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The Probability Distributions of Daily Rainfall for Kuantan River Basin in Malaysia

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Abstract: ***The extreme hydrological events such as flood and drought can have severe impacts on society. Malaysia has experienced extreme rainfall events during the monsoon seasons that last for several hours and lead to flash flood. The location of interest of this study is Kuantan river basin in Pahang State, Malaysia since flash floods occur in Kuantan every year. Rainfall data at four stations for Kuantan river basin are collected and used in this study. The objectives of this study are: (i) to perform the frequency analysis with some commonly used probability distributions, (ii) to identify the most appropriate probability distribution, and (iii) to estimate the maximum annual daily rainfall for selected return periods. In this study, Normal, 2P and 3P Lognormal, Gamma, Gumbel, Generalized Extreme Value, Pearson Type III and Log-Pearson Type III are identified to evaluate the best fit probability for rainfall distribution in Kuantan river. Based on the analysis of goodness of fit tests, Generalised Extreme Value distribution proves to be the most appropriate distribution for annual maximum daily rainfall at all stations under study for Kuantan river basin. The estimated extreme rainfall with various frequencies can be used as the basic inputs in hydrologic design such as in the design of storm sewers, culverts and many other structures as well as inputs to rainfall runoff models.***

Keywords: annual maximum daily rainfall, frequency analysis, Generalised Extreme Value distribution, Kuantan river basin, goodness of fit tests

1. Introduction

The extreme hydrological events such as flood and drought can have severe impacts on society. Extreme rainfall is one of the main causes for extreme flood and therefore the probability of occurrence of a particular extreme rainfall, for example, a 24-hr maximum rainfall is important [1]. Since most of the extreme rainfall phenomena are stochastic processes, extensive use of probability theory and frequency analysis are needed to fully understand and describe the phenomena [2].

Choosing a probability distribution that provides a good fit to daily rainfall has long been a topic of interest in hydrology, meteorology and others. Hanson and Vogel [3] have mentioned that daily rainfall distribution are investigated in three main research areas, namely (1) stochastic precipitation models, (2) frequency analysis of precipitation, and (3) precipitation trends related to global climate change. The focus area of this study is on the frequency analysis of precipitation which involves selection of a suitable distribution for representing precipitation depth to investigate the extreme events.

Hanson and Vogel [3] showed that the Pearson Type III (P3) distribution fits the series of daily precipitation records at 237 U.S. stations remarkably well. In their study, probability plot correlation test statistics and L-moment diagrams were used for goodness of fit tests. Rao and Kao [4] tested Gumbel (EVI), Generalized Extreme Value (GEV), P3, Log-Pearson Type III (LP3), and Pareto distributions and selected the GEV distribution as the suitable distribution for the Indiana rainfall data in U.S.

Svensson and Jones [5] reviewed nationwide methods for point rainfall frequency estimation currently in use in nine different countries: Canada, Sweden, France, Germany, the United States, South Africa, New Zealand, Australia and the United Kingdom. They concluded that different statistical distributions and fitting methods are used in different countries, with the GEV distribution being the most common.

Jordon et al. [6] used the GEV distribution fitted by linear combinations of probability-weighted moments (or L-moments) in all of the CRC-FORGE projects in Australia. Canterford et al. [7] used LP3 distribution to fit the annual maximum rainfall data in Australia.

Annual one day maximum rainfall and two to five consecutive day's maximum rainfall corresponding to a return period of 2 to 100 years have been conducted by Bhakar et al. [8] for Banswara, Rajasthan, India. Three commonly used probability distributions: Normal (N2), Lognormal (LN) and Gamma (G2) distributions have been tested and G2 distribution was the best fit probability distribution for one day, two to five consecutive days' annual maximum rainfall for the region. Similar study was conducted by Kwaku and Duke [9] for Accra, Ghana. LN distribution was the best fit probability distribution for one day, two to five consecutive days' annual maximum rainfall for the region. The daily rainfall data of 39 years were analyzed to determine the annual one day maximum rainfall of Jhalarapatan area of Rajasthan, India by Singh et al. [10]. Among N2, LN, LP3 and EVI distributions used, LP3 distribution was found to be the best fit probability distribution to forecast annual one day maximum rainfall for different return periods based on the Chi-square test.

Nadarajah and Choi [11] studied annual maxima of daily rainfall of 41 years for five locations in South Korea and found that the GEV distribution is fitted to data from each location to describe the extremes of rainfall. Alias and Takara [12] have proposed N2, LN three parameters (3P), EVI, Extreme Value Type II (EVII), Extreme Value Type III (EVIII), 3P Gamma (G3), and LP3 and identified LP3 distribution as the best fit distribution to both annual maximum daily rainfall data sets of the Yodo river basin in Japan and Kuala Lumpur river basin in Malaysia. Shabri et al. [13] identified GEV and Generalized Logistic (GLO) distributions as the most suitable distributions for representing the statistical properties of extreme rainfall in Selangor in Malaysia. Frequency analysis of annual maximum rainfall for the Klang River basin, Malaysia using GEV distribution was conducted in 1993 by Amir et al. [14].

Malaysia has experienced extreme rainfall events during the monsoon seasons that last for several hours and lead to flash flood. The location of interest of this study is Kuantan river basin in Pahang State since flash floods occur in Kuantan every year. The objectives of this study are: (i) to perform the frequency analysis of daily rainfall with some commonly used probability distributions to Kuantan river basin, (ii) to identify the most appropriate probability distribution, and (iii) to estimate the maximum annual daily rainfall for selected return periods.

2. Data Used in This Study

Kuantan River Basin is in the district of Kuantan at the north eastern end of Pahang State in Peninsular Malaysia. It is one of the important river basins in Pahang and covers an area of 1630 km^2 catchment area which started from forest reserved area in Mukim Ulu Kuantan through agricultural areas, Kuantan town (state capital of Pahang) towards the South China Sea. Kuantan River Basin consists of several important tributaries and these rivers drain the major rural, agricultural, urban and industrial areas of Kuantan District and discharge into South China Sea [15].

For frequency analysis, the completeness of data during an entire year is important. Frequently there are periods when data are missing in a year due to different reasons such as the breakdown of instruments, moving stations, or some other reasons which will cause periods without data. Rao and Kao [4] discussed on the length of an “acceptable” missing period. If the missing period is too long, data of the annual maximum event will be missed. On the contrary, if the missing period is too short, many observed records may have to be abandoned. They selected a 3-month period as the longest acceptable missing data period. In our study, if data length is less than 9 months in a year, the data for that year is not considered further.

Rainfall data at four stations (3832015, 3833002, 3931013 and 3931014) for Kuantan river basin are collected and used in this study. The location of rainfall stations under study is shown in Figure 1.

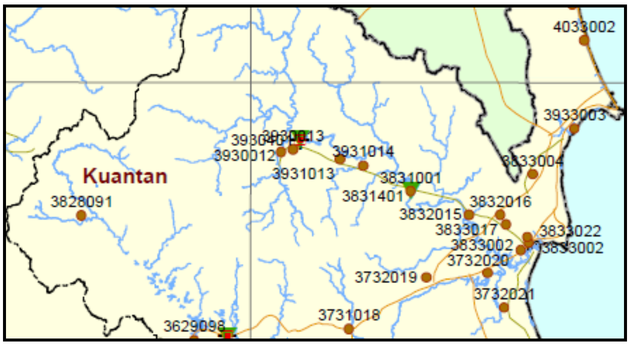


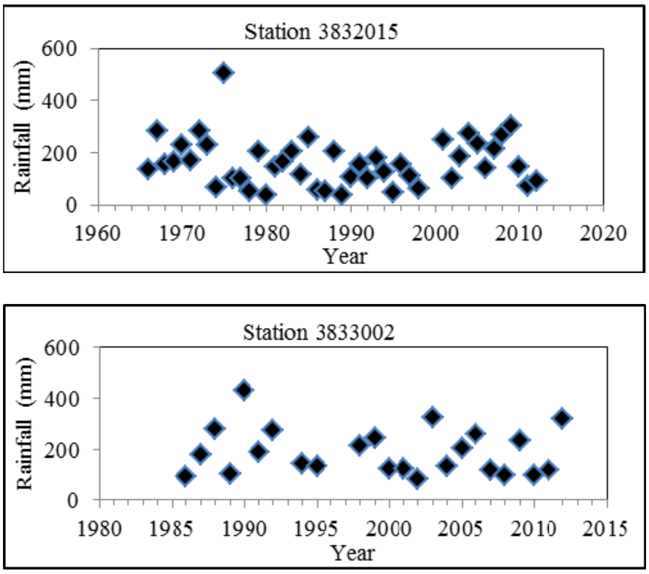
Figure 1: Location of rainfall stations at Kuantan river basin, Pahang state, Malaysia

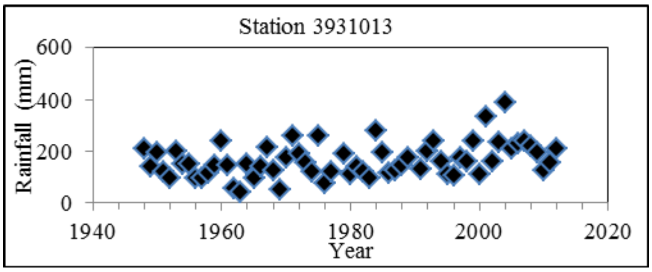
The statistical characteristics of annual maximum daily rainfall series for each station are given in Table 1.

Table 1: Statistical characteristics of the data series

Station	Mean (mm)	Std. dev. (mm)	Skew -ness	Kurto-sis
3832015: Rancangan Pam Paya Pinang	161.60	91.75	1.213	2.979
3833002: Pejabat JPS Negeri Pahang	190.28	90.63	0.975	0.512
3931013: Ldg. Nada	165.47	65.84	0.834	1.327
3931014: Ldg. Kuala Reman	168.66	58.14	0.556	-0.187

It is observed from Table 1 that the data series for all stations are skewed right (positive skewness) and they have the peak distributions except for the station 3931014. The series of annual maximum daily rainfall of all stations under study are shown in Figure 2.





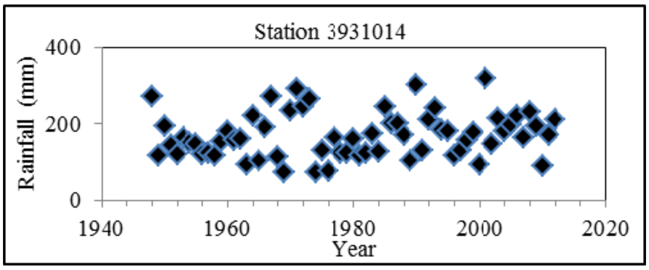


Figure 2: Series of annual maximum daily rainfall of each station

It can be seen from Figure 2 that the rainfall in the year 1975 in Station 3832015 and year 1990 in Station 3833002 are relatively high. Testing for high and low outliers is explained in the next section.

3. Methodology

3.1 Testing for outliers

Chow et al. [16] recommends that adjustments be made for the outliers of the data. Hydrology Subcommittee Bulletin #17B [17] guided that if the station skew is greater than +0.4, tests for high outliers are considered first and if the station skew is less than -0.4, tests for low outliers are considered first. Where the skew is between ± 0.4, tests for both high and low outliers should be applied before eliminating any outliers from the data set. The following equation is used to detect high outliers:

$$y_H = \bar{y} + K_N s \quad (1)$$

where
y_H = high outlier threshold in log units
$\bar{y}$ = mean logarithm of variate
s = standard deviation of y's
K_N = 10 percent significance level K values
The following equation is used to detect low outliers:

$$y_L = \bar{y} - K_N s \quad (2)$$

where y_L = low outlier threshold in log units and other terms are as defined earlier.

3.2 Frequency analysis using frequency factors

Chow et al. [16] proposed the frequency factor equation shown in (3) which is applicable to many probability distributions used in hydrologic frequency analysis.

$$x_T = \bar{x} + K_T s \quad (3)$$

where
x_T = value of the variate x of a random hydrologic series with a return period T,
$\bar{x}$ = mean of the variate,
s = standard deviation of the variate,
K_T = frequency factor which depends upon the return period T and assumed frequency distribution.
In the event that the variable analyzed is y = log x, then the same method is applied to the statistics for the logarithms of the data using

$$y_T = \bar{y} + K_T s \quad (4)$$

and the required value of x_T is found by taking the antilog of y_T.

3.3 Fitting the probability distributions

EVI, LP3 and GEV distributions are commonly used in the frequency analysis. In this study, N2, LN 3P, LN 2P, G2, EVI, GEV, P3 and LP3 are identified to evaluate the best fit probability for rainfall distribution in Kuantan river basin. The probability density function, the range of the variable, and the parameter involved are summarized in Table 2.

Table 2: Summary of probability density function, the range of the variable, and the distribution's parameters

Distribution	Probability density function
Normal	$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp[-\frac{(x-\mu)^2}{2\sigma^2}]$ $-\infty < x < \infty$, μ = mean, σ = standard deviation
Lognormal 2P	$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} \exp(-\frac{(\ln(x)-\mu)^2}{2\sigma^2})$ $0 < x < \infty$
Lognormal 3P	$f(x) = \frac{1}{(x-\gamma)\sigma\sqrt{2\pi}} \exp(-\frac{(\ln(x-\gamma)-\mu)}{2\sigma^2}$ $\gamma < x < \infty$, γ = location parameter σ = scale parameter, $\sigma > 0$ μ = shape parameter, $\mu > 0$
Generalized Extreme value (GEV) EVI (Gumbel)	$f(x) = \frac{1}{\sigma} \exp(-(1+kz)^{-\frac{1}{k}})(1+kz)^{-1-\frac{1}{k}}$ k $\neq 0$ $f(x) = \frac{1}{\sigma} \exp(-z - \exp(-z))$ k = 0 For $k \neq 0$, $1 + k(\frac{x-\mu}{\sigma}) > 0$ For k = 0, $-\infty < x < \infty$ σ = scale parameter, $\sigma > 0$ k = shape parameter μ = location parameter $z = \frac{x-\mu}{\sigma}$
Gamma (2P)	$f(x) = \frac{x^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)} \exp(-\frac{x}{\beta})$ $0 \le x < \infty$
Pearson Type III	$f(x) = \frac{(x-\gamma)^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)} \exp(-\frac{(x-\gamma)}{\beta})$

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	$\gamma \le x < \infty$, γ = location parameter α = shape parameter, $\alpha > 0$ β = scale parameter, $\beta > 0$ Γ = Gamma function
Log-Pearson Type III	$f(x) =$ $\frac{1}{x\lvert\beta\rvert\Gamma(\alpha)}\left(\frac{\ln(x)-\gamma}{\beta}\right)^{\alpha-1}\exp\left(-\frac{\ln(x)-\gamma}{\beta}\right)$ $0 < x \le e^{\gamma}$, $\beta < 0$ $e^{\gamma} \le x < \infty$, $\beta > 0$ α = shape parameter, $\alpha > 0$ β = scale parameter, $\beta \ne 0$ γ = location parameter Γ = Gamma function

3.4 Checking the goodness of fit

The two most commonly used tests of goodness of fit namely Chi-Square (CS) and Kolmogorov-Smirnov (KS) tests are applied to the data series for checking the fit of probability distributions used in this study. The test statistics of each test are computed and tested at level of significance (α = 0.05). If the computed statistic is smaller than the critical value, it indicates that the distribution fits the data well and the distribution can be accepted. Based on the test results, probability distributions are ranked from 1 (the highest rank with minimum value of test statistic) to 3 (the lowest). The highest to lowest ranked probability distributions are given the score of three, two, and one respectively.

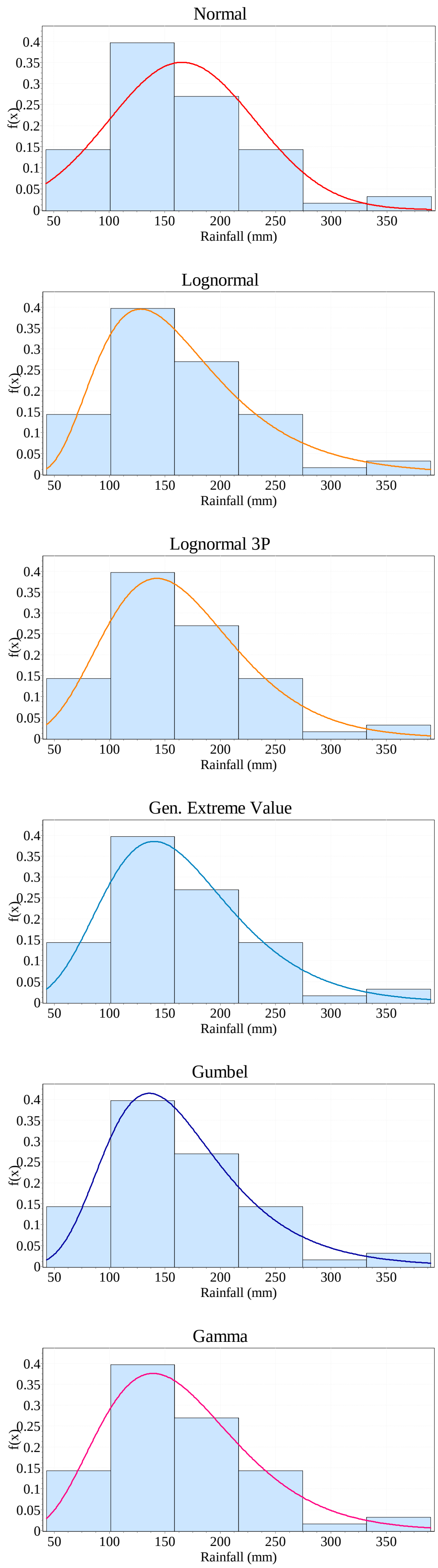
4. Results and discussion

Annual maximum daily rainfall for Kuantan river at four stations are checked whether outliers exist in the data series before using them. Based on the number of data in the series used, outliers are calculated using Eqs. (1) and (2) and given in Table 3. K_N value based on the number of data in the series is obtained from the table for outlier test in [17]. It is observed that there is no high and low outlier in all data series.

Table 3: Outliers for each data series

Station	No. of data	K_N	High outlier (mm)	Low outlier (mm)
3832015	45	2.727	724.40	25.76
3833002	24	2.467	529.60	55.70
3931013	63	2.854	506.77	45.93
3931014	65	2.866	436.70	57.82

The probability density functions of eight distributions chosen in this study for each series are plotted to observe how well the distribution fit with the data series in terms of visual comparison. As an example, the probability density functions for the distributions for Kuantan river at Station 3931013 are given in Figure 3. It is observed from Fig. 3 that all density functions fit quite well with the series except the N2 distribution.



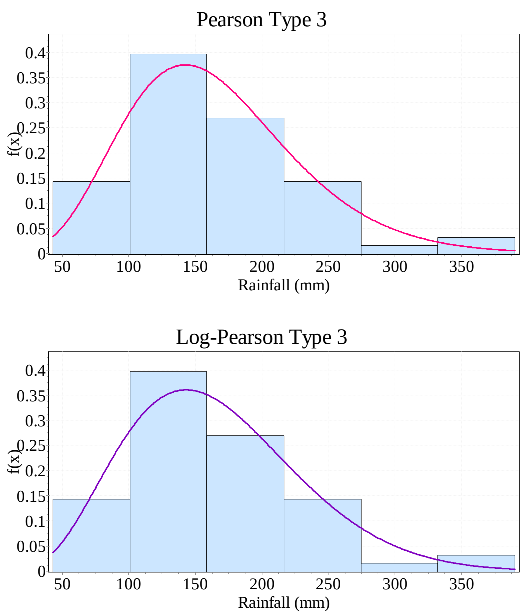


Figure 3: Probability density function of Kuantan river basin at Station 3931013

The parameters of the eight distributions under study are estimated for three data series using EasyFit software [18] and shown in Table 4. The method of moments is used to estimate the parameters for distributions with available moment estimates while the maximum likelihood estimate and least square estimate are used for other estimations. Annual maximum daily rainfall for the desired return periods are calculated using these parameters.

Table 4: Estimated parameters for distributions under study

Distribution	Stations			
	3832015	3833002	3931013	3931014
Normal	σ=91.75 μ=161.6	σ=90.64 μ=190.3	σ=65.84 μ=165.5	σ=58.15 μ=168.7
Lognormal 2P	σ=0.61 μ=4.92	σ=0.45 μ=5.15	σ=0.42 μ=5.03	σ=0.35 μ=5.07
Lognormal 3P	σ=0.43 μ=5.25 γ=-46.58	σ=0.89 μ=4.40 γ=74.92	σ=0.25 μ=5.5, γ=-91.88	σ=0.28 μ=5.27 γ= -34.23
Gamma	α= 3.10 β= 52.09	α= 4.41 β= 43.17	α=6.31 β=26.20	α=8.41 β=20.05
Pearson Type III	α= 1.94 β=70.19 γ= 25.27	α= 0.87 β=101.3 γ= 87.0	α=8.03 β=22.92 γ=-18.62	α=5.12 β=26.12 γ=34.81
Log-Pearson Type III	α=20.04 β= -0.14 γ= 7.66	α=48.99 β=0.065 γ=1.95	α=12.12 β=-0.12 γ=6.49	α=98.12 β=-0.035 γ=8.56
Generalised Extreme Value	k=-0.028 σ= 74.03 μ=120.9	k=0.113 σ=64.83 μ=144.7	k=-0.06 σ=55.32 μ=136.7	k=-0.076 σ=50.79 μ=142.91
Gumbel	σ=71.54 μ=120.3	σ=70.67 μ=149.5	σ=51.34 μ=135.8	σ=45.34 μ=142.49

The goodness of fit tests is performed to check which distribution fits the best to the data series. The values of Chi-square statistics (χ^2) and Kolmogorov-Smirnov (D) are calculated and shown in Tables 5 and 6 respectively for all data series. It is noted that the superscript number refers to the ranking of the best distribution for each station from 1 (the best) to 3 (the worst). Then the scores of points 3, 2 and 1 are given to the ranks 1, 2 and 3 respectively.

Table 5: Chi-square test for all data series

Distribution	Stations			
	3832015	3833002	3931013	3931014
N2	2.671	3.333	5.705	2.731^{1}
LN 2P	1.315	3.286	1.296^{2}	4.611^{2}
LN 3P	1.315	3.252	3.715	6.089
G2	0.393^{1}	1.582^{3}	1.737^{3}	6.510
P3	0.530^{3}	N/A	3.702	5.592
LP3	0.409^{2}	1.382^{1}	3.700	6.092
GEV	0.919	1.396^{2}	1.784	6.570
EVI	0.907	2.638	1.001^{1}	5.392^{3}

It can be seen from Table 5 that all distributions are acceptable to fit to all the data series at the significant level, α of 0.05 except P3 for Station 3833002. Based on the Chi-square test, G2 and LP3 obtained the highest scores of five.

Table 6: Kolmogorov-Smirnov test for all data series

Distribution	Stations			
	3832015	3833002	3931013	3931014
N2	0.084	0.197	0.105	0.095
LN 2P	0.099	0.160	0.067	0.063^{1}
LN 3P	0.073	0.119^{1}	0.060^{1}	0.073
G2	0.064^{2}	0.157	0.064	0.075
P3	0.089	0.165	0.063^{3}	0.065^{2}
LP3	0.070	0.144^{3}	0.069	0.070^{3}
GEV	0.060^{1}	0.142^{2}	0.0603^{2}	0.071
EVI	0.067^{3}	0.163	0.073	0.078

It can be observed from Table 6 that all distributions are acceptable to fit to the data at the significant level, α of 0.05. Based on the Kolmogorov-Smirnov test, GEV distribution obtained the highest scores of seven followed by LN 3P with the score of six.
It can be concluded from Tables 5 and 6 that G2 distribution for Station 3832015, LP3 and GEV for Station 3833002, G2 and EVI for Station 3931013 and LN 2P for Station 3931014 are considered as the best fit distributions.

In overall, based on both tests, GEV distribution obtained the highest score of nine and it is considered as the best fit for all data series of Kuantan river basin. GEV could be more suitable since it chooses EVI, EVII, and EVIII according to the characteristics of each data series. LN 2P, G2 and LP3 distributions are equally good since each distribution obtained the score of seven. The findings from this study are consistent with the findings obtained for Kuala Lumpur, Selangor and Klang river basins by Alias and Takara [12], Shabri et al. [13] and Amir et al. [14] respectively. Feng et al. [19] also used GEV distribution to model the annual extreme precipitation in China.

Annual maximum daily rainfall with recurrence intervals of 2, 10, 25, 50 and 100 years are calculated using Eqs. (3) and (4) for four probability distributions: GEV, G2, LN 2P, and LP3 distributions. The results are given in Table 7.

Table 7: Annual maximum daily rainfall (mm) obtained by different distributions for all stations

Distribution	Return period (years)				
	2	10	25	50	100
Station 3832015					
Gen. Extreme Value	147.8	282.3	347.3	394.4	440.3
Gamma	144.6	284.6	351.9	400.1	446.9
Lognormal 2P	136.8	297.2	394.9	474.4	559.5
Log-Pearson Type III	143.2	289.5	361.8	413.8	464.0
Station 3833002					
Gen. Extreme Value	169.0	310.9	394.7	462.9	536.2
Gamma	176.1	311.7	374.4	418.8	461.4
Lognormal 2P	171.8	304.7	375.7	430.2	486.0
Log-Pearson Type III	168.1	312.2	398.8	469.7	546.2
Station 3931013					
Gen. Extreme Value	156.7	253.1	297.6	329.0	358.9
Gamma	156.8	253.5	296.6	326.9	355.7
Lognormal 2P	152.6	260.4	316.8	359.5	402.8
Log-Pearson Type III	158.8	263.2	291.4	316.5	339.1
Station 3931014					
Gen. Extreme Value	161.3	248.0	287.1	314.4	340.1
Gamma	162.0	246.1	282.8	308.3	332.4
Lognormal 2P	158.9	248.8	293.2	326.1	358.7
Log-Pearson Type III	160.8	247.7	287.4	315.5	342.5

It can be seen from Table 7 that annual maximum daily rainfall estimated by LN 2P is the highest at larger return periods for the all data series except Station 3833002. Estimated values obtained by other three distributions do not vary significantly for all stations except Station 3833002. There is no trend observed for Station 3833002 since the data length is short as compared to other stations.

In overall, GEV and LP3 distributions are recommended for estimation of annual maximum daily rainfall for the Kuantan river basin. This is consistent with the findings obtained by Svensson and Jones [5] and other researchers.

5. Conclusions

A total of eight probability distributions are applied to the series of annual maximum daily rainfall of four stations for Kuantan river basin. The conclusions obtained from this study are as below.

- Based on the analysis of statistical tests, Generalised Extreme Value distribution proves to be the most appropriate distribution for annual maximum daily rainfall at all stations under study for Kuantan river basin.
- In overall, Generalised Extreme Value and Log-Pearson Type III distributions are recommended for estimation of annual maximum daily rainfall for the Kuantan river basin.
- The estimated extreme rainfall with various frequencies and durations can be used as the basic inputs in hydrologic design such as in the design of storm sewers, culverts and many other structures as well as inputs to rainfall runoff models.
- Future research can be carried out by using other rainfall stations in Klang river basin to verify that Generalized Extreme Value and Log-Pearson Type III distributions are the recommended distributions.

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