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Distributions of Annual Maximum Rainfall Series of North-East India

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Abstract: An attempt has been made to determine the best fitting distribution to describe the annual series of maximum daily rainfall data for the period 1966 to 2007 of nine distantly located stations in North East India. Five extreme value distributions viz. generalized extreme value distribution, generalized logistic distribution, generalized Pareto distribution, lognormal distribution and Pearson distribution are fitted for this purpose using the method of L-moment and LQ-moment. The performances of the distributions are evaluated using three goodness of fit tests namely relative root mean square error, relative mean absolute error and probability plot correlation coefficient. Further, L-moment ratio diagram is also used to confirm the goodness of fit for the above five distributions. Finally, goodness of fit test results are compared and generalized logistic distribution is empirically proved to be the most appropriate distribution for describing the annual maximum rainfall series for the majority of the stations in North East India.

Key Words: Extreme rainfall, L-moments, LQ-moments, Quantile function, North East India.

1. INTRODUCTION

Extreme rainfall events can have severe impacts on society. It afflicts the worst environmentally related tragedy, which contributes to loss of crops and valuable property and untold human misery. Stochastic models for extreme rainfall events over an area may be used for such disaster prevention purposes. Moreover, knowledge of spatial and temporal variability of extreme rainfall events is very much useful for the design of dam and hydrological planning. A detailed regionalized study is practically useful for the planners and other users. So there is a pressing need to know the magnitudes of the extreme rainfall events over different parts of the area under study. So far no rigorous work has been pursued in the North East India to study the annual maximum rainfall events. Considerable efforts have been made in this direction using the annual series of maximum daily rainfall data for the period of 42 years of nine stations in North East India. For this purpose, five three-parameter extreme value distributions viz. Generalized Extreme Value distribution (GEV), Generalized Logistic distribution (GLD), Generalized Pareto distribution (GPD), Lognormal distribution (LN3) and Pearson (P3) distribution are considered. The estimation of the parameters for each distribution has been done using the methods of L-Moment and LQ-Moment independently. Applications of extreme value distributions to rainfall data have been investigated by several authors from different region of the world. Rakhecha et al. (1994) analyzed the annual extreme rainfall series at 316 stations over the Indian region, covering 80-years of rainfall data for trend and persistence using standard statistical tests. For investigating more generalized issues regarding the adequacy of extreme value distributions for extreme rainfall analysis, Baloutsos et al. (2000) made the statistical analysis for the longest rainfall record available in Greece. In the same direction, Koutsoyiannis (2004) made an extensive empirical investigation of the longest available rainfall records worldwide, each having 100-154 years of data. Nadarajah et al. (2001) and Nadarajah (2005) provided the application of extreme value distributions to rainfall data over sixteen locations spread throughout New Zealand and fourteen locations in West Central Florida, respectively. Extreme value distributions have been also used by Aronica et al. (2002) to analyze the trend in the extreme rainfall series for a fixed return period by estimating the maximum rainfall depth in Palermo, Sicily, Italy. They estimated the parameters using *L*-moments. Zalina et al. (2002) discussed the comparative assessment of eight candidate distributions in providing accurate and reliable maximum rainfall estimates for Malaysia. Model parameters were estimated using the L-moment method. They concluded that the GEV distribution is the most appropriate distribution for describing the annual maximum rainfall series in Malaysia. On the other hand, Zin et al. (2008) found GLD as the most frequently selected best fitting distribution and LN3 as the least frequently selected distribution for extreme rainfall in Peninsular Malaysia. Those results differ from the results obtained by Zalina et al. (2002). Therefore, a regionalized study on the statistical modeling of extreme rainfall is very much essential as the statistical model may vary according to the geographical locations of the area considered. So an attempt has been made to study the annual maximum daily rainfall data in North East India and the findings of the same along with the methodology adopted are presented in this paper.

While Kotz et al. (2000) made an extensive study on the fitting of extreme value distribution, the detailed references on the statistical modeling of annual maximum rainfall based on L-moment and LQ-moment can be found in Zin et al. (2008). The most commonly used distributions for extreme rainfall data can be found from the references such as Hosking and Wallis (1997) and Rao and Hamed (2000). For the application of L-moments in flood frequency analysis we refer to Hussain and Pasha (2009).

2. DATA AND AREA OF STUDY

Series of annual maximum daily rainfall data of nine stations in North East India viz Imphal, Mohanbari, Guwahati, Cherrapunji, Pasighat, North Lakhimpur, Silchar, Shillong and Tezpur for a period of 42 years from 1966 to 2007 have been considered for this study. The geographical locations of the nine rain gauge stations are shown in Figure 1. The series of annual maximum daily rainfall is collected from Regional Meteorological Centre, Guwahati and the graphical representation of the data is shown in Figure 2.

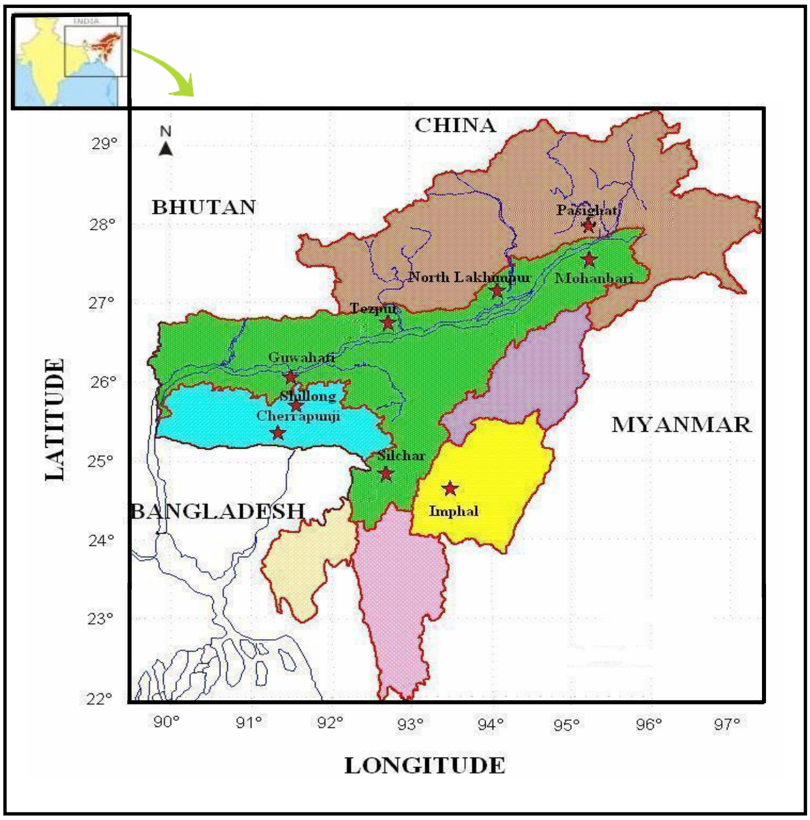

Figure 1. Locations of rain gauge stations used in this study

The brief description, especially hydroclimatoloy, of nine rain gauge stations used in this study is prescribed below:

Guwahati: Guwahati is the largest city in the North East Region of India and is located at 26° 11'N 91° 44'E. Guwahati's climate is mildly sub-tropical with warm, dry summers from April to late May, a strong monsoon from June to September and cool, dry winters from late October to March.The city experiences an annual rainfall of 180 cm (from May to September) with an average number of 77.3 rainy days. While summer temperatures range from 22 to 38°C, in winters the mercury ranges from 10 to 25°C.

Shillong: Shillong is the capital of Meghalaya, one of the smallest states in India. Shillong is located at 25°34′N 91°53′E / 25.57°N 91.88°E. It is on the Shillong Plateau, the only major pop-up structure in the northern Indian shield. Due to its latitude and high elevation Shillong has a sub-tropical climate with mild summers and chilly to cold winters. Shillong is subject to vagaries of the monsoon. The monsoons arrive in June and it rains almost until the end of August. In summers the temperature varies from 23 degree Celsius and in winters the temperature varies from 4 degree Celsius.

Cherrapunji: Cherrapunji is the world's wettest place and is just 56km from the capital Shillong of Meghalaya. Geographically it is located at 25°18′N 91°42′E / 25.30°N 91.70°E. Cherrapunji's yearly rainfall average stands at 11,430mm (450 in). This figure places it behind only nearby Mawsynram, Meghalaya, whose average is 11,873 mm (467 in) and Mount Waialeale (USA) on the Hawaiian island of Kauai, whose average is 11,684 mm (460 in). The orography of the hills with many deep valleys channels the low flying (150-300 m) moisture laden clouds from a wide area to converge over Cherrapunjee which falls in the middle of the path of this stream. The winds push the rain clouds through these gorges and up the steep slopes. The rapid ascendance of the clouds into the upper atmosphere hastens the cooling and helps vapours to condense. Most of Cherrapunjee's rain is the consequence of air being lifted as a large body of water vapour. Extremely large amount of rainfall at Cherrapunjee is perhaps the most well known feature of orographic rain in northeast India.

Imphal: Imphal is the capital of Manipur, located at 24°49′N 93°57′E / 24.82°N 93.95°E. It has an average elevation of 786 metres (2578 feet). It is located in the extreme east of India. The Imphal Valley is drained by several small rivers originating from the hills surrounding it. Imphal has a sub-tropical climate with cool, dry winters, a warm summer and a moderate monsoon season. July is the hottest month with temperatures averaging around 25^{o}C (78^{o}F), while January is the coldest with average lows near 4^{o}C (40^{o}F). The city gets about 1320 mm (52 inches) of rain with June being the wettest month.

Mohanbari: Mohanbari is located 15 km from the city center Dibrugarh of district Dibrugarh, Assam, India. Being located 27° 26' 60N 95° 1' 60E and with its unique physiographic elements, the area experiences subtropical monsoon climate with mild winter, warm and humid summer. Rainfall decreases from south to north and east to west in the area. The average annual rainfall of the Dibrugarh city in the north is 276 cm with a total number of 193 rainy days, while at Naharkatia in the south, it is 163 cm with 147 rainy days.

North Lakhimpur: North Lakhimpur is situated in the eastern parts of India in the state of Assam. The district of Lakhimpur lies on north bank of the mighty river Brahmaputra. It is situated at 27° 13' 60 N and 94° 7' 0 E.

Pasighat: Pasighat is the headquarters of East Siang district in the Indian state of Arunachal Pradesh and located at 28.07°N 95.33°E . It has an average elevation of 153 metres (501 ft). The area experience tropical humid climate during summer and dry mild winter. The place is known for receiving highest rainfall in a single year. In fact Pasighat and area around it receive heavy rainfall every year during monsoon season starting from May till September.

Silchar: Silchar is the headquarters of Cachar district in the state of Assam in India. Silchar is located at the southern part of Assam, situated on the Barak River near the Bangladesh border. It has an average elevation of 22 metres (72 feet).

Tezpur: Tezpur is situated in the eastern parts of India in the state of Assam and located at 26.63°N 92.8°E. It has an average elevation of 157 ft. The climate in this part of Assam is usually pleasant apart from the high humidity factor. In summer the temperature rises up to 38.6°C and during winters the temperatures may drop to 12°C.

3. METHODOLOGY

In order to describe the behavior of extreme rainfall at a particular area, it is necessary to identify the distribution(s), which best fit the data. In this study, five three-parameter extreme value distributions namely Generalized Extreme Value, Generalized Logistic, Generalized Pareto, Lognormal and Pearson distribution are considered to find the best fitting probability distribution function to extreme rainfall data.

The probability density functions of the above distributions along with their quantile functions are exhibited below.

Generalized Extreme Value (GEV) Distribution:

$$f(x) = \frac{1}{\alpha}\left\{1 - k\frac{(x-\xi)}{\alpha}\right\}^{\frac{1}{k}-1} \exp\left[-\left\{1 - k\frac{(x-\xi)}{\alpha}\right\}^{\frac{1}{k}}\right] \tag{3.1}$$

where $-\infty < x \le \xi + \frac{\alpha}{k}$ for $k > 0$ and $\xi + \frac{\alpha}{k} \le x < \infty$ for $k < 0$.

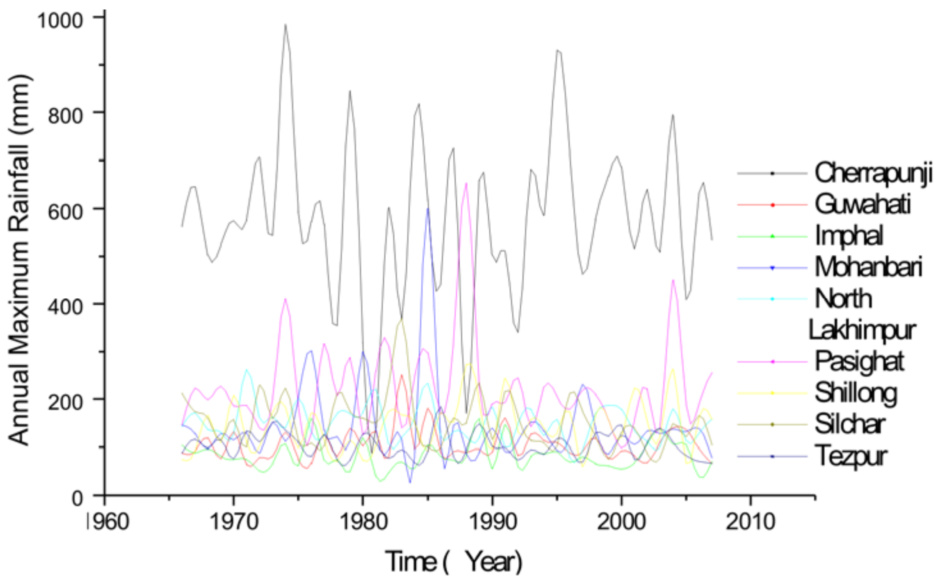

Figure 2. Representation of annual maximum rainfall data.

Quantile function of GEV:

$$Q(F) = \xi + \alpha Q_0(F) \tag{3.2}$$

where

$$Q_0(F) = [1 - (-\log F)^k]/k \, . \tag{3.3}$$

Generalized Logistic Distribution (GLD):

$$f(x) = \frac{1}{\alpha}\left\{1 - k\frac{(x-\xi)}{\alpha}\right\}^{\frac{1}{k}-1}\left[1 + \left\{1 - k\frac{(x-\xi)}{\alpha}\right\}^{\frac{1}{k}}\right]^{-2} \tag{3.4}$$

where $-\infty < x \le \xi + \frac{\alpha}{k}$ for $k > 0$ and $\xi + \frac{\alpha}{k} \le x < \infty$ for $k < 0$.

Quantile function of GLD:

$$Q(F) = \xi + \alpha Q_0(F) \tag{3.5}$$

where

$$Q_0(F) = [1 - \{(1-F)/F\}^k]/k \, . \tag{3.6}$$

Generalized Pareto Distribution (GPD):

$$f(x) = \frac{1}{\alpha}\left\{1 - k\frac{(x-\xi)}{\alpha}\right\}^{\frac{1}{k}-1} \tag{3.7}$$

where $\xi < x \le \xi + \frac{\alpha}{k}$ for $k > 0$ and $\xi \le x < \infty$ for $k \le 0$.

Quantile function of GPD:

$$Q(F) = \xi + \alpha Q_0(F) \tag{3.8}$$

where

$$Q_0(F) = [1 - (1-F)^k]/k \tag{3.9}$$

Lognormal Distribution (LN3):

$$f(x) = \frac{1}{\alpha\sqrt{2\pi}} e^{-\log\left\{1-k\frac{(x-\xi)}{\alpha}\right\}-\frac{1}{2}\left[-\frac{1}{k}\log\left\{1-k\frac{(x-\xi)}{\alpha}\right\}\right]^2} \tag{3.10}$$

where $-\infty < x \le \xi + \frac{\alpha}{k}$ for $k > 0$ and $\xi + \frac{\alpha}{k} \le x < \infty$ for $k < 0$.

Quantile function of LN3:

$$Q(F) = \zeta + \exp(\mu) Q_0(F) \tag{3.11}$$

where

$Q_0(F) = \exp[\sigma \Phi^{-1}(F)]$ and $\Phi^{-1}(\cdot)$ has a standard normal distribution with mean zero and unit variance. Parameters ζ, μ and σ are the standard parameterizations which can be obtained by setting

$$k = -\sigma, \quad \alpha = \sigma e^{\mu}, \; \xi = \zeta + e^{\mu}. \tag{3.12}$$

Pearson Distribution (P3):

$$f(x) = \frac{1}{|\beta|\Gamma(\alpha)} \left(\frac{x-\xi}{\beta}\right)^{\alpha-1} \exp\left(-\left(\frac{x-\xi}{\beta}\right)\right) \tag{3.13}$$

where $-\infty < x < \infty$.

The quantile function of P3:

$$Q(F) = \mu + \sigma Q_0(F) \tag{3.14}$$

where

$Q_0(F) = \frac{2}{\gamma}\left[1 + \frac{\gamma \Phi^{-1}(F)}{6} - \frac{\gamma^2}{36}\right]^3 - \frac{2}{\gamma}$ and $\Phi^{-1}(\cdot)$ has a standard normal distribution with mean zero and unit variance. Parameters γ, μ and σ are the standard parameterizations which can be obtained by setting

$$\alpha = \frac{4}{\gamma^2}, \quad \beta = \frac{1}{2}\sigma|\gamma|, \; \xi = \mu - \frac{2\sigma}{\gamma} \tag{3.15}$$

To estimate the parameters for each of the aforesaid distributions, methods of L-Moment and LQ-Moment are used independently.

3.1 Method of L-moment

The L-moments (LMOM) were introduced by Sillitto (1951) and comprehensively reviewed by Hosking (1986, 1990) for estimating the parameters of certain statistical distributions. The L-moments are linear functions of the expectations of order statistics and they can be viewed as an alternative system of describing the shapes of probability distributions. The main advantages of using the method of LMOM are that the parameter estimates are more reliable (i.e. smaller mean-squared error of estimation) and are more robust, and are usually computationally more tractable than the conventional moments and maximum likelihood.

Let $X_1, X_2, ..., X_n$ be a sample from a continuous distribution function F(.) with quantile function Q(F) and let $X_{1:n} \le X_{2:n} \le ... \le X_{n:n}$ denotes the order statistics. Then the rth L-moment λ_r is given by

$$\lambda_r = r^{-1} \sum_{k=0}^{r-1} (-1)^k \binom{r-1}{k} E(X_{r-k:r}), \quad r = 1,2,.... \tag{3.1.1}$$

The details on the estimation of parameters for each of the aforesaid distributions can be found in Hosking and Wallis (1997).

3.2 Method of LQ-moment

Mudholkar and Hutson (1998) extended LMOM to a new moment called LQ-moments (LQM) by introducing some quick estimators such as median, trimean or Gastwirth in places of expectations in LMOM. They found that LQM always exists, are often easier to compute and estimate than LMOM, and in general behave similarly to the LMOM. In fact, in some recent literature such as Shabri et al. (2007) it has found that LQM gives better performance in high quantile estimation as compared to the conventional LMOM.

Analogous to λ_r, the rth LQ-moments ζ_r of X is defined as

$$\zeta_r = r^{-1} \sum_{k=0}^{r-1} (-1)^k \binom{r-1}{k} \tau_{p,\alpha}(X_{r-k:r}), \quad r = 1,2,...; \tag{3.2.1}$$

where $0 \le \alpha \le 1/2,\ 0 \le p \le 1/2$, and

$$\tau_{p,\alpha}(X_{r-k;r}) = pQ_{X_{r-k;r}}(\alpha) + (1-2p)Q_{X_{r-k;r}}(1/2) + pQ_{X_{r-k:r}}(1-\alpha) \tag{3.2.2}$$

and $Q_X(.)$ is the quantile function. $\tau_{p,\alpha}$ is called the median for p=0, $\alpha = 1$, trimean for p=1/4, $\alpha = 1/4$ and Gastwirth for p=.3, $\alpha = 1/3$. In this study trimean based estimator is considered.

The LQ moment can be estimated from the sample by estimating the quick estimator

$$\hat{\tau}_{p,\alpha}(X_{r-k;r}) = p\hat{Q}_{X_{r-k;r}}(\alpha) + (1-2p)\hat{Q}_{X_{r-k;r}}(1/2) + p\hat{Q}_{X_{r-k:r}}(1-\alpha) \tag{3.2.3}$$

of the location of the order statistic $X_{r-k:r}$ and $\hat{Q}_X(.)$ denotes the linear interpolation estimator given by

$$\hat{Q}_X(u) = (1-\varepsilon)X_{[n'u]:n} + \varepsilon X_{[n'u]+1:n} \qquad (3.2.4)$$

where $\varepsilon = n'u - [n'u]$ and $n' = n+1$. Details procedure for parameter estimations of different distributions using LQM for extreme events can be found in the existing references such as Mudholkar and Hutson (1998), Shabri and Jemain (2007), Zin et al. (2008).

3.3 Goodness of fit

The tests applied for judging the goodness of fit for the fitted distributions for annual maximum rainfall series are relative root mean squared error (RRMSE), relative mean absolute error (RMAE) and probability plot correlation coefficient (PPCC). While the first two tests involve the assessment on the difference between the observed values and expected values of the assumed distributions, the last one measures the correlation between the ordered values and the corresponding expected values. The formulae for the tests are

$$\text{RRMSE}=\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{x_{i:n}-\hat{Q}(F_i)}{x_{i:n}}\right)^2} \qquad (3.3.1)$$

$$\text{RMAE}=\frac{1}{n}\sum_{i=1}^{n}\left|\frac{x_{i:n}-\hat{Q}(F_i)}{x_{i:n}}\right| \qquad (3.3.2)$$

$$\text{PPCC}=\frac{\sum_{i=1}^{n}(x_{i:n}-\bar{x})\{\hat{Q}(F_i)-\overline{Q}(F)\}}{\sqrt{\sum_{i=1}^{b}(x_{i:n}-\bar{x})^2}\sqrt{\sum_{i=1}^{n}\{\hat{Q}(F_i)-\overline{Q}(F)\}^2}} \qquad (3.3.3)$$

where $x_{i:n}$ is the observed values of the ith order statistics of a random sample of size n, $\hat{Q}(F_i)$ is the estimated quantile values associated with the ith Gringorten plotting position, $F_i = \frac{i-.44}{n+.12}$ and $\overline{Q}(F) = \frac{1}{n}\sum_{i=1}^{n}\hat{Q}(F_i)$.

The smallest values of RRMSE and RMAE correspond to the best fitting distribution where as in the case of PPCC, the distribution with the computed PPCC closest to 1 indicates the best. In order to confirm the goodness of fit for the above five distributions we additionally applied L-moment ratio diagram. L-moment ratio diagram was first introduced by Hosking (1990) which can be drawn by plotting L-kurtosis τ_4 as ordinate and L-skewness τ_3 as abscissa. According to Hosking and Wallis (1997), the simple explicit expressions for τ_4 in terms of τ_3 for the assumed distributions can be written as

$$\tau_4 = \sum_{k=0}^{8} A_k \tau_3^k \qquad (3.3.4)$$

where the coefficients A_k are given in the Table 1. Although this is a crude method, it can provide some insights on the selection of the best fitting distribution.

Table1. Polynomial approximations of τ_4 as a function of τ_3.

A_i	GPD	GEV	GLD	LN3	P3
A_0	0	0.10701	0.16667	0.12282	0.1224
A_1	0.20196	0.11090	-	-	-
A_2	0.95924	0.84838	0.83333	0.77518	0.30115
A_3	-0.20096	-0.06669	-	-	-
A_4	0.04061	0.00567	-	0.12279	0.95812
A_5	-	-0.04208	-	-	-
A_6	-	0.03763	-	-0.13638	-0.57488
A_7	-	-	-	-	-
A_8	-	-	-	0.11368	0.19383

The observed sample L-skewness t_3 for all the nine stations are substituted in place of τ_3 in Eq. (3.3.4) to get the estimated L-kurtosis τ_4 for the assumed distributions. These computed values (τ_3, τ_4) for each distributions along with the observed (t_3, t_4) are plotted on the L moment ratio diagram. For a particular station, the distances between (τ_3, τ_4) and (t_3, t_4) for all distributions are compared and evaluated. The distribution corresponding to the smallest distance is considered to be the best.

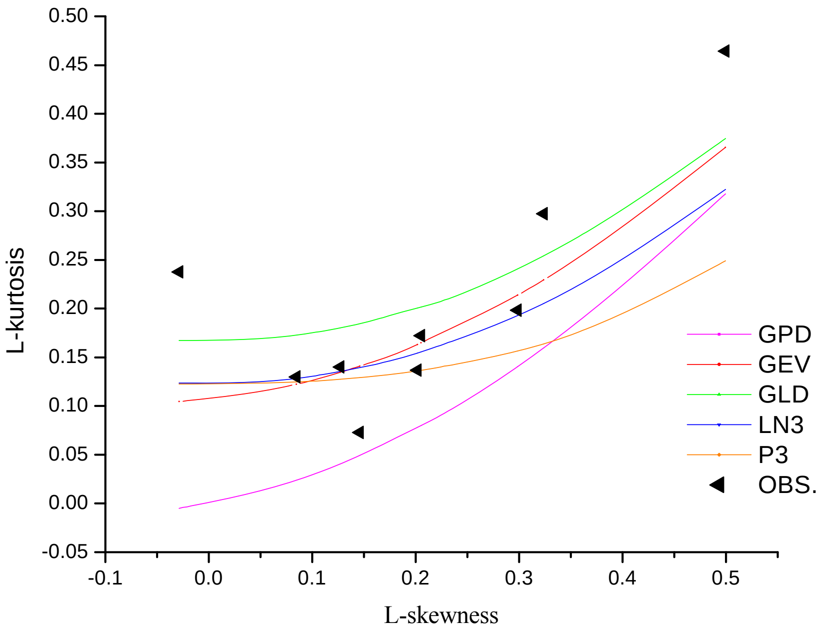

Fig. 3. L-moment ratio diagram for annual maximum rainfall of 9 stations of North East India.

4. RESULTS AND DISCUSSION

The extreme rainfall amount can be characterized by mean, standard deviation and coefficient of variation. Table 2 provides a quantitative comparison between the rain gauge stations, and it can be concluded that Cherrapunji received the highest mean and standard deviation of annual maximum daily rainfall amount during Indian summer. The coefficients of variations for Mohanbari followed by Pasighat are found to be higher as compared to the stations in other areas. This may indicate that the amounts of extreme rainfall in those two stations are relatively more spread as compared to the other regions of North East India.

Table 2. Main characteristics of the rain gauge stations in North-East India

Stations	*Mean*	*SD*	*`CV*
Cherrapunji	*573.6167*	*172.6664*	*.3010*
Guwahati	*104.9786*	*35.2915*	*.3362*
Imphal	*82.7619*	*29.5122*	*.3566*
Mohanbari	*142.9476*	*86.7992*	*.6072*
North Lakhimpur	*149.1619*	*38.1247*	*.2556*
Pasighat	*225.3238*	*98.8148*	*.4385*
Shillong	*144.5048*	*51.3595*	*.3554*
Silchar	*153.2524*	*56.4452*	*.3683*
Tezpur	*103.7476*	*27.3783*	*.2639*

Table 3. Estimates of the parameters for each distribution using LMOM and LQM

Stations	GEV		GPD		GLD		LN3		P3	
	LMOM	LQM	LMOM	LQM	LMOM	LQM	LMOM	LQM	LMOM	LQM
	k α ξ	k α ξ	k α ξ	k α ξ	k α ξ	k α ξ	k α ξ	k α ξ	γ σ μ	γ σ μ
	0.3363	0.3560	1.1173	1.000	0.0285	0.0360	0.0583	0.0640	-0.1749	-0.1920
Cherrapunji	172.6430	149.3092	628.8920	419.5162	95.1530	90.1574	168.6404	148.8653	169.0413	149.2093
	518.5045	513.103	276.5963	371.6294	578.0814	582.3670	578.5398	582.4713	573.6167	577.7027
	-0.1915	-0.3000	0.0805	0.0360	-0.2985	-0.4160	-0.6242	-0.7280	1.7919	2.0040
Guwahati	20.8402	21.7337	40.1017	38.11	15.3371	17.3146	26.8691	28.4477	34.8749	37.2045
	88.1314	87.0536	67.8646	69.1262	96.5968	95.5698	95.7198	95.3781	104.9786	106.3616
	-0.0543	-0.3280	0.3192	-0080	-0.2051	-0.4360	-0.4240	-0.7640	1.2403	2.0880
Imphal	22.1224	17.5081	49.4519	30.0019	15.0686	14.1161	26.5802	23.1368	30.0530	31.0654
	68.7411	70.2415	45.2743	55.9885	77.4199	77.1384	76.8654	76.9724	82.7619	86.4243
	-0.4565	-0.3200	-0.3324	0.2920	-0.4995	-0.2960	-1.0912	-0.5160	3.0763	1.4760
Mohanbari	24.7200	23.4385	36.6807	46.7769	20.9966	17.3864	35.4176	28.6435	75.7399	32.9933
	108.5838	114.0436	88.0068	93.2714	119.0238	122.9397	116.5368	122.8082	142.9416	130.4069
	0.0680	0.0320	0.5486	0.5520	-0.1272	-0.1800	-0.2613	-0.3160	0.7755	0.9280
North Lakhimpur	32.4959	32.4931	83.8063	74.0877	20.6730	22.4868	36.5793	37.0933	38.3489	39.1814
	132.4625	130.9820	95.0454	99.9498	144.7546	142.9309	144.3000	142.8181	149.1619	148.7270
	-0.2270	-0.0440	0.0217	0.4360	-0.3238	-0.2320	-0.6798	-0.4040	1.9426	1.1760
Pasighat	53.0678	51.9931	98.4042	111.9100	39.8415	37.1670	69.6121	61.2882	94.6700	66.9654
	179.5084	184.1884	128.0075	136.0804	201.2315	203.6091	198.7062	203.3914	225.3238	215.9816
	0.1379	0.5840	0.6878	1.0000	-0.0847	0.1840	-0.1736	0.3200	0.5181	-0.9430
Shillong	46.7575	56.1169	131.3953	145.2479	28.6249	30.8502	50.6990	50.8995	51.7721	53.8564
	123.1935	128.1228	66.6530	72.1260	140.4849	146.4686	140.0714	146.6097	144.5048	138.3708
	-0.0489	-0.1840	0.3290	0.2120	-0.2016	-0.3320	-0.4165	-0.5800	1.2192	1.6400
Silchar	41.3860	39.5753	93.0847	75.8442	28.1038	30.0186	49.5829	49.4166	55.8246	58.9284
	127.2679	127.9298	83.2108	93.6376	143.4791	143.1093	142.4651	142.8484	153.2524	157.6936
	0.0380	0.0367	0.4908	0.5600	-0.1459	-0.1760	-0.3000	-0.3080	0.8877	0.9113
Tezpur	23.0766	26.0570	57.4158	59.6667	14.9269	17.9989	26.3969	29.6939	28.0887	31.2981
	91.2652	89.7576	65.2339	64.8108	100.0761	99.3349	99.6970	99.2498	103.7476	103.8820

The Next analysis involves the estimation of parameters for each distribution using LMOM and LQM. The estimated values are given in Table 3. The computation is carried out using the software Matlab 6. Subsequent analysis involves selection of the best fitting distribution out of the five candidate distributions. Results for all GOF tests for each station based on L-moment and LQ-moment are presented in Table 4. The distribution that is found best at least twice out of the three GOF tests will be selected as the best fitting distribution for both the LMOM and LQM. Then, we summarize the results based on the L-moment ratio diagram (Figure 3), LMOM and LQM under the three GOF tests to decide the best fitting distribution for a particular station in Table 5.

Under LMOM, it is found that the number of stations identified best using GLD, GEV, LN3, GPD and P3 are 3, 3, 0, 1 and 2 respectively. On the other hand, under LQM, it is found that the number of stations identified best using GLD, GEV, LN3, GPD and P3 are 3, 1, 2, 0 and 3 respectively. Further in the L-moment ratio diagram, number of stations identified best using GLD, GEV, LN3, GPD and P3 are 3, 1, 3, 1 and 1 respectively. This information can be summarized in Table 6 by ranking them in descending order to show the best fitting distribution for all the stations in North-East India.

Table 4. Outcomes of the GOF tests based on LMOM and LQM methods

Stations	LMOM				LQM			
	RRMSE	RASE	PPCC	BEST	RRMSE	RASE	PPCC	BEST
Cherrapunji	GLD	GLD	GLD	GLD	GLD	GLD	GLD	GLD
Guwahati	GEV	GEV	GLD	GEV	LN3	LN3	GEV	LN3
Imphal	GEV	GEV	P3	GEV	LN3	LN3	GPD	LN3
Mohanbari	GLD	GLD	GLD	GLD	GLD	P3	GLD	GLD
North Lakhimpur	GEV	GEV	GLD	GEV	GEV	P3	GEV	GEV
Pasighat	GLD	GLD	GLD	GLD	GLD	GLD	GLD	GLD
Shillong	P3	GEV	P3	P3	P3	P3	GPD	P3
Silchar	P3	P3	GLD	P3	P3	P3	LN3	P3
Tezpur	GPD	GPD	P3	GPD	P3	P3	P3	P3

Table 5. Best fitting distributions based on L-moment ratio diagram, LMOM and LQM methods for all rain gauge stations

Stations	LMOM	LQM	LMOM Ratio Diagram
Cherrapunji	GLD	GLD	GLD
Guwahati	GEV	LN3	LN3
Imphal	GEV	LN3	GEV
Mohanbari	GLD	GLD	GLD
North Lakhimpur	GEV	GEV	LN3
Pachighat	GLD	GLD	GLD
Shillong	P3	P3	LN3
Silchar	P3	P3	P3
Tezpur	GPD	P3	GPD

Table 6. Ranking (in descending order) of the distributions for all stations based on methods of LMOM, LQM and L-moment ratio diagram

Ranking	LMOM	LQM	LMOM Ratio Diagram
1	GEV, GLD	GLD, P3	GLD, LN3
2	P3	LN3	GEV, GPD, P3
3	GPD	GEV	-
4	LN3	GPD	-

5. CONCLUDING REMARKS

This study reveals that the results of the best fitting distributions may differ for a particular station depending on either LMOM or LQM is used. However, GLD is found to be more consistent in comparison to the other three best fitting distributions. If we consider LMOM, GEV shares the first rank with GLD but fails to perform under LQM and in LMOM ratio diagram. For LQM, P3 is found to be best fitting distribution along with GLD but receives second rank in LMOM and works poorly in case of LMOM ratio diagram. Further, in case of LMOM ratio diagram LN3 distribution holds the first rank with GLD but it is found to be least frequently selected under LMOM methods. From the above discussions, it can be concluded that GLD is the most suitable distribution to describe the annual maximum rainfall in North East India, which also agrees with the result obtained by Zin et al. (2008). But GPD is found to be the least frequently selected distribution. This result differs from the result obtained by Zin et al. (2008) for extreme rainfall in Peninsular Malaysia.

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