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Fitting a Probability Distribution to Extreme Precipitation for a Limited Mountain Area in Vietnam

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Abstract

In this paper, an analysis of adapted 20 extreme precipitation indices is calculated for a limited mountain area in southern Vietnam. The daily precipitation data from four stations in the period of more than 30 years are selected. The statistical characteristics of maximum, minimum, mean, standard deviation, skewness, and kurtoris for each index are also analysed. A variety of distributions such as Normal, Lognormal, Beta, Gamma, Exponential, Loglogistic, and Johnson is used to find the best fit probability distribution for this area on the basic of the highest score. The scores are estimated based on the ranking of statistical goodness of fit test. The goodness of fit tests is the Anderson-Darling and Shapiro-Wilks tests. The best fit distribution for each index of extreme precipitation at each station is found out. Results revealed that the Johnson distribution is the best fit distribution to the data of very heavy precipitation days greater than 50 mm. Over a limited mountain area, it is difficult to fit a probability distribution to the precipitation fraction due to extremely wet days, number of extremely wet days, and number of extremely wet days when precipitation greater than 99 percentage. The lognormal, Johnson, and Loglogistic distribution are the best choices to fit most of the extreme precipitation indices over this area.

Keywords

Extreme Precipitation, Mountain, Distribution, Vietnam

1. Introduction

In the field of climate research, precipitation is considered to be one of the key terms for balancing the energy budget, and one of the most challenging aspects of climate modeling, especially for convection precipitation parameterization schemes. Therefore, high quality estimations of precipitation distribution, amounts and intensity are important to fully interpret the climate regime and the effects of climate on other fields (e.g., water and agriculture) at a variety of scales from global to local. For daily precipitation, a Markow chain was firstly suggested for the representation of the sequence of wet and dry days [1]. Later, this approach has been broadly used to model for the occurrences of wet and dry days (e.g., [2] [3]). As a part of the Markow chain, a chain dependent process was also proposed to compute the distribution of the maximum amount of daily precipitation and the total amount of precipitation on the example of State College, Pennsylvania [4]. In the Markow process, an assumption of precipitation state on the next day is related to the state of precipitation on the numbers of previous days. On a wet day as a defined precipitation amount is commonly generated using the distributions of Gamma [5] [6] [7] [8], an exponential and a mixed Exponential distribution [9] [10] [11], a skewed Normal [12], and a truncated power of Normal [13] [14]. The first-order Markov chain-dependent exponential, gamma, mixed-exponential, and lognormal distributions also applied to model the daily precipitation for the observed data from 10 stations in the Yishu River [15]. Reviews on the modeling of precipitation can be found in [9] [16] [17] [18] [19].

Wilks [20] used the daily precipitation data from 30 locations across the USA to investigate the effects of different formulations for the occurrence- and amounts-components of stochastic daily precipitation. The study showed that a mixed exponential distribution offered an improvement only in case the extremes were not very high (less than 100 mm). The extreme daily precipitation amounts were underestimated using the Gamma model in comparison to a mixed exponential model.

Semenow [21] used the weather data from 20 locations at Baker Lake, Canada, to desert at Boise, USA to investigate how well weather extreme events were simulated by weather generators. Annual maximum daily precipitation was modeled using the generalized extreme value distribution and computing confidence intervals. The results showed a good simulation for extreme events in the range of the observations with diverse climates.

Olofintoye [22] used a variety of distribution (*i.e.*, Gumbel, Log-Gumbel, Normal, Log-Normal, Pearson and Log-Pearson distributions) to study the peak daily precipitation in Nigeria. The weather data from 20 stations were taken into account with a period of 54 years (1952-2005). The tests of chi-square, Fisher, correlation coefficient, and coefficient of determination were used to define how best the fits are. The results showed that the best performance of log-Pearson type III distribution, followed by the Pearson type III, and log-Gumbel with a percentage of the considered station 50%, 40%, and 10% respectively.

Su [23] performed a simulation of extreme precipitation using Wakeby distribution. Data from 147 stations in the Yangtze River Basin were selected. To quantify the high and low extreme precipitation characteristics, the distribution of probability were applied (*i.e.*, Gerneral Extreme Value, General Pareto, General Logistic, and Wakeby). Results showed that the Wakeby distribution well simulated the probability distribution of extreme precipitation, both in observed and projected data.

In most of the hydrological models, a long series of precipitation data is significantly of great importance to assess the effects of precipitation regime on water resources, environmental and agricultural planning fields. A temporally and spatially continuous distribution of precipitation can robust the quality of computing results. However, it is quite difficult to find enough evenly spread weather variables like precipitation to cover the entire nation in general and the area of interest in particular, both in space and time resolution. The reason for this is the limitations of observation system (e.g., density of precipitation measuring network). Furthermore, insufficient terrestrial meteorological observations are considered to be the most important source of uncertainty in the different studies (e.g., [7]). To overcome this problem, a stochastic weather generator (e.g., [24]) is applied to produce synthetic time series of weather data of unlimited length based on the statistical characteristics of observed weather data for a given location [25].

Located on the eastern margin of the Indochinese peninsula, Vietnam's climate is strongly dominated by a typical climate of tropical monsoon of a peninsula in the Southeast of the European-Asian continent. The geographical characteristics of Vietnam is a long coastline of 3260 kilometers, series of mountain in the direction from northwest to southeast (in the northeast mountain regions), from west to east (in the central regions), central highland, and a limited low mountain area in the Southeast Vietnam. Besides that, with a long and narrow shape, the climate of Vietnam is significantly complex from place to place and time to time. Under a global warming, change in extreme weather events (e.g., heavy precipitation) is unevenly, especially for a limited mountain area in southern Vietnam in which the weather patterns are dominated by a variety of natural conditions (e.g., oceanic air mass and elevation). Thus, it is a cruel task to analyse and define the variability in extreme precipitation characteristics as well as its distribution to get significant information for a limited area. This information will be very useful for different objects, especially in the studies in flood events, urban flooding, flash flood, or environmental planning fields.

As pointed out by the Expert Team of the World Meteorological Organization and Climate Variability and Predictability on Climate Change Detection and Indices, 11 [26] [27] and later on updated to 15 extreme precipitation indices are suggested in the climate change projects. In this study, however, adapted 20 extreme precipitation indices are analysed for a limited mountain area located in southern Vietnam. The daily precipitation at four precipitation measuring stations has been selected to find a fitted distribution of probability to mountain extreme precipitation for this area.

2. Data and Methods

2.1. Data

A limited mountain area of southern Vietnam is selected to investigate extreme precipitation indices (Figure 1). Daily precipitation data has been obtained from the Vietnam Hydro Metorological Data Center (Table 1). The records from four precipitation measuring stations cover a period of more than 30 years (1981 to 2013). A tropical monsoon climate pattern with two distinguishable seasons (*i.e.*, rainy season and dry season) dominates the climate regime over this area. Rainy season prolongs from May to November and dry season lasts from December to April. The rainy seasonal precipitation contributes about 93% of the annual precipitation (2000 mm).

Table 2 shows a list of extreme precipitation indices. All characteristics of precipitation are aggregated from the time scale of daily. A wet day is defined as daily precipitation greater than or equal to 0.5 mm.

2.2. Methods

In this study, the distribution of probability included normal, lognormal, gamma, loglogistic, beta, Johnson, and exponential were taken into account to define the best fit probability distribution for extreme precipitation. The description of various probability distribution functions and density functions, ranges and the parameters involved are shown in Table 3.

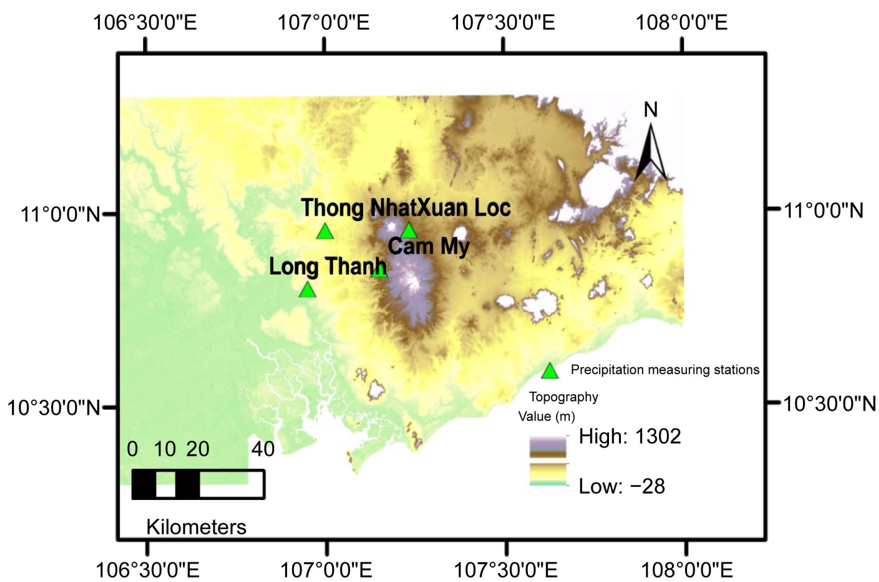

Figure 1. Topography map of the study area.

Table 1. Lists of the precipitation measuring stations.

Nr.	Station	Station code	Coordinates		Elevation (m a.s.l)	Period
			Latitude (N)	Longitude (E)		
1.	Long Thanh	30901006	10˚27	106˚33	41	1978-2013
2.	Cam My	30901004	10˚51	107˚09	145	1981-2013
3.	Thong Nhat	30901013	10˚57	107˚00	61	1981-2010
4.	Xuan Loc	30901016	10˚57’	107˚14’	190	1990-2010

Table 2. Extreme precipitation indices.

Nr.	Indices	Abbrev.	Unit	Nr.	Indices	Abbrev.	Unit
1.	Annual total precipitation	RR	mm	2.	No. of wet days (≥0.5 mm)	RR5	days
3.	Moderate precipitation days (≥10 mm)	RR10	days	4.	Heavy precipitation days (≥25 mm)	RR25	days
5.	Very heavy precipitation days (≥50 mm)	RR50	days	6.	Extreme heavy precipitation days (≥100 mm)	RR100	days
7.	Highest 1-day precipitation amount	RX1day	mm	8.	Highest 3-day precipitation amount	RX3day	mm
9.	Highest 5-day precipitation amount	RX5day	mm	10.	Highest 7-day precipitation amount	RX7day	mm
11.	Maximum no. of consecutive wet days	MCWD	days	12.	Maximum no. of consecutive dry days	MCDD	days
13.	Simple precipitation intensity index	SDII	mm/wd	14.	No. of moderate wet days >75 percentage	R75p	days
15.	Precipitation fraction due to moderate wet days	R75pTOT	%	16.	No. of very wet days >95 percentage	R95p	days
17.	Precipitation fraction due to very wet days	R95pTOT	%	18.	No. of extremely wet days >99 percentage	R99p	days
19.	Precipitation fraction due to extremely wet days	R99pTOT	%	20.	Annual total precipitation in wet days	PRCPTOT	mm

Table 3. Description of various probability distribution functions.

Distributions	Probability density functions	Ranges	Parameters
Normal	$f(x)=\frac{1}{\alpha\sqrt{2\pi}}\mathrm{e}^{-\frac{1}{2}\left(\frac{x-\beta}{\alpha}\right)^2}$	$-\infty < x < \infty$	α: standard deviation β: mean
Beta	$f(x,\alpha,\beta)=\frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}x^{\alpha-1}(1-x)^{\beta-1}$	$0 \le x \le 1$ $\alpha, \beta > 0$	α: shape parameter β: scale parameter
Exponential	$f(x,\alpha,\beta)=\begin{cases} 0 & \text{when } x \le \alpha \\ \frac{1}{\beta}\mathrm{e}^{-\frac{(x-\alpha)}{\beta}} & \text{when } x > \alpha \end{cases}$	$\gamma \le x < \infty$ $-\infty < \alpha < \infty$ $\beta > 0$	α: location parameter β: scale parameter
Gamma	$f(x,\alpha,\beta,\gamma)=\begin{cases} 0 & \text{when } x \le \alpha \\ \frac{1}{\beta^{\gamma}\Gamma(\gamma)}(x-\gamma)^{\gamma-1}\mathrm{e}^{-\frac{(x-\gamma)}{\beta}} & \text{when } x > \alpha \end{cases}$	$\gamma \le x < \infty$ $-\infty < \alpha < \infty$ $\beta > 0$ $\gamma > 0$	α: location parameter β: scale parameter γ: shape parameter
Loglogistic	$f(x,\alpha,\beta)=\frac{\mathrm{e}^{\frac{x-\alpha}{\beta}}}{\beta\left(1+\mathrm{e}^{\frac{x-\alpha}{\beta}}\right)}$	$-\infty < x < \infty$ $-\infty < \alpha < \infty$ $\beta > 0$	α: location parameter β: scale parameter
Lognormal	$f(x,\alpha,\beta,\gamma)=\begin{cases} 0 & \text{when } x \le \alpha \\ \frac{1}{(x-\alpha)\sqrt{2\pi}}\mathrm{e}^{-\frac{(\ln(x-\gamma)-\beta)^2}{2\gamma^2}} & \text{when } x > \alpha \end{cases}$	$\gamma < x < \infty$ $-\infty < \alpha < \infty$ $-\infty < \beta < \infty$ $\gamma > 0$	α: location parameter β: scale parameter γ: shape parameter
Johnson	$f(x,\alpha,\beta,\gamma,m)=\begin{cases} 0 & \textit{when } x \le m-\frac{\gamma}{2}, x \ge m+\frac{\gamma}{2} \\ \frac{\alpha\gamma}{\sqrt{2\pi}\left(x-m+\frac{\gamma}{2}\right)\left(m+\frac{\gamma}{2}-x\right)}\mathrm{e}^{-\frac{1}{2}\left(\beta+\alpha\ln\left(\frac{x-m+\frac{\gamma}{2}}{m+\frac{\gamma}{2}-x}\right)\right)^2} & \textit{when } m-\frac{\gamma}{2} < x < m+\frac{\gamma}{2} \end{cases}$	$m - \gamma/2 < x < m + \gamma/2$ $-\infty < m < \infty$ $-\infty < \beta < \infty$ $\alpha > 0$ $\gamma > 0$	m: location parameter α: shape parameter β: shape parameter γ: scale parameter

The goodness of fit test refers to measuring how well do the compatibility of random sample with the theoretical probability distribution. A goodness of fit statistic tests is applied for testing the following null hypothesis:

H_0: the model of extreme precipitation parameter fits the specified distribution

H_A: the model of extreme precipitation parameter does not fit the specified distribution.

The Anderson-Darling and Shapiro-Wilks tests were used to identify if a sample comes from a population with a specific distribution. The chi-square test at α (0.05) level of significance for the selection of the best fit probability distribution was applied. Several studies related to these tests can be found in [28] [29] [30], or [31]. According to Anderson and Darling [28], a Anderson-Darling statistic (AD) is defined as follows:

$$AD_n^2 = -n - \frac{1}{n}\sum_{i=1}^{n}(2i-1)\left[\log u_{(i)} + \log\left(1-u_{(n-i+1)}\right)\right] \tag{1}$$

where $u_{(i)} = F^o\left(x_{(i)}\right)$ and $x_{(1)} < x_{(2)} < \cdots < x_{(n)}$ is the ordered sample

This test allows comparing the fit of an observed cumulative distribution function to an expected cumulative distribution function.

The Shapiro-Wilks (SW) test, suggested in [29], calculates a SW statistic. It is defined as follows:

$$SW = \frac{\left(\sum_{i=1}^{n} a_i x_{(i)}\right)^2}{\sum_{i-1}^{n}\left(x_i - \bar{x}\right)^2} \tag{2}$$

where

$x_{(i)}$ are the ordered sample values ($x_{(1)}$ is the smallest).

a_i are constants generated from the means, variances and covariances of the order statistics of a sample of size n from a normal distribution.

$$\bar{x} = \frac{\left(x_1 + \cdots + x_n\right)}{n} \tag{3}$$

3. Results

Statistical characteristics of extreme precipitation indices for a limited mountain area in Vietnam are shown in **Supplementary** (from **Tables 5-8**). They are mean, standard deviation, skewness, kurtoris, maximum, and minimum values. It was observed that the maximum and minimum of very heavy precipitation days and extreme heavy precipitation can be reached sixteen and thirteen days in a year at Long Thanh station, respectively. The maximum of maximum number of consecutive wet days is calculated for Long Thanh and Cam My station (49 days), followed by Xuan Loc (36 days). Meanwhile, the maximum of maximum number of consecutive dry days is calculated for Cam My station (126 days), followed by Long Thanh station (114 days). Specifically, the maximum of highest 7-day precipitation amount are calculated for Thong N hat station (508.9 mm), followed by Xuan Loc station (442.2 mm). The maximum value of coefficient of skewness was observed at the station Xuan Loc for the maximum number of consecutive wet days.

In this study, the statistic of each test were tested at $\alpha = 0.05$ level of significance. Based on minimum test statistic value, the ranking of different probability distributions were marked from 1 to 7 for the Anderson-Darling and Shapiro-Wilks tests of mentioned probability distributions. In case the value of test is not significant at α level, they are marked as zero. To find the best fit distribution, the maximum score of probability distribution was totaled based on the cumulative ranking. With the highest scored obtained is selected as the best fit distribution. The value of test is additionally considered as a criterion in case the same scores are seen between the probability distributions. The p-values of statistical tests are presented in **Supplementary** (from Tables 9-12).

Based on the calculated total test score obtained for each index for seven probability distributions, the best selected probability distributions for each data set are presented in Table 4. These distributions were defined using maximum total score from the selected goodness of fit test. As shown in Table 4, it is noteworthy that none of these probability distributions fits to the precipitation fraction due to extremely wet days, number of extremely wet days, number of

Table 4. Best fit probability distributions for extreme precipitation indices.

Stations Indices	Thong Nhat	Long Thanh	Cam My	Xuan Loc
RR	Lognormal	Loglogistic’	Lognormal	Johnson
RR5	Gamma	Johnson	Gamma	Johnson
RR10	Lognormal	Johnson	Johnson	Loglogistic
RR25	Beta	Lognormal	Lognormal	Johnson
RR50	Johnson	Johnson	Johnson	Johnson
RR100	0	0	0	0
RX1day	Lognormal	Johnson	Lognormal	Johnson
RX3day	Johnson	Lognormal	Loglogistic	Johnson
RX5day	Johnson	Lognormal	Loglogistic	Johnson
RX7day	Lognormal	Lognormal	Loglogistic	Johnson
MCWD	Johnson	Gamma	Johnson	Johnson
MCDD	Gamma	Lognormal	Beta	Lognormal
SDII	Johnson	Lognormal	Johnson	Loglogistic
R75p	Gamma	Johnson	Lognormal	Loglogistic
R75pTOT	Johnson	Lognormal	Lognormal	Loglogistic
R95p	Gamma	Johnson	Beta	Loglogistic
R95pTOT	Lognormal	Johnson	Gamma	Loglogistic
R99p	0	0	0	0
R99pTOT	0	0	0	Lognormal
PRCPTOT	Lognormal	Loglogistic	Lognormal	Johnson

extremely wet days when precipitation greater than 99 percentage, and extreme heavy precipitation days (≥100 mm) at α level except the lognormal distribution is the best fit distribution to the precipitation fraction due to extremely wet days at Xuan Loc station.

It was shown that the best fit distributions of lognormal, Johnson, and loglositic fit to most of the extreme precipitation indices over this area. Specially, it was found out that the Johnson distribution is the best fit distribution to the data of very heavy precipitation days greater than 50 mm for a limited mountain area as presented in Table 4.

4. Conclusions

The results indicated a large range of fluctuation during the period of study for the maximum number of consecutive wet days from 4 days (minimum) to 49 days (maximum) and the maximum number of consecutive dry days from 13 days (minimum) to 126 days (maximum), respectively. The number of heavy precipitation could be up to 25% of days in a year (e.g., at Xuan Loc station). The maximum of annual precipitation (nearly 2900 mm) was seen at Long Thanh station. Analysis results revealed a potential precipitation amount over this area. The highest precipitation amount of 1, 3, 5, and 7-days could significantly contribute to potential the extreme flood events due to a large recorded precipitation amount.

It was seen that the best probability distributions were different for different extreme precipitation indices. In general, the distributions of Johnson, Loglogistic, and Lognormal are the best choices for most of extreme precipitation indices for a limited mountain area. Over this area, the best probability distributions are Lognormal and Loglogistic for the highest precipitation amount of 3, 5, and 7 days, respectively. Therefore, the author gives a recommendation that it should be firstly investigated the Lognormal, Loglogistic, and Johnson distributions in the studies dealing with extreme precipitation indices for other limited mountain areas in which are normally challenging to gather data.

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Supplementary

Table 5. Summary of statistics for extreme precipitation indices at Xuan Loc station.

	Maximum	Minimum	Mean	Standard deviation	Skewness	Kurtoris
RR	2645.0	1677.6	2140.1	227.0	0.4	0.5
RR5	170.0	59.0	81.1	23.2	3.0	11.3
RR10	89.0	25.0	38.2	13.7	2.9	9.8
RR25	26.0	0.0	18.2	5.4	−1.9	5.8
RR50	11.0	0.0	6.7	2.7	−0.3	0.9
RR100	3.0	0.0	1.1	1.0	0.5	−0.8
RX1day	246.7	23.8	109.6	44.3	1.4	4.2
RX3day	313.7	51.9	167.8	52.6	0.5	2.5
RX5day	375.2	78.3	206.9	59.5	0.8	2.8
RX7day	442.2	105.6	242.2	73.4	1.1	2.3
MCWD	36.0	10.0	28.8	50.1	4.5	20.4
MCDD	105.0	15.0	53.0	24.5	0.5	−0.1
SDII	17.7	8.0	15.0	2.1	−1.9	5.6
R75p	46.0	7.0	36.3	8.1	−2.4	8.1
R75pTOT	77.6	8.9	68.3	14.2	−4.0	17.2
R95p	11.0	0.0	7.3	3.0	−0.6	0.0
R95pTOT	48.0	0.0	31.7	11.0	−1.3	2.4
R99p	4.0	0.0	1.5	1.3	0.7	−0.5
R99pTOT	26.9	0.0	10.6	8.5	0.5	−0.8
PRCPTOT	2639.4	1675.7	2136.8	226.3	0.4	0.5

Table 6. Summary of statistics for extreme precipitation indices at Long Thanh station.

	Maximum	Minimum	Mean	Standard deviation	Skewness	Kurtoris
RR	2870.9	1260.6	1983.2	311.8	0.3	1.1
RR5	113.0	11.0	63.9	30.3	−0.2	−1.2
RR10	72.0	18.0	35.3	10.3	1.4	3.4
RR25	29.0	10.0	18.2	4.5	0.0	−0.1
RR50	13.0	0.0	6.5	2.8	0.2	0.2
RR100	3.0	0.0	0.8	1.0	0.9	−0.1
RX1day	226.5	39.9	106.7	40.6	1.4	2.0
RX3day	307.2	90.4	160.4	51.5	1.3	1.5
RX5day	350.2	118.5	195.0	57.5	1.3	1.5
RX7day	432.2	144.7	226.7	65.7	1.5	2.4
MCWD	49.0	4.0	14.8	9.5	1.7	3.7
MCDD	114.0	22.0	61.1	25.0	0.3	−0.7
SDII	31.9	9.8	17.0	4.8	1.0	1.2
R75p	44.0	17.0	30.6	6.4	−0.1	−0.5
R75pTOT	82.7	33.4	64.0	12.9	−0.9	0.5
R95p	13.0	0.0	6.0	2.9	0.2	−0.2
R95pTOT	42.6	0.0	22.6	11.1	0.0	−0.9
R99p	5.0	0.0	1.2	1.2	1.1	1.7
R99pTOT	26.4	0.0	6.8	6.8	0.9	0.5
PRCPTOT	2868.0	1260.6	1980.4	311.7	0.3	1.0

Table 7. Summary of statistics for extreme precipitation at indices Cam My station.

	Maximum	Minimum	Mean	Standard deviation	Skewness	Kurtoris
RR	2460.6	624.3	1646.9	490.3	−0.6	−0.3
RR5	94.0	34.0	61.8	14.8	−0.2	−0.6
RR10	49.0	17.0	34.3	7.8	−0.1	−0.6
RR25	28.0	0.0	14.9	7.9	−0.6	−0.3
RR50	10.0	0.0	3.4	3.0	0.5	−1.0
RR100	3.0	0.0	0.8	0.8	0.9	0.5
RX1day	169.0	18.1	84.6	38.3	0.0	−0.3
RX3day	323.8	35.2	135.9	62.7	0.7	1.2
RX5day	347.3	45.4	166.8	67.4	0.4	0.6
RX7day	366.7	60.1	194.4	72.3	0.0	0.2
MCWD	49.0	4.0	12.9	8.4	2.9	10.5
MCDD	126.0	31.0	74.8	28.4	0.1	−1.2
SDII	19.6	6.7	14.1	3.1	−0.8	0.5
R75p	50.0	1.0	28.7	12.7	−0.9	0.0
R75pTOT	73.3	2.8	56.1	21.0	−1.6	1.2
R95p	13.0	0.0	5.8	4.3	0.1	−1.2
R95pTOT	41.3	0.0	19.5	13.5	−0.1	−1.2
R99p	4.0	0.0	1.2	1.2	0.8	−0.3
R99pTOT	20.2	0.0	6.2	5.9	0.7	−0.3
PRCPTOT	2460.6	624.3	1646.7	490.3	−0.6	−0.3

Table 8. Summary of statistics for extreme precipitation indices at Thong Nhat station.

	Maximum	Minimum	Mean	Standard deviation	Skewness	Kurtoris
RR	2394.7	1307.4	1856.0	256.8	0.1	−0.1
RR5	85.0	10.0	60.9	17.3	−1.0	1.1
RR10	46.0	22.0	32.5	5.8	0.2	0.0
RR25	25.0	10.0	17.4	4.6	0.1	−1.1
RR50	10.0	1.0	5.5	2.3	0.0	−0.5
RR100	3.0	0.0	0.8	0.9	0.6	−0.8
RX1day	241.7	53.1	105.8	41.9	1.6	2.8
RX3day	429.3	73.8	153.4	67.7	2.6	9.0
RX5day	453.4	88.1	196.9	72.7	1.8	4.4
RX7day	508.9	139.2	232.0	76.2	2.0	5.5
MCWD	31.0	5.0	13.8	5.8	1.2	1.6
MCDD	111.0	13.0	65.1	26.4	0.1	−0.8
SDII	26.8	11.5	15.9	3.3	1.7	3.5
R75p	40.0	17.0	29.7	5.6	−0.3	−0.2
R75pTOT	79.5	42.9	64.2	7.3	−0.6	1.7
R95p	10.0	1.0	6.0	2.5	0.1	−0.8
R95pTOT	44.7	3.4	23.2	9.4	0.3	0.2
R99p	5.0	0.0	1.2	1.3	1.0	0.6
R99pTOT	22.6	0.0	6.9	7.4	0.7	−0.9
PRCPTOT	2388.7	1306.7	1852.9	256.1	0.1	−0.1

Table 9. Summary of Anderson-Darling and Shapiro-Wilks tests of probability distributions statistics for extreme precipitation indices at Thong Nhat station.

	Normal		Lognormal		Beta		Gamma		Exponential		Loglogistic		Johnson	
Indices	AD test	SK test	AD test	SK test	AD test	SK test	AD test	SK test	AD test	SK test	AD test	SK test	AD test	SK test
RR	0.9166	0.9552	0.9304	0.9677	0.8309	0.937	0.9299	0.9677	0	0	0.9274	0.9199	0.8636	0.9514
RR5	0.0894	0.0395	0.9633	0.9797	0.5064	0.3962	0.9827	0.9941	0	0	0.5014	0.4301	0.9784	0.9961
RR10	0.8456	0.8404	0.8511	0.8746	0.3977	0.6385	0.8348	0.8663	0.0114	0.0104	0.8705	0.8217	0.6232	0.7856
RR25	0.2677	0.157	0.3557	0.19	0.7374	0.696	0.3904	0.2006	0.0715	0.0224	0.1748	0.0944	0.6281	0.6498
RR50	0.1088	0.2523	0.1081	0.256	0.0997	0.211	0.1081	0.2561	0.0041	0.0014	0.0642	0.16	0.1233	0.2813
RR100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RX1day	0.0028	0.0013	0.9885	0.9972	0.02	0.0134	0.8604	0.9483	0.1279	0.0157	0.3056	0.3251	0.6371	0.7417
RX3day	0	0	0.2263	0.44	0	0	0.082	0.1365	0.0028	0	0.2054	0.4498	0.8375	0.9354
RX5day	0.0012	0	0.4147	0.6191	0.0573	0.0793	0.2081	0.3465	0.0005	0	0.5275	0.7779	0.9983	0.9999
RX7day	0.0008	0	0.4058	0.54	0.0038	0	0.1908	0.3115	0.0028	0	0.5701	0.5374	0.3953	0.2813
MCWD	0.0188	0.0194	0.638	0.8772	0.0752	0.1315	0.5175	0.814	0.3068	0.3678	0.4319	0.6213	0.6392	0.8781
MCDD	0.6032	0.5226	0.652	0.562	0.0981	0.1117	0.7079	0.6012	0.0278	0	0.4251	0.3278	0.5233	0.6104
SDII	0.0005	0	0.451	0.7735	0.0029	0.0045	0.2393	0.527	0.0088	0	0.3861	0.5101	0.9111	0.9507
R75p	0.5962	0.7413	0.6882	0.8296	0.5096	0.7832	0.6885	0.8307	0.0045	0	0.5495	0.6487	0.5977	0.8395
R75pTOT	0.1431	0.1862	0.2506	0.3996	0.142	0.1839	0.2373	0.3817	0	0	0.5026	0.7416	0.7694	0.8328
R95p	0.0375	0.0806	0.0437	0.0905	0.0276	0.0653	0.0531	0.1026	0.037	0.0136	0.0212	0.0484	0.0132	0.0355
R95pTOT	0.8246	0.8216	0.9429	0.9566	0.8972	0.921	0.9413	0.9551	0	0	0.9211	0.9253	0.9226	0.9408
R99p	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R99pTOT	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRCPTOT	0.9207	0.95	0.9359	0.9674	0.8411	0.936	0.9357	0.9674	0	0	0.9264	0.9158	0.871	0.9501

Table 10. Summary of Anderson-Darling and Shapiro-Wilks tests of probability distributions statistics for extreme precipitation indices at Long Thanh station.

	Normal		Lognormal		Beta		Gamma		Exponential		Loglogistic		Johnson	
	AD test	SK test	AD test	SK test	AD test	SK test	AD test	SK test	AD test	SK test	AD test	SK test	AD test	SK test
RR	0.8816	0.8991	0.9272	0.9761	0.8813	0.8988	0.9346	0.98	0	0	0.9998	1	0.9998	1
RR5	0.0297	0.0401	0.0521	0.0588	0.2185	0.3597	0.1743	0.1165	0.0003	0.0005	0.0218	0.0252	0.2297	0.3973
RR10	0.0263	0.0056	0.5318	0.7949	0.3361	0.4842	0.4345	0.6568	0.0882	0.0396	0.5551	0.8473	0.6877	0.9294
RR25	0.2656	0.3691	0.2682	0.3713	0.1606	0.2494	0.2682	0.3713	0.0001	0.0002	0.2611	0.3304	0.2056	0.3021
RR50	0.322	0.5833	0.3808	0.6463	0.3218	0.5831	0.3818	0.6452	0.0243	0.0029	0.4126	0.6379	0.4163	0.6714
RR100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RX1day	0.0004	0.001	0.1986	0.3748	0.0283	0.0813	0.0989	0.228	0.0003	0	0.284	0.4345	0.9416	0.9334
RX3day	0.0002	0.0007	0.4423	0.6359	0.0018	0.006	0.2453	0.4929	0.0113	0.002	0.1105	0.1507	0.129	0.3481
RX5day	0.0006	0.0006	0.4715	0.5135	0.0021	0.0076	0.3141	0.454	0.023	0.0041	0.2927	0.1568	0.0665	0.1863
RX7day	0.0003	0.0003	0.6563	0.8078	0.0064	0.0139	0.4084	0.7206	0.0409	0.0138	0.383	0.2491	0.1591	0.4311
MCWD	0.0016	0.0003	0.9106	0.9279	0.2729	0.0509	0.9814	0.9936	0.9813	0.9938	0.2533	0.1718	0.9104	0.9276
MCDD	0.6074	0.3296	0.6083	0.3682	0.4888	0.6376	0.4658	0.3067	0.0167	0.0144	0.4539	0.2261	0.4152	0.7461
SDII	0.0276	0.0256	0.4568	0.6597	0.0002	0.0001	0.3854	0.6247	0	0	0.3072	0.4141	0.4568	0.6594
R75p	0.9136	0.9612	0.9204	0.9672	0.9224	0.991	0.9208	0.9675	0.0128	0.0019	0.7025	0.7481	0.9428	0.9948
R75pTOT	0.0092	0.0077	0.4566	0.4541	0.0002	0.0014	0.3805	0.4225	0	0	0.2914	0.1834	0.0739	0.1742
R95p	0.6131	0.7842	0.5958	0.8178	0.6135	0.8384	0.5879	0.8655	0.0747	0.0284	0.4297	0.5836	0.6156	0.8443
R95pTOT	0.547	0.4121	0.5386	0.4095	0.5873	0.6555	0.5386	0.4096	0	0	0.3629	0.2275	0.6974	0.848
R99p	0.0001	0.0002	0	0.0001	0.0002	0.0003	0.0001	0.0005	0.0001	0.0005	0.0001	0.0007	0.0001	0.0003
R99pTOT	0.0021	0.0012	0	0	0	0	0	0	0	0	0.0027	0	0.0001	0
PRCPTOT	0.8811	0.8967	0.9289	0.9769	0.8808	0.8964	0.9355	0.9805	0	0	0.9997	1	0.9996	1

Table 11. Summary of Anderson-Darling and Shapiro-Wilks tests of probability distributions statistics for extreme precipitation indices at Cam My station.

	Normal		Lognormal		Beta		Gamma		Exponential		Loglogistic		Johnson	
	AD test	SK test	AD test	SK test	AD test	SK test	AD test	SK test	AD test	SK test	AD test	SK test	AD test	SK test
RR	0.0128	0.0368	0.2437	0.3483	0.0001	0.0006	0.2301	0.3454	0	0	0.0688	0.1168	0.0654	0.2388
RR5	0.2419	0.348	0.3235	0.4108	0.1299	0.2357	0.3688	0.4257	0.0004	0.0005	0.1852	0.2409	0.2552	0.3744
RR10	0.7806	0.8397	0.8169	0.8676	0.8385	0.9162	0.8344	0.8732	0.0149	0.0006	0.5504	0.5825	0.9019	0.9565
RR25	0.0105	0.0188	0.2274	0.2293	0.0016	0.0106	0.2073	0.2211	0	0	0.0884	0.0867	0.0004	0.0042
RR50	0.0036	0.005	0.0005	0.0009	0.0463	0.0346	0.0059	0.0061	0.0059	0.0061	0.0023	0.0037	0.0529	0.0419
RR100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RX1day	0.294	0.3634	0.3019	0.3675	0.0014	0.0065	0.3019	0.3675	0	0	0.3173	0.3105	0.0727	0.2294
RX3day	0.4027	0.2004	0.3663	0.5802	0.1125	0.3266	0.3109	0.559	0.0004	0.0003	0.5199	0.5838	0.2887	0.5335
RX5day	0.146	0.24	0.1044	0.3155	0.0551	0.2586	0.1061	0.3171	0	0	0.2024	0.3711	0.1129	0.3218
RX7day	0.0412	0.1206	0.0388	0.1195	0.0065	0.061	0.0388	0.1195	0	0	0.0641	0.1438	0.0348	0.1126
MCWD	0	0	0.3195	0.4954	0.0008	0.0002	0.0609	0.0671	0.0615	0.0683	0.3303	0.4461	0.7727	0.9552
MCDD	0.2149	0.1374	0.2191	0.139	0.9117	0.9706	0.2197	0.1394	0.0176	0.0094	0.1089	0.0676	0.6613	0.8444
SDII	0.0529	0.0732	0.4907	0.7059	0.2168	0.4098	0.4431	0.6684	0	0	0.4127	0.5104	0.4917	0.7066
R75p	0.0002	0.0019	0.0296	0.075	0.0003	0.0042	0.0174	0.0573	0	0	0.0055	0.0235	0.0106	0.0429
R75pTOT	0	0	0.5512	0.4278	0.007	0.013	0.1043	0.0778	0	0	0	0.0001	0	0.0003
R95p	0.0782	0.0245	0.0742	0.0235	0.1262	0.0599	0.0743	0.0235	0.0003	0.0005	0.0497	0.0163	0.0722	0.0466
R95pTOT	0.0719	0.0246	0.0865	0.029	0	0.0002	0.124	0.0458	0	0	0.0579	0.0189	0	0
R99p	0	0.0003	0	0.0002	0.0002	0.0007	0.0001	0.0006	0.0001	0.0006	0.0001	0.0005	0.0002	0.0009
R99pTOT	0.003	0.0024	0	0	0	0	0	0	0	0	0.0045	0	0	0
PRCPTOT	0.0128	0.0367	0.248	0.3477	0.0002	0.0007	0.2285	0.3443	0	0	0.0684	0.1165	0.0611	0.2303

Table 12. Summary of Anderson-Darling and Shapiro-Wilks tests of probability distributions statistics for extreme precipitation indices at Xuan Loc station.

	Normal		Lognormal		Beta		Gamma		Exponential		Loglogistic		Johnson	
	AD test	SK test	AD test	SK test	AD test	SK test	AD test	SK test	AD test	SK test	AD test	SK test	AD test	SK test
RR	0.286	0.6031	0.3799	0.7337	0.2855	0.6025	0.3687	0.7303	0	0	0.4581	0.7794	0.467	0.8004
RR5	0.0001	0	0.7334	0.821	0.0158	0.005	0.2913	0.265	0.2898	0.2645	0.7564	0.64	0.7339	0.8222
RR10	0	0	0.2873	0.5293	0.0024	0.0021	0.0756	0.1411	0.0755	0.1417	0.5939	0.6952	0.2892	0.5319
RR25	0.0114	0.0025	0.4179	0.6239	0.0464	0.0477	0.2874	0.4177	0	0	0.6843	0.8876	0.846	0.9621
RR50	0.0364	0.0817	0.028	0.0832	0.003	0.018	0.0276	0.0832	0.0006	0.0002	0.0465	0.1188	0.0873	0.1588
RR100	0.0045	0.0066	0.0003	0.0015	0.0055	0.0077	0.0015	0.0038	0.0015	0.0038	0.0036	0.0063	0.0053	0.0078
RX1day	0.0046	0.0084	0.0251	0.073	0.0046	0.0084	0.0202	0.0592	0	0	0.1222	0.311	0.9645	0.9378
RX3day	0.1964	0.2109	0.2166	0.2779	0.1956	0.2098	0.2163	0.3114	0	0	0.442	0.7165	0.6588	0.8013
RX5day	0.0866	0.0955	0.1567	0.2109	0.0865	0.0953	0.1459	0.197	0	0	0.4691	0.6431	0.6702	0.8868
RX7day	0.0223	0.035	0.1441	0.2484	0.0223	0.035	0.1149	0.2117	0	0	0.3701	0.5907	0.9154	0.9321
MCWD	0.006	0.0081	0.7354	0.8533	0.0433	0.0955	0.5358	0.7444	0.5089	0.7029	0.2863	0.302	0.736	0.853
MCDD	0.4821	0.4428	0.7718	0.7628	0.0966	0.2177	0.7461	0.7507	0.0261	0.0176	0.7113	0.6262	0.2476	0.476
SDII	0.0384	0.0042	0.632	0.7424	0.0007	0.0012	0.0005	0.0005	0	0	0.8774	0.8731	0.6334	0.7431
R75p	0.0037	0.0003	0.8111	0.8868	0.0532	0.0203	0.5324	0.5558	0	0	0.9345	0.9361	0.8129	0.888
R75pTOT	0	0	0.0169	0.0419	0	0.0002	0.0001	0.0013	0	0	0.1187	0.0941	0.0171	0.042
R95p	0.3207	0.1624	0.2469	0.1881	0.3633	0.218	0.1193	0.1057	0.0041	0.0006	0.3798	0.2359	0.2345	0.1731
R95pTOT	0.0121	0.0207	0.1604	0.4926	0.0001	0.0001	0.1311	0.4411	0	0	0.192	0.4741	0.1743	0.4411
R99p	0.0072	0.0109	0.0086	0.0125	0.0019	0.0222	0.0176	0.0226	0.0175	0.0225	0.0116	0.0165	0.0227	0.0263
R99pTOT	0.2621	0.1352	0.4239	0.1813	0.0013	0.0074	0	0	0	0	0.3508	0.1585	0	0.0006
PRCPTOT	0.2929	0.606	0.3926	0.7412	0.2913	0.6044	0.3341	0.6774	0	0	0.4742	0.7878	0.4867	0.8101

Table 13. Total score of probability distributions for extreme precipitation indices at Thong Nhat station.

	Normal	Lognormal	Beta	Gamma	Exponential	Loglogistic	Johnson
RR	10	14	6	13	0	8	8
RR5	2	10	7	13	0	7	13
RR10	10	13	4	10	0	11	6
RR25	6	8	14	10	1	4	12
RR50	10	10	7	11	0	5	14
RR100	0	0	0	0	0	0	0
RX1day	0	14	0	12	3	8	10
RX3day	0	11	0	8	0	11	14
RX5day	0	9	5	7	0	12	14
RX7day	0	13	0	8	0	13	10
MCWD	0	12	4	10	6	8	14
MCDD	9	11	4	13	0	6	11
SDII	0	13	0	9	0	9	14
R75p	7	11	6	13	0	5	12
R75pTOT	6	10	4	8	0	12	14
R95p	5	6	4	14	0	0	0
R95pTOT	4	14	6	12	0	8	10
R99p	0	0	0	0	0	0	0
R99pTOT	0	0	0	0	0	0	0
PRCPTOT	9	14	6	13	0	8	9

Table 14. Total score of probability distributions for extreme precipitation indices at Cam My station.

	Normal	Lognormal	Beta	Gamma	Exponential	Loglogistic	Johnson
RR	0	14	0	12	0	9	9
RR5	8	12	4	14	0	6	10
RR10	6	8	12	10	0	4	14
RR25	0	14	0	12	0	10	0
RR50	0	0	0	0	0	0	7
RR100	0	0	0	0	0	0	0
RX1day	11	13	0	13	0	12	8
RX3day	8	11	5	9	0	14	7
RX5day	8	7	5	9	0	14	11
RX7day	6	5	3	5	0	14	4
MCWD	0	11	0	6	8	11	14
MCDD	6	8	14	10	0	4	12
SDII	4	12	6	10	0	8	14
R75p	0	7	0	6	0	0	0
R75pTOT	0	14	0	12	0	0	0
R95p	6	4	14	5	0	0	3
R95pTOT	5	6	0	7	0	4	0
R99p	0	0	0	0	0	0	0
R99pTOT	0	0	0	0	0	0	0
PRCPTOT	0	14	0	12	0	9	9

Table 15. Total score of probability distributions for extreme precipitation indices at Long Thanh station.

	Normal	Lognormal	Beta	Gamma	Exponential	Loglogistic	Johnson
RR	8	10	6	12	0	14	14
RR5	0	8	12	10	0	0	14
RR10	0	10	6	8	2	12	14
RR25	12	14	6	14	0	10	8
RR50	8	8	6	8	0	10	14
RR100	0	0	0	0	0	0	0
RX1day	0	10	3	8	0	12	14
RX3day	0	14	0	12	0	8	10
RX5day	0	14	0	12	0	9	9
RX7day	0	14	0	12	0	9	9
MCWD	0	10	3	13	13	5	8
MCDD	10	12	11	7	0	5	9
SDII	0	14	0	11	0	9	13
R75p	6	9	12	9	0	4	14
R75pTOT	0	14	0	12	0	10	8
R95p	8	8	11	10	1	4	13
R95pTOT	10	7	12	8	0	4	14
R99p	0	0	0	0	0	0	0
R99pTOT	0	0	0	0	0	0	0
PRCPTOT	7	9	5	11	0	14	13

Table 16. Total score of probability distributions for extreme precipitation indices at Xuan Loc station.

	Normal	Lognormal	Beta	Gamma	Exponential	Loglogistic	Johnson
RR	6	10	4	8	0	12	14
RR5	0	11	0	8	6	12	13
RR10	0	10	0	7	7	14	12
RR25	0	10	0	8	0	12	14
RR50	4	5	0	5	0	6	14
RR100	0	0	0	0	0	0	0
RX1day	0	5	0	4	0	12	14
RX3day	6	9	4	9	0	12	14
RX5day	6	10	4	8	0	12	14
RX7day	0	10	0	8	0	12	14
MCWD	0	13	2	10	8	6	13
MCDD	7	14	4	12	0	10	7
SDII	0	10	0	0	0	14	12
R75p	0	10	3	8	0	14	12
R75pTOT	0	0	0	0	0	14	0
R95p	8	9	12	4	0	14	7
R95pTOT	0	12	0	8	0	13	11
R99p	0	0	0	0	0	0	0
R99pTOT	5	14	0	0	0	12	0
PRCPTOT	6	10	4	8	0	12	14