	SW	FW	SW
Maximum 1-hour rainfall in mm						
25	0.39	70.2	64	80	73	100
50	0.39	78	76	98	93	124
100	0.39	93.6	89	117	118	153

for 25-, 50- and 100-year return period is computed for 24-hour and 1-hour rainfall duration and discussed subsequently.

4.4.6. *Rainfall depth-duration-frequency*

The maximum observed 24-hour and 1-hour rainfall depth for various return period is presented in Figs. 9(a&b). The rainfall depth for 24-hr and 1-hr duration for 25-year return period can be taken as 190 mm and 70 mm respectively. From Figs. 9(a&b), the n-year 24-hour and n-year 1-hour extreme rainfall amount can be evaluated for the Jaipur rain gauge station.

The development of peak rainfall intensity-duration-frequency curve for less than 1-hour storm duration is not attempted in the present study due to non-availability of metadata and can be considered as future scope of the present study.

5. Conclusions

The statistical modelling of extreme rainfall at Jaipur city, India is performed in the present study. The RCF model is developed using hourly rainfall data. The discretisation effect is analysed to support the selection of SW maxima value. The extremes have shown non-significant decreasing trend over the region with higher CHCF than IS 5542 : 2003 recommendation. The findings of the present study are listed below:

(*i*) The RCF model is derived in the study to convert 1-day (1-hour) maximum rainfall to 24-hour (60-minute) true accumulation. The RCF is evaluated as 1.30 for sampling ratio 1

(*ii*) The CHCF to convert 24-hour FW to 24-hour SW is found to be 1.176 (1.212) for AMS (POT). The CHCF reported in IS 5542 : 2003 as 1.15 may not be conservative for the present study area.

(*iii*) The model diagnosis plots and GoF tests revealed that the model is showing reasonably a good fit and can be acceptable.

(*iv*) The extreme evaluated for 25-, 50- and, the 100-year return periodis projecting the GPD (FW) is a better statistical model for the Jaipur city, India.

(*v*) The 1-hour peak rainfall is evaluated using the conversion factors given in CWC (1988) and the Flood estimation report (sub-zone 1b). The 1-hour 5-year and 50-year extreme rainfall are computed as 53.1mm and93mm respectively.

(*vi*) The peak rainfall depth-duration-frequency curve plotted to estimate the n-year 24-hour and n-year 1-hour extreme rainfall amount for the Jaipur rain gauge station which will be useful to the infrastructure design engineer.

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