Frequency analysis for annual maximum rainfall for Kohima (Nagaland), India

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Abstract: In this study, daily rainfall data recorded at Kohima, Nagaland (India) over a span of 26 years (1997-2022) were gathered. Each year's daily data was aggregated into 2–7-day consecutive rainfall totals by summing the rainfall from the corresponding preceding days. The maximum 1-day and 2–7-day consecutive rainfall for each year was used for analysis. A turning point test was used to check the randomness of the data. Five continuous probability distributions functions (Normal, lognormal, Gamma, Log Pearson type III and Extreme value type I) were fitted and the best fitted function were selected based on the lowest value of Chi-square, A turning point test suggested that one to seven consecutive days annual maximum rainfall could be considered random. A Lognormal probability distribution function was found to be the best fit for 1-day annual maximum rainfall data, while a Log-Pearson Type III probability distribution function was found to be the best fit for 3, 4, and 6-days consecutive days annual maximum rainfall data. Extreme value type-I probability distribution function was found to be the best fit for 2, 5, and 7-days consecutive days annual maximum rainfall data. For a recurrence interval of every two years, an annual maximum rainfall of 72.9 mm in one day, 93.8 mm in two days, 107.18 mm in three days, 119.98 mm in four days, 132.68 mm in five days, 138.58 mm in six days, and 158.98 mm in seven days is expected. For a recurrence interval of 100 years, the expected annual maximum rainfall in one day, two days, three days, four days, five days, six days, and seven days are 144 mm, 188.1 mm, 199.8 mm, 269 mm, 270.2 mm, 332.9 mm, and 324.4 mm, respectively. Single-parametric models were developed for 1-day as well as 2-7 consecutive day annual maximum rainfall corresponding to 1-100 years return period. The coefficient of determination ranged from 0.964 to 0.997. Relationships were established for 2-7 consecutive maximum rainfall with one-day annual maximum rainfall, with the coefficient of determination varying from 0.994 to 0.997. It's important to note that these relationships are specific to the data used, and their application can significantly simplify the analysis of long-term data for individual stations.

Keywords: Consecutive days annual maximum rainfall, turning point test, continuous probability distribution function, regression models

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1 Introduction

Increasing global surface temperature is very likely to lead to changes in precipitation and atmospheric moisture because of changes in atmospheric circulation, a more active hydrological cycle, and increases in the water-holding capacity throughout the atmosphere. The warming of the planet also has repercussions on rainfall with both droughts and extreme rainfall becoming more common in different parts of the world. Climate change is also leading to

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heavier rainfall and extreme floods in other areas. Global precipitation patterns are being moved in new directions by climate change and there is increased variance of precipitation everywhere. Wet areas become wetter, and dry and arid areas become more and more dry. Increased precipitation in high latitudes is also seen (Dore, 2005).

Rainfall is one of the important hydrological variables for which historical data are available. This helps in the probability-based analysis of various aspects of data. Bhattacharya and Sarkar (1982) suggested that for estimating drainage coefficient of agricultural crops there is need to know the total rainfall over the duration of crop tolerance period. The tolerance period of commercially grown crops varies for 1 day (for pulses) to 6 days (for rice). If the crops remain waterlogged for more days, these shows signs of irreversible damage, resulting in diminished yields. The procedure for determining the consecutive day rainfall totals with the desired interval is rather laborious and often necessitates computational aid. The process becomes more manageable with one-day rainfall data. Hence, predicting rainfall for consecutive days from one-day data with reasonable accuracy is imperative for expeditious analysis.

The maximum rainfall over consecutive days of varying return periods holds significant implications for the safe and cost-effective planning and design of small and medium hydraulic structures like dams, bridges, culverts, and drainage systems. Additionally, it aids in flood forecasting downstream. While there isn't a universally accepted method for forecasting one-day maximum rainfall, hydrological frequency analysis offers a probabilistic approach for predicting future events. Several studies have explored frequency analysis of rainfall data across different regions in India (Rizvi et al., 2001; Singh, 2001; Tomar and Ranade, 2001; George and Kolappadan, 2002; Kumar, 2003; Sethy et al., 2005; Dingre and Atre, 2005; Dingre and Shahi, 2006; Pandey and Bisht, 2006, Kumar et al., 2007; Pilare and Durbude, 2007).

Dabral and Pandey (2008) used 20 years daily rainfall data of 20 years (1988-2007) of Doimukh (Itanagar), Arunachal Pradesh (India) which comes under Northeast India. They converted daily rainfall data to 2-7 days consecutive days rainfall by summing up the rainfall of corresponding previous days. The maximum amount of 1 day and 2 to 7 days consecutive days rainfall for each year was then taken for analysis. They fitted normal, Lognormal and Gamma probability distribution function to 1 day and 2 to 7 days consecutive annual maximum rainfall and best fit function was selected based on the lowest value of chi-square test. Lognormal distribution was found to be the best fitted to 1 day to 3 days and 7 days maximum annual rainfall data. Gamma function was found to be the best fitted for 4 days to 6 days maximum rainfall data. They predicted one to seven consecutive days of annual maximum rainfall at various return periods using the best probability distribution functions. They also developed the regression relationship of 2 to 7 consecutive days annual rainfall with 1-day annual maximum rainfall. Dabral et al. (2016), and Back and Back (2022) also carried out the similar type of study.

Nagaland is a mountainous state of North-East India and Khima is the capital of Nagaland. Kohima town is located on the top of the surrounding mountain. The major share of rainfall received during April to September which is around 1600 mm. During December normally no rainfall is received. During January to March the rainfall is very low. No systematic information is available on frequency analysis for one day to seven consecutive days annual maximum rainfall for Kohima. Thus, the present study aims to:

a) Determine the statistical parameters of one to seven consecutive days of annual maximum rainfall.

b) Predict one to seven consecutive days of annual maximum rainfall at various return periods using probability distribution functions.

c) Develop various regression relationships pertaining to one to seven consecutive days of annual maximum rainfall.

2 Methods and material

2.1 Study area

Nagaland is a mountainous state of North-East India having diverse climate ranging from sub-tropical to sub-montane temperate with high humidity level. The average annual rainfall is between 1000 mm to 2500 mm, occurring over a period of 6 months (May to October). There are 15 meteorological observatories spread over the state at various altitudes ranging from 160 m to 1780 m above sea mean level and Kohima is one of them. The selected study area Kohima, as illustrated in Figure 1, is the capital of Nagaland which is at the altitude of 1444 m having average rainfall of 2280 mm.

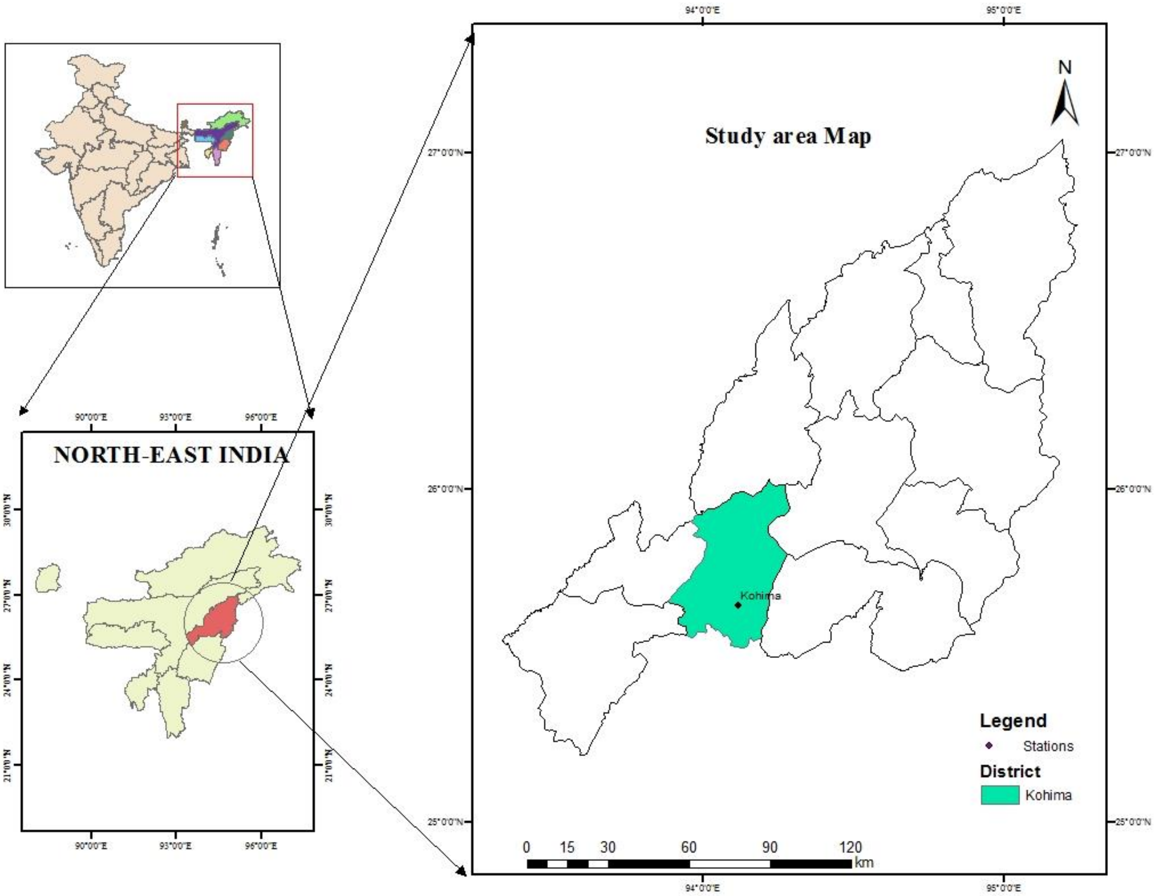

Figure 1 Location map of the study area

2.2 Collection of data

For the current study, we utilized daily rainfall data of Kohima (25°40’N latitude and 94°07’E longitude, altitude1 444 m) over a span of 26 years (1997-2022 collected from Directorate of Soil Water Conservation (Soil Survey Wing) Govt. of Nagaland (India). These data were crucial for our analysis. Each year's daily data was aggregated into 2–7 days consecutive rainfall totals by summing the rainfall from the corresponding preceding days. Subsequently, we selected the maximum 1 day and 2–7 days consecutive rainfall totals for each year for further analysis.

2.3 Statistical data analysis

The statistical behaviour of any hydrological series can be effectively described by certain key parameters. Typically, measures of variability such as mean, standard deviation, coefficient of variation, and coefficient of skewness are employed for this purpose. These parameters offer insights into the central tendency, spread, and shape of the hydrological data distribution, thereby aiding in the characterization of its statistical behaviour**.**

2.4 Randomness checking of the1 day to 7 days consecutive maximum rainfall data

To determine the randomness of the 1 day to 7 days consecutive maximum rainfall data, the turning point test method was applied. This test assesses the number of turning points within a dataset. A turning point is identified when a data point (x_i) is either greater than its preceding and succeeding values or less than both. Thus, the condition $x_{i-1}<x_i> x_{i+1}$ or $x_{i-1} > x_i < x_{i+1}$ indicates the presence of a turning point. The test procedure is outlined as follows:

a) The data were arranged in the order of their occurrence.

b) The condition $x_{i-1}<x_i> x_{i+1}$ or $x_{i-1} > x_i < x_{i+1}$ was applied to determine the number of turning points in the series.

c) Let the total number of turning points be denoted as '*p*.'

d) The expected number of turning points in the series is calculated as $E(p)=\frac{2(N-2)}{3}$, where *N* represents the total number of data points.

e) The variance of *p* is calculated as *var(p),* $z=\frac{(p-E(p))}{\sqrt{Var(p)}}$

f) If the calculated value of '*z*' falls within the critical range of ±1.96 for a 5% level of significance, the hypothesis of randomness of the data is accepted.

2.5 1 day to 7 days consecutive maximum rainfall at different return periods using different probability distribution functions

The 1 day to 7 days consecutive maximum rainfall data were subjected to fitting various probability distribution functions, as detailed in Table 1.

2.6 Testing the goodness of fit

To assess the goodness of fit, comparison of the theoretical and sample values of the relative frequency of the cumulative frequency function is essential. For the relative frequency function, the Chi-square test is employed. The sample value of the relative frequency of interval "*i*" is calculated as:

$$f_s(X_i) = \frac{n_i}{n} \quad (1)$$

where, n_i = number of observations in interval *i*, and *n* = total number of observations.

Table 1 Description of various probability distribution functions

Distribution	Probability density function	Range	Equation for the parameters in terms of the sample moments
Normal	$f(x)=\frac{1}{\sigma\sqrt{2\pi}}exp\left\{-\frac{(x-\mu)^2}{2\sigma^2}\right\}$	$-\alpha \le x \le \alpha$	$\mu=\bar{x}, \sigma=S_x$
Lognormal	$f(x)=\frac{1}{x\sigma\sqrt{2\pi}}exp\left\{-\frac{(y-\mu_y)^2}{2(\sigma_y)^2}\right\}$	$x > 0$	$\mu_y = y, \sigma_y = S_y$
Gamma	$f(x)=\frac{\lambda^\beta x^{\beta-1}e^{-\lambda x}}{\Gamma(\beta)}$	$x \ge 0$	$\lambda=\frac{\bar{x}}{S_x^2}$, $\beta=\left(\frac{\bar{x}}{S_x}\right)^2$
Log Pearson TypeIII	$f(x)=\frac{\lambda^\beta(y-\epsilon)^{\beta-1}e^{-\lambda(y-\epsilon)}}{x\Gamma(\beta)}$ Where, $y=log\ x$	$Log\ x \ge \varepsilon$	$\lambda=\frac{s_y}{\sqrt{\beta}}$, $\beta=[\frac{2}{c_s(y)}]^2$, $\epsilon=\bar{y}-s_y\sqrt{\beta}$ (Assuming $c_s(y)$ is positive)
Extreme value Type-I	$f(x)=\frac{1}{\alpha}\exp[-\frac{x-u}{\alpha}-\exp\left(-\frac{x-u}{\alpha}\right)]$	$-\infty < x < \infty$	$U=\bar{x}-0.5772\alpha$, $\alpha=\frac{\sqrt{6}\ s}{\pi}$

Note: $f(x)$ = cumulative probility distribution function, μ = mean of the sample, σ = standard deviation of the sample, $\bar{x}$ = mean value of *x*, S_x= standard deviation of sample *x* , c_s= skewness coefficient, $\alpha, \beta, \varepsilon$ = parameters.

The theoretical value of the relative probability function is $P(x_i) = f(x_i) - f(x_{i-1})$

The Chi- square test static χ_c^2 is given by the equation:

$$\chi_c^2 = \sum_{i=1}^{m} n\left[\frac{(f_s(x_i)-p(x_i))^2}{p(x_i)}\right] \quad (2)$$

Where,

m = number of intervals, $f_s(x_i) = ni$ i.e the observed number of occurrence in interval *i*, and $p(x_i)$ = corresponding expected number of occurrences in interval *i*.

The χ^2 distribution functions are tabulated in many statistics texts. In the χ^2 test, $\nu = m - p - 1,$

Where *m*= number of intervals, *p* = number of parameters used in fitting the proposed distribution

A confidence level is chosen for the test, it is often expressed as $1 - \alpha$, where 'α' is termed as the significant level. A typical value for the confidence level is 95 percent. The null hypothesis for the test is that the proposed probability fits the data adequately. This hypothesis is rejected if the value of χ^2_v (which is determined from the χ^2 distribution with v degrees of freedom at 5% level of significance). Otherwise, it was accepted.

2.7 Frequency analysis using frequency factors

Chow (1951) has shown that many frequencies analysis can be reduced to form

$$X_T = \overline{X}\,(1 + CVxK_T) \quad (3)$$

Where, CV = coefficient of variation, K_T = frequency factor, $\overline{X}$ = mean value of X, and X_T = magnitude of the event having a return period T.

For Normal and Lognormal distribution, the frequency factor can be expressed by the following equation:

$$K_T = \frac{(X_T - \mu)}{\sigma} \quad (4)$$

Where, X_T = magnitude of the hydrological event, K_T = frequency factor, μ = mean of the sample, σ = standard deviation of the sample.

This is the same as the standard normal variable z. The value of z corresponding to an exceeding probability of p $(p = 1/T)$ can be calculated by finding the value of an intermediate variable 'w';

Where,

$$W = \left[ln\left(\frac{1}{P^2}\right)\right]^{1/2} \quad (0 < p \leq 0.5) \quad (5)$$

$$z = w - \left[\frac{(2.515517 + 0.802853w + 0.010328w^2)}{(1 + 1.432788w + 0.189269w^2 + 0.001308w^3)}\right] \quad (6)$$

When p > 0.5, 1 – p is substituted for p in Equation (5) and the value of z is computed by Equation (6) is given a negative sign. For the Extreme Value Type I distribution, Chow (1953) derived the expression.

$$K_T = -(\sqrt{6})/\pi\,[0.5772 + \ln\{\ln(\frac{T}{T-1})\}] \quad (7)$$

Where, T=return period (in years).

For Log- Pearson type III distribution, the first step is to take the logarithms (base 10) of the hydrological data. The mean, standard deviation and coefficient of skew ness are calculated for logarithms of the data. The frequency factor depends on the return period T and coefficient of Skewness Cs. When $Cs=0$, the frequency factor is equal to the standard normal variable z. When $Cs \neq 0$, K_T is approximated by Kite (1977) as

$$K_T = z + (z^2 - 1)\,k + \frac{1}{3}(z^3 - 6z)\,k^2 - (z^2 - 1)k^3 + z\,k^4 + \frac{1}{3}k^5 \quad (8)$$

In case of Gamma probability distribution function, values of λ (= mean(S.D.)$^{-2}$), β (= (mean)^2 (S.D.)$^{-2}$) and ν (= $2\times\beta$) were calculated for the fitted weeks. For a particular probability level, χ^2 was calculated from the table for a certain ν value. Expected value of the rainfall at certain probability was calculated from the following relationship:

$$Xp = \chi^2 / (2 \times \lambda) \quad (9)$$

Frequency analysis was carried out for the following return periods as given in Table 2.

Table 2 Return period and probability level

T (Return Period, Years)	1.053	1.25	2	10	20	25	50	100
P (Probability level in %)	95	80	50	10	5	4	2	1

2.8 Development of regression relationships

The following regression relationship will be developed using Microsoft Excel and SPSS software:

Then calculating z using the equation：

a) Regression models for 1 day to 7 consecutive days annual maximum rainfall corresponding to 1 to 100 years return period.

b) Relationship of 2 to 7 consecutive days annual maximum rainfall with 1day annual maximum rainfall

3 Result and discussion

3.1 Year wise 1 to 7 consecutive days annual maximum rainfall and statistical parameters

Table 3 presents the yearly data for one to seven consecutive days' annual maximum rainfall. Table 4 outlines the statistical parameters for one to seven consecutive days' annual maximum rainfall. The maximum and the minimum value of one-day maximum rainfall were found to be 134.2 mm and 46.4 mm, respectively. The mean value of one-day maximum rainfall was found to be 76.6 mm with standard deviation and coefficient of variation of 22.8 mm and 30%, respectively. The coefficient of skewness was observed to be 0.8.

For 2 to 7 consecutive days maximum annual rainfall, the range values for mean, standard deviation, coefficient of skewness were observed to be 76.6 to 167.1, 22.8 to 50.0 and 0.5 to 1.6 respectively.

Table 3 Year wise one to seven consecutive days annual maximum rainfall (mm)

Year	One to seven consecutive days annual maximum rainfall (mm)						
	1day	2days	3 days	4 days	5 days	6 days	7 days
1997	51	57.6	60.2	85.8	98.4	96.7	101.7
1998	46.4	54.6	59.9	70.9	83.8	91.1	109.4
1999	50.6	77.2	93.5	97.2	125.5	130.6	157.1
2000	107.4	178.2	180	259	260.8	184.6	292
2001	66.2	107.6	101.2	107.4	113	119.8	144.6
2002	107.4	109.2	151.6	187.6	195.6	288	289.8
2003	134.2	134.7	134.7	184.9	183.9	202	206.3
2004	93	149	176	159.2	192.2	141.2	197.2
2005	59	75.2	98.2	90.6	119.6	131.4	134.4
2006	62	85.4	112.4	112.4	88	126.4	127.1
2007	64.2	103.6	95.7	135.1	144.8	153.4	158
2008	84.6	98.6	147.4	141.6	172.8	179	223.6
2009	60	73.2	84.6	116.6	131.5	132.9	125.9
2010	69.4	118	91.3	128.6	142.3	183.4	187.4
2011	116.8	120.8	146	150	123	124	146.9
2012	49	63	72.3	114.9	101.5	118.8	120.9
2013	102	107.5	110.1	122.2	136.2	135.6	187.6
2014	71.8	89.3	97.4	98.8	134.8	123.3	153
2015	60	74.9	83	130.2	130.2	132.2	167.2
2016	95	95	109.8	98.2	113	112.2	145.8
2017	77.2	82.6	125.8	146	138.9	205.7	158.4
2018	79.8	118.6	120	176.2	218.6	271	243
2019	78	120.8	122.6	137.2	118.6	157.2	168.4
2020	62.8	84.4	88.6	87	109.4	115.6	128
2021	62.4	82.6	102.8	104.6	117.4	127.2	127.2
2022	82	97.8	121	107.2	129.8	143.2	143.2

Table 4 Statistical parameters of 1 day to 7 consecutive days annual maximum rainfall

S.No.	Parameters	1 day	2 days	3 days	4 days	5 days	6 days	7 days
1	Minimum (mm)	46.4	54.6	59.9	70.9	83.8	91.1	101.7
2	Maximum (mm)	134.2	178.2	180	259	260.8	288	292
3	Mean (mm)	76.6	98.4	111.0	128.8	139.4	151.0	167.1
4	Standard deviation (mm)	22.8	28.5	31.2	40.6	41.6	48.0	50.0
5	Coefficient of variation (%)	30	30	30	30	30	30	30
6	Coefficient of skewness	0.8	0.9	0.5	1.4	1.3	1.6	1.3

3.2 Result of turning point test

The randomness of the data was assessed through a turning point test, where the hypothesis of randomness was formulated and examined. The results of the turning point test are summarized in Table 5, showcasing the test statistics. It was found that the values of the test statistics fell within the 5% level of significance for one to seven consecutive days' annual maximum rainfall. Consequently, the data for one to seven consecutive days' annual maximum rainfall could be deemed as random. Dabral et al. (2016) have carried out turning point test for checking the randomness of the one to seven consecutive days' annual maximum rainfall data of the Doimukh (Arunachal Pradesh, India) and reported the similar pattern of results. Dabral et al. (2019) have also carried out same test for weekly rainfall of Kohima (Nagaland).

3.3 Fitting of various probability distribution functions

The original data ranging from one-day to seven consecutive days' annual maximum rainfall was subjected to fitting with various probability distribution functions, including Normal, Log Normal, Gamma Log-Pearson III, and Extreme Value Type I distributions. The calculated χ^2 values were then compared with tabulated values at a 5% level of significance.

The analysis revealed significant fits for all probability distribution functions, as summarized in Table 6. Specifically, the Lognormal probability distribution function exhibited the best fit for one-day annual maximum rainfall data. For three, four, and six consecutive days' annual maximum rainfall data, the Log-Pearson Type III probability distribution function proved to be the best fit. Lastly, the Extreme Value Type I probability distribution function demonstrated the best fit for two, five, and seven consecutive days' annual maximum rainfall data (Table 6). Dabral et al. (2016) have carried out the frequency analysis of one to seven consecutive days' annual maximum rainfall data of the Doimukh (Arunachal Pradesh, India) by fitting Normal, Log Normal and Gamma probability distribution functions. They reported Log normal probability distribution function best fitted for one day annual maximum rainfall and Normal probability distribution function for 2 to 7 days annual consecutive maximum rainfall. Dabral et al. (2019) have also carried out same analysis for weekly rainfall of Kohima (Nagaland).

Table 5 Result of turning point test

Consecutive days annual rainfall maximum	Turning point (*P*)	*N*	*E(P)*	*Var (P)*	*Z*	Whether data in random or not?
1 day	16	26	16	4.3	0	Random
2 days	17	26	16	4.3	0.4832	Random
3 days	16	26	16	4.3	1.45	Random
4 days	14	26	16	4.3	-0.965	Random
5 days	15	26	16	4.3	-0.48	Random
6 days	14	26	16	4.3	-0.965	Random
7 days	13	26	16	4.3	-1.45	Random

Table 6 Chi-square (χ2) value for different probability distribution functions

Rainfall maximum	Normal		Log Normal		Gamma		Log-Pearson III		Extreme value type -I	
	Computed χ2	Tabulated χ2	Computed χ2	Tabulated χ2	Computed χ2	Tabulated χ2	Computed χ2	Tabulated χ2	Computed χ2	Tabulated χ2
1 day	1.2596	14.1	0.306*	14.1	0.344	14.1	0.328	14.1	0.344	14.1
2 days	3.579	14.1	4.517	14.1	5.03	14.1	2.4	14.1	1.04*	14.1
3 days	1.638	14.1	2.377	14.1	0.588	14.1	0.462*	14.1	1.217	14.1
4 days	1.736	14.1	0.421	14.1	1.136	14.1	0.062*	14.1	0.133	14.1
5 days	3.579	14.1	4.571	14.1	5.030	14.1	2.397	14.1	1.040*	14.1
6days	7.989	14.1	6.927	14.1	1.721	14.1	1.027*	14.1	1.048	14.1
7 days	3.7	14.1	0.853	14.1	0.723	14.1	0.531	14.1	0.1111*	14.1

Note: *= best fit function

Table 7 Values of w and K_T for various return periods (Lognormal probability distribution function)

T(years)	1.053	1.25	2	10	20	25	50	100
w	2.448	1.794	1.177	2.15	2.45	2.54	2.79	3.035
$K_T = Z$	-1.6455	-0.8413	-0.0006	1.286663	1.647886	1.754289	2.045925	2.326951

3.4 Estimation of 1-day to 7 consecutive days annual maximum rainfall for different return periods

As discussed in section 3.3, the Lognormal probability distribution function was identified as the best fit for one-day annual maximum rainfall data. Table 7 presents the values of w and K_T for various return periods.

As discussed in Section 3.3, the Log-Pearson Type III probability distribution function was identified as the best fit for three, four, and six consecutive days' annual maximum rainfall data. Table 8 presents the values of *z*, *k*, and K_T for various return periods.

Table 8 Values of z, k and K_T for various return periods (Log-Pearson Type III probability distribution function)

For 3 days								
T (Years)	1.053	1.25	2	10	20	25	50	100
k	-0.02847	-0.02847	-0.02847	-0.02847	-0.02847	-0.02847	-0.02847	-0.02847
Z	-1.73886	-0.841284	-0,01856	1.388862	1.6455	1.730702	2.054005	2.326941
K_T	-1.79503	-0.83177	0.00991	1.36091	1.59546	1.67254	1.96145	2.2010
For 4 Days								
T (Years)	1.03	1.25	2	10	20	25	50	100
k	0.08411	0.08411	0.08411	0.08411	0.08411	0.08411	0.08411	0.08411
Z	-1.73886	-0.841284	-0.01856	1.388862	1.6455	1.730702	2.054005	2.326941
K_T	-1.55774	-0.85523	-0.10178	1.45318	1.77543	1.88517	2.31431	2.69254
or 6 days								
T (Years)	1.053	1.25	2	10	20	25	50	100
k	0.15000	0.15000	0.15000	0.15000	0.15000	0.15000	0.15000	0.15000
Z	-1.73866	-0.841284	-0.01856	1.388862	1.6455	1.730702	2.054005	2.326941
K_T	-1.40418	-0.85114	-0.16429	1.48340	1.85612	1.98518	2.49963	2.96525

Table 9 Values of K_T at various return periods (Extreme value type- I distribution probability distribution function)

T (years)	1.053	1.25	2	10	20	25	50	100
K_T	-1.034	-0.821	-0.164	1.31	1.867	2.045	2.594	3.142

Table 10 1-day to 7 consecutive days annual maximum rainfall at various return periods

S. No.	Return Period (Years)	Maximum rainfall (mm)						
		1 day	2 days	3 days	4 days	5 days	6 days	7 days
1	1.053	44.3	61.3	64.1	78.7	85.2	97.8	101.9
2	1.25	57.4	75	84.3	96.5	105.2	114.2	126.1
3	2.0	72.9	93.8	107.1	119.9	132.6	138.5	158.9
4	10.0	109.7	135.8	157.3	188	194	219.7	232.7
5	20.0	118.1	151.5	168.2	206.4	216.8	243.9	260.1
6	25.0	121.1	156.5	171.9	213	224.2	252.9	269
7	50.0	133	172.4	186.6	241.1	247.3	292.2	296.8
8	100.0	144	188.1	199.8	269	270.2	332.9	324.4

As discussed in section 3.3, the Extreme Value Type-I probability distribution function was identified as the best fit for two, five, and seven consecutive days' annual maximum rainfall data. Table 9 presents the values of K_T for various return periods.

Utilizing Equation 2 and the values of K_T described in Tables 7, 8, and 9, the one-day to seven consecutive days' annual maximum rainfall at various return periods were determined using the best-fit distribution functions, as summarized in Table 10. An annual maximum rainfall of 72.9 mm in one day, 93.8 mm in two days, 107.18 mm in three days, 119.98 mm in four days, 132.68 mm in five days, 138.58 mm in six days, and 158.98 mm in seven days is expected to occur every two years. For a recurrence interval of 100 years, the annual maximum rainfall expected in one day, two days, three days, four days, five days, six days, and seven days are 144 mm, 188.1 mm, 199.8 mm, 269 mm, 270.2 mm, 332.9 mm, and 324.4 mm, respectively. It is generally recommended that a return period ranging from 2 to 100 years is sufficient for soil and water conservation measures, construction of dams, irrigation, and drainage works. The results reported above are different from Dabral and Baithuri (2008) and Dabral et al. (2016) who had done the similar type of study for North Lakhimpur (Assam) and Doimukh (Arunachal Pradesh) respectively.

3.5 Regression models

Single-parametric models developed for one-day as well as two to seven consecutive days' annual maximum rainfall, corresponding to return periods of 1 to 100 years, are presented in Table 10. The coefficient of determination ranged from 0.964 to 0.997. Utilizing the regression equations, it is expected to provide meaningful and reasonably accurate values for both one-day and two to seven consecutive days' annual maximum rainfall across various return periods.

Additionally, relationships between two to seven consecutive days' maximum rainfall and one-day annual maximum rainfall are outlined in Table 11. The coefficient of determination varied from 0.994 to 0.997. Notably, a coefficient of determination of 0.975 was observed for two consecutive days against one-day annual maximum rainfall, indicating a strong dependence of two consecutive days' annual maximum rainfall on one-day annual maximum rainfall.

Using the regression equations, it is anticipated to generate meaningful and reasonably accurate values for two to seven consecutive days' annual maximum rainfall corresponding to one-day maximum annual rainfall.

The relationship developed in the present study are specific to the data used, the use of this will greatly reduce the cumbersome analysis of individual station's long-term data. Similar study was conducted by Dabral et al. (2009) for Doimukh (Arunachal Pradesh) and they obtained less co-efficient of determination (R^2) values of the regression models compared to the present study. This might be due to variation of rainfall received due to different geographical locations.

Table 10 Regression models for 1 day to 07 consecutive days annual maximum rainfall corresponding to 1 to 100 years return period (T)

Duration (Days)	Relationship	Coefficient of determination(R^2)
1	$R_1 = 20.967\ Ln(T) + 52.880$	0.975
2	$R_2 = 26.837\ Ln(T) + 68.909$	0.989
3	$R_3 = 28.439\ Ln(T) + 78.416$	0.964
4	$R_4 = 40.089\ Ln(T) + 86.362$	0.993
5	$R_5 = 39.161\ Ln(T) + 96.314$	0.989
6	$R_6 = 49.386\ Ln(T) + 100.381$	0.997
7	$R_7 = 47.075\ Ln(T) + 115.306$	0.989

Table 11 Relationship of 2 to 7consecutive days annual maximum rainfall with 1day annual maximum rainfall

Relationship between one day and consecutive days	Developed Equation	Co-efficient of determination (R^2)
2 days v/s 1 day	$Rc_2 = 1.586\ R_1^{0.956}$	0.997
3 days v/s 1 day	$Rc_3 = 1.704\ R_1^{0.961}$	0.999
4 days v/s 1 day	$Rc_4 = 1.413\ R_1^{1.047}$	0.994
5 days v/s 1 day	$Rc_5 = 1.986\ R_1^{0.984}$	0.997
6 days v/s 1 day	$Rc_6 = 1.711\ R_1^{1.044}$	0.982
7 days v/s 1 day	$Rc_7 = 1.711\ R_1^{0.986}$	0.997

4 Conclusions

The study meticulously explored annual maximum rainfall across various durations, from single-day events to seven consecutive days for Kohima (Nagaland). Turning point test indicated that, one to seven consecutive days annual maximum rainfall could be considered random. After thorough analysis, it was observed that different probability distribution functions were best suited for different durations: the Lognormal distribution for one-day events, Log-Pearson Type III for three, four, and six consecutive days, and Extreme Value Type-I for two, five, and seven consecutive days. The study provided expected annual maximum rainfall values for each duration: 72.9 mm for one day, 93.8 mm for two days, 107.18 mm for three days, 119.98 mm for four days, 132.68 mm for five days, 138.58 mm for six days, and 158.98 mm for seven days, occurring every two years. For a recurrence interval of 100 years, the annual maximum rainfall expected in one days, two days, three days, four days, five days, six days, and seven days are 144 mm, 188.1mm, 199.8 mm, 269 mm, 270.2 mm, 332.9 mm, and 324.4 mm respectively.

Single parametric models were developed for each duration corresponding to return periods ranging from one to 100 years. These models exhibited high coefficients of determination, ranging from 0.964 to 0.997. Additionally, relationships were established between consecutive-day maximum rainfall and one-day maximum rainfall, further enhancing the predictive capability of the models, with coefficients of determination ranging from 0.994 to 0.997. It is important to note that the relationships developed in this study are specific to the dataset used. Nonetheless, their application can significantly streamline the analysis of annual maximum rainfall data, reducing complexity and enhancing understanding.

References

Back, Á. J., and L. Back. 2022. Characterization and frequency analysis of long-term maximum rainfall from São Martinho, Manta Catarina, Brazil. *Revista Engeniharia Na Agricultura-REVENG*, 30(Contínua): 142-155.

Bhattacharya, A. K., and T. K. Sarkar. 1982. Analysis of rainfall data for agricultural land drainage design. *Journal of Agricultural Engineering*, 19(1): 15-25.

Chow, V. T. 1951. A general formula for hydrological frequency analysis. *Eos, Transactions American Geophysical Union,* 32(2): 231-237.

Chow, V. T. 1953. Frequency analysis of hydrological data with special application to rainfall intensities. Bullletin no.414. Urbana, Illinois, USA: University of Illinois.

Dabral, P. P., and A. Pandey. 2008. Frequency Analysis for One Day to seven Consecutive Days of Annual maximum Rainfall for the District of North Lakhimpur, Assam. *IE(I) Journal (Agricultural Engg. Division)*, 89: 29-33.

Dabral, P. P., M. Pal, and R. P. Singh. 2009. Probability analysis for one day to seven consecutive days annual maximum rainfall for Doimukh (Itanagar), Arunachal Pradesh. *Journal of Indian Water Resources Society*, 29(2): 9-15.

Dabral, P. P., A. Kumar, and G. Tana. 2016. Determination of surface drainage coefficient-a case study of Doimukh (ArunachalPradesh), India. *CIGR Journal.* 18(4): 1-10.

Dabral, P. P., M. Dada, and H. Odi. 2019. Probability analysis of rainfall at Kohima (Nagaland) for crop planning. *Journal of Soil and water Conservation*, 18(4): 364-371.

Dingre, S., and A. A. Atre. 2005. Probability analysis for prediction of annual maximum daily rainfall of Srinagar region (Kashmir Valley). *Indian Journal of Soil Conservation*, 33(3): 262-263.

Dingre, S., and N. C. Shahi. 2006. Consecutive days maximum rainfall prediction from one day maximum rainfall for Srinagar in Kashmir Valley. *Indian Journal of Soil Conservation*, 34(2): 153-156.

Dore, M. H. I. 2005. Climate change and change in global precipitation patterns: What do you know? *Environment International*, 31(8): 1167-1181.

George, C., and C. Kolappadan. 2002. Probability analysis for prediction of annual maximum daily rainfall of Periyar basin Kerala. *Indian Journal of Soil Conservation*, 30(3): 273-276.

Kite, G. W. 1977. *Frequency and Risk Analysis in Hydrology.* Fort Collins, Colorado, USA: Water Resources Publications.

Kumar, V. 2003. Frequency analysis of consecutive days maximum rainfall at Srinagar (J&K). *Indian Journal of Soil Conservation*, 31(2): 295-298.

Kumar, A., K. K. Kaushal, and R. D. Singh. 2007. Prediction of annual maximum daily rainfall of Almora based on probability analysis. *Indian Journal of Soil Conservation*, 35(1): 82-83.

Pandey, S. C., and K. K. S. Bisht. 2006. Probability analysis for prediction of annual maximum daily rainfall for Hawalbagh (Almora). *Indian Journal of Soil Conservation*, 34(1): 75-76.

Pilare, V. R., and D. G. Durbude. 2007. Probability analysis of maximum one day and daily monsoon rainfall at CIAE Bhopal. *Indian Journal of Soil Conservation*, 6(3): 146-151.

Rizvi, R. H., R. Singh, R. S. Yadav, R. K. Tiwari, K. S. Dadhwal, and K. R. Solanki. 2001. Probability analysis of annual maximum daily rainfall for Bundelkhand region of Uttar Pradesh. *Indian Journal of Soil Conservation*, 29(3): 259-262.

Sethy, B. K., S. Ali, and S. N. Prasad. 2005. Frequency analysis for one day to five consecutive days annual maximum rainfall for South Eastern Rajasthan. *Indian Journal of Soil Conservation*, 13(1): 22-26.

Singh, R. K. 2001. Probability analysis for prediction of annual maximum daily rainfall of Eastern Himalaya (Sikkim mid hills). *Indian Journal of Soil Conservation*, 29(3): 263-265.

Tomar, A. S., and D. H. Ranade. 2001. Predicting consecutive day maximum rainfall for1day maximum rainfall for Indore region for Madhya Pradesh. *Indian Journal of Soil Conservation*, 29(3): 271-275.