ESTIMATION OF HOURLY AND DAILY RAINFALL INTENSITY USING PROBABILITY DISTRIBUTION IN KEMAMAN

Shairul Rohaziawati Samat, Aasha Thiaharajan, Norasman Othman

Abstract

Malaysia has experienced uttermost rainfall events during the monsoon seasons that last for several hours and consequently lead to flash floods. This study was located at Kemaman, Terengganu. Annual maximum (AM) hourly and daily rainfall data at seven stations were collected from the Department of Irrigation and Drainage (DID), and the probability distributions are analysed for these set of data. This study aims to estimate the AM hourly and daily rainfall intensity for selected Average Recurrence Interval (ARI) using Log-Pearson Type III (LPIII) distribution and Gumbel distribution. In this study, the goodness of fit test for the distribution is tested using Kolmogorov-Smirnov (KS) test and Anderson-Darling (AD) test. Based on the output generated, LPIII distribution is proven to be the most appropriate probability distribution function for AM hourly and daily rainfall for Kemaman. The estimated extreme rainfall intensity for various ARIs can be used as the basic inputs in hydrologic design.

Keywords Annual Maximum, Rainfall Intensity, Probability Distribution, Log-Pearson Type III Distribution and Gumbel Distribution.

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Introduction

The catastrophic hydrological events such as drought and flood can directly or indirectly affect the health and welfare of human beings, hence the study of the probability of uttermost rainfall, for instance, a 24 hours maximum rainfall is vital (Subramanya, 2009). The analysis of probability allows people such as researchers, designers and engineers to obtain relevant information and knowledge, and describe the extreme rainfall phenomena (Raghunath, 2006). Malaysia is still being subjected to frightful floods, even after flood management for over half a century (Taib et al., 2016).

Parts of Terengganu annually experience damages and losses by flooding phenomena. Kemaman especially faced uncertainties and risk of flooding in the consecutive years of 2014 and 2015. In November 2014, 15 major roads in five districts were closed in Terengganu (Societies, 2014). Generally, excessive rainfall during the monsoon season led to monster flooding in the state of Terengganu. The unavoidable and continuous rainfall has caused almost all the eight districts of Terengganu to be paralysed in terms of all kinds of daily routines of the community, massive property and life losses, and flop in economic stability.

The probability distribution of flood determination is one of the most interesting parts by engineers and planners in designing and planning water resources projects, including hydraulic structures such as dams, bridges, culverts and levees, to control and manage flood water movement. Probability distribution analysis is one of the main approaches preferred compared to the rational method, unit hydrograph method and rainfall-runoff models' method, to explain the relationship between magnitude and frequency of the flood event. Pattern and distribution of rainfall are the main factors of water resources management of a country. Hourly and daily rainfall data are mostly needed, especially in urban areas, as the rainfall input are too quick for the sensitivity of the storm water management system due to the short time of concentration.

In the hydrology field, the selection of a probability distribution that can provide a good fitness to hourly and daily rainfall has been a topic of interest for a long time. Log-Pearson Type III (LPIII) is primarily being used as a base method for hydrologic probability analyses, since suggested by the Water Resources Council (1967, 1982) of the United States. This distribution is a technique for the statistical study of the prediction of design flood of a water body using rainfall data. Extreme events such as floods can be predicted using Gumbel distribution statistical methods. Regardless of whether the number of samples is minimum or maximum, Gumbel distribution is widely practised for forecasting flood events.

Hanson and Vogel (2008) stated that 237 rainfall stations in the United States have perfectly fitted the series of daily precipitation using LPIII distribution. Fikre (2017) has reported that LPIII distribution has best fitted the Bale zone, Ethiopia for daily rainfall. Report of Topaloglu (2002) stated that Gumbel distribution is the best fit model for the Seyhan River Basin, which was evaluated by Chi-Square test and estimated using a method of moment. Win and Win (2012) found that LPIII and Generalised Extreme Value estimate annual maximum daily rainfall for the Kuantan River Basin. The maximum hourly rainfall intensity data using Gumbel distribution were relatively in higher rank based on the AD fitness test. It is concluded that based on the findings, the pattern of hourly rainfall distribution in Mumbai could be better fit by Gumbel distribution function (Mujiburrehman, 2017).

Method of moment has been widely and regularly practised in the modelling of linear hydrologic to estimate the parameter. Occasionally, appraise precise details about the distribution shape, which was transferred by third or higher order moments is hard. However, probability distributions obtained with small sample size can be non-identical to the values of numerical of sample moment. Besides, the fitness of approximated parameters of probability distribution by method of moment, oftentimes inexact compared to other methods of parameter estimation such as least square or probability weighted moment (Hosking, 1990).

Prognosis of time and space parameters in a given set of data is the principal aim of developing the physical process of modelling in the field of hydrologic science. Fitness of evaluated modelling to the collected variable is normally validated by pairwise comparison of the observed data with the model stimulated or predicted values. An evaluation of the estimation ability of the model is provided through quantitative assessment.

The examination of the Kolmogorov-Smirnov (KS) test is to determine whether a sample is from a continuously hypothesised probability density function. This test is based on the difference in vertical between theoretical and empirical cumulative distribution function. Meanwhile, AD test compares the difference between both tails of the distribution, meaning discrepancies within observed and expected cumulative distribution function. This test is proven to be better in providing weight to tail, compared to KS test (Sharma and Singh, 2010).

Hence, the study is carried out to analyse the best approach that is either Gumbel distributions or LPIII distributions, for hourly and daily rainfall at Kemaman, where the probability distribution result will be greatly adopted for the development of water resource planning in terms of drainage design, forecasting of flood and estimation of rainfall frequency.

Methodology

Data Collection

Kemaman district is the district of the Terengganu Darul Iman with the total area of about 254,000 hectares. A total of seven stations was selected and presented in Figure 1, and Table 1 covers a land area of 2,353.59 km^2 that was analysed.

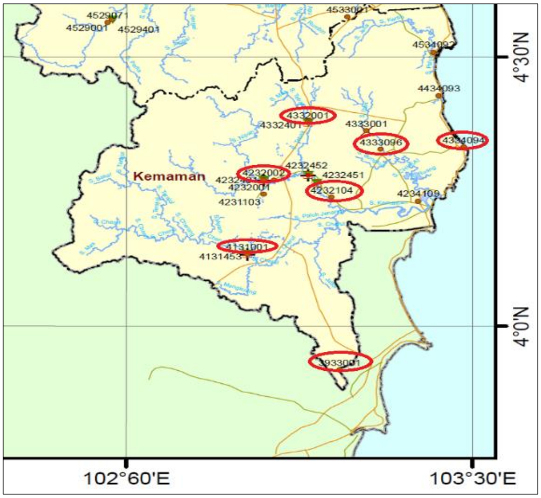

Figure 1: Rainfall Stations in Kemaman, Terengganu
Source: Department of Irrigation and Drainage (DID)

Table 1: Rainfall Stations in Kemaman, Terengganu

Station ID	Station Name	Latitude	Longitude
3933001	Hulu Jabor di Kemaman	03°55′05"	103°18′30"
4131001	Kg. Ban Ho	04°08′00"	103°10′30"
4232002	Jambatan Air Putih	04°16′15"	103°11′55"
4232104	Sek. Keb. Pasir Gajah	04°14′20"	103°17′50
4332001	Jambatan Tebak	04°22′40"	103°15′45"
4333096	Klinik Bidan di Kg. Ibok	04°19′40"	103°22′05"
4334094	Sek. Keb. Kijal	04°19′55"	103°29′15"

The annual maximum hourly and daily rainfall data were collected to stimulate probability density function. The data series were obtained from the Department of Irrigation and Drainage (DID) from 1971 until 2016.

Predominantly, probability distribution requires continuous years of data concatenation of at least 10 years. Anyhow, the higher the number of samples, it gives much accurate and precise values of analysis. Hence, every station has a different number of samples, as it does not affect one another in the analysis. Tables 2 and 3 display the statistical characteristics of annual maximum hourly and daily rainfall of all seven stations in Kemaman.

Table 2: Statistical Characteristics of Annual Maximum Hourly Data Series

Station ID	Mean (mm)	Std. Dev. (mm)	Skewness	Kurtosis
3933001	71.79	19.65	0.71	0.47
4131001	68.46	15.64	0.61	-0.15
4232002	63.74	14.82	0.22	-0.14
4232104	75.07	12.24	0.60	-0.92
4332001	68.88	20.13	0.94	1.08
4333096	77.93	14.47	1.32	1.84
4334094	74.56	16.80	1.10	0.59

Table 3: Statistical Characteristics of Annual Maximum Daily Data Series

Station ID	Mean (mm)	Std. Dev. (mm)	Skewness	Kurtosis
3933001	246.55	162.98	2.19	4.56
4131001	195.81	65.77	0.88	1.23
4232002	204.33	84.09	0.44	0.16
4232104	263.33	92.08	-0.06	-1.22
4332001	231.49	104.87	0.61	-0.12
4333096	267.81	109.93	0.30	-0.90
4334094	287.49	133.57	1.03	-0.12

Testing for Outliers

According to Chow et al. (1988), the adjustment to the data should be made by eliminating outliers. Hydrology Subcommittee Bulletin #17B (1982) has recommended that for stations skewed higher than +0.4, a higher outlier test must be carried out first, whereas a low outlier analysis must be carried out for skew less than -0.4. Meanwhile, when the skew is within ±0.4, the test of both low and high outlier test must be applied before removing data from the set. The following equations, recommended by U.S Water Resource Council (1981), are applied to identify the high and low outliers. The formulas of high and low outlier are shown in Equation (1) and (2), respectively;

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

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

where N is the sample size, K_N is 10% significance level K values, y_H is high outlier threshold in log units, y_L is low outlier threshold in log units, s_y is standard deviation and $\underline{y}$ is mean logarithm of variate.

Frequency Analysis using Frequency Factor for Different ARI

In hydrologic frequency analysis, Equation (3) was proposed by Chow et al. (1988), which is applicable for many probability distributions used.

$$x_T = \underline{x} + K_T\sigma \quad (3)$$

where x_T is the value of the variate x of a random hydrologic series with an ARI T, $\underline{x}$ is mean of the variate, K_T is frequency factor that depends upon the ARI T and σ is the standard deviation of the variate.

In the event that the variable analysed is $y = log\ x$, then the same method is applied to the statistics for the logarithms of the data using Equation (4);

$$y_T = \underline{y} + K_T\sigma \quad (4)$$

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

Fitting of Probability Distribution

Every province of the world has a record of historical rainfall data in hourly, daily, monthly or annually time scale; henceforth, for the development of this planet, the probability distribution is mostly performed for the resolution of characterising the data concatenation of rainfall. In this study, the LPIII distribution and Gumbel distribution were used to analyse the data sample at Kemaman district, because these methods are widely used and practised for extreme events. Every annual maximum hourly and daily rainfall set was analysed with three parameters using LPIII distribution, while Gumbel distribution generates only two parameters. Equation (5) implies the formula used in this study for probability density function for LPIII distribution, and Equation (6) and (7) are probability functions for Gumbel distribution respectively;

$$f(x) = \frac{1}{x|\beta|\Gamma(\alpha)}\left(\frac{\ln(x)-\gamma}{\beta}\right)^{\alpha-1}\exp\left(-\frac{\ln(x)-\gamma}{\beta}\right) \quad (5)$$

where $0 < x \leq e^{\gamma}, \beta < 0$, $e^{\gamma} \leq x < \infty, \beta > 0$, α is shape parameter, β is the scale parameter, γ is location parameter and Γ is gamma function.

$$f(x) = \frac{1}{\sigma}\exp[-z-\exp(-z)]; -\infty \langle x \langle +\infty \quad (6)$$

$$z = \frac{x-\mu}{\sigma} \quad (7)$$

where μ is continuous (location) parameter and σ is continuous (scale) parameter, $(\sigma > 0)$.

Checking of Goodness of Fit

Goodness of fit for the modelling of hydro-climatic is extensively assessed through computation of relationship or correlation related measures. Prognosis of time and space parameter in a given set of data is the principal aim of evaluated modelling for the collected variable, which is normally validated by pairwise comparison of the observed data with the model stimulated or predicted values. KS test and AD test were implemented in this study for the checking of fitness of probability distributions. The computation of the statistic test is tested at 0.05 level of significance. A conclusion can be derived by comparing the statistical value and critical value, where the distribution fit well the data concatenation if the computed statistical value is smaller than the critical value. The fitness of distribution is denoted with the highest rank (one) as it approaches the zero value. Hence, the smaller the output of goodness of fit test, the best the probability distribution function to the set of samples.

EasyFit

EasyFit enables users to stimulate probability distribution that best fits the data by performing appropriate equations and calculations using the best fitting model. This software is designed with automatic data fitting mode, which is capable of supporting 55 different types of the probability distribution, including LPIII and Gumbel distribution. EasyFit delivers productive work through data management, organising and reporting, and data analysis.

Results and Discussion

Outliers

The annual maximum hourly and daily rainfall for the Kemaman district are analysed after the checking and elimination process of outlier using Equations (1) and (2), which are used based on the number of samples in a series available at each station, and the output is tabulated in Table 4 and 5. The K_N value based on the number of samples is obtained from the table for outlier suggested in Hydrology Subcommittee Bulletin #17B (1982). The result of the outlier test concluded that except 3933001, 4131001, 4232104 and 4333096 stations, the remaining three stations had outliers in the sample of data.

Table 4: Outlier of Annual Maximum Hourly Data Series

Station ID	Sample (N)	K_N	High outlier	Low outlier
3933001	32	2.591	141.5	33.8
4131001	30	2.577	117.5	37.2
4232002	29	2.549	107.0	37.2
4232104	14	2.213	105.9	51.9
4332001	30	2.563	134.1	32.5
4333096	10	2.036	113.0	53.4
4334094	14	2.213	114.6	45.8

Table 5: Outlier of Annual Maximum Daily Data Series

Station ID	Sample (N)	K_N	High outlier	Low outlier
3933001	32	2.591	141.5	33.8
4131001	30	2.577	117.5	37.2
4232002	29	2.549	107.0	37.2
4232104	14	2.213	105.9	51.9
4332001	30	2.563	134.1	32.5
4333096	10	2.036	113.0	53.4
4334094	14	2.213	114.6	45.8

Probability Distribution Function

The probability distribution function of this study, LPIII distribution and Gumbel distribution for annual maximum hourly and daily data for seven stations, were plotted to visually observe and compare the fitness of distribution for the data concatenation. Figure 2, 3, 4 and 5 illustrate the annual maximum hourly and daily rainfall data for Station 433096, Klinik Bidan di Kg. Ibok for LPIII distribution and Gumbel distribution. From the figures, it is observed that two probability density functions fit fairly well with the data series.

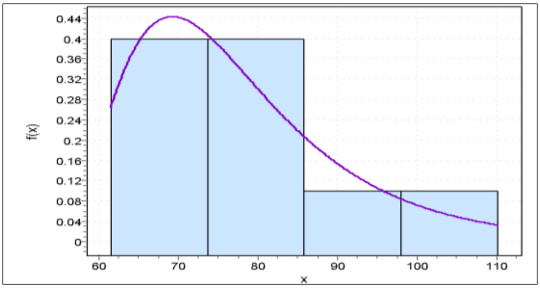

Figure 2: LPIII Distribution for Annual Maximum Hourly Rainfall

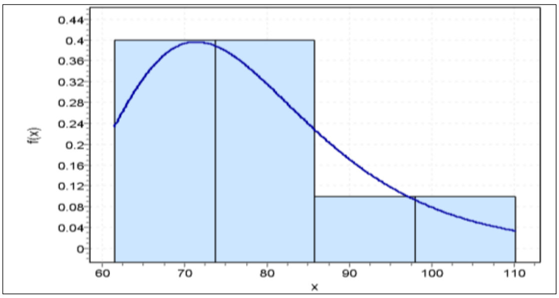

Figure 3: Gumbel Distribution for Annual Maximum Hourly Rainfall

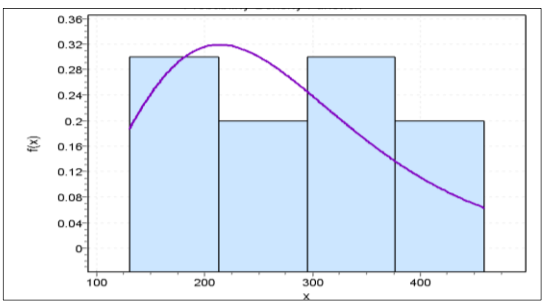

Figure 4: LPIII Distribution for Annual Maximum Daily Rainfall

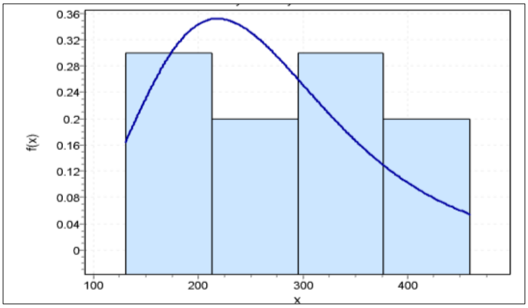

Figure 5: Gumbel Distribution for Annual Maximum Daily Rainfall

Parameter Estimation

The parameters of the two distribution functions were generated using EasyFit software. EasyFit uses the method of moment to estimate the parameters for distributions. Table 6 shows the parameter of LPIII and Gumbel distribution for annual maximum hourly and daily data.

Table 6: Parameter Estimation of Gumbel Distribution and Log-Pearson Type III for Annual Maximum Hourly and Daily Data

	Hourly		Daily	
Station ID	**Parameter of Gumbel**	**Parameter of Log-Pearson Type III**	**Parameter of Gumbel**	**Parameter of Log-Pearson Type III**
3933001	σ = 12.196 μ = 61.422	α = 190.110 β = 0.016 λ = 1.107	σ = 127.070 μ = 173.200	α = 4.517 β = 0.240 λ = 4.275
4131001	σ = 15.321 μ = 62.948	α = 1673.200 β = 0.007 λ = -6.799	σ = 51.278 μ = 166.210	α = 129.170 β = -0.030 λ = 9.036
4232002	σ = 10.853 μ = 58.518	α = 708.560 β = -0.008 λ = 9.882	σ = 61.917 μ = 174.310	α = 500.180 β = -0.017 λ = 13.846

	Hourly		Daily	
Station ID	**Parameter of Gumbel**	**Parameter of Log-Pearson Type III**	**Parameter of Gumbel**	**Parameter of Log-Pearson Type III**
4232104	σ = 9.541 μ = 69.565	α = 23.003 β = 0.033 λ = 3.544	σ = 71.796 μ = 221.890	α = 14.826 β = -0.100 λ = 6.993
4332001	σ = 15.697 μ = 59.816	α = 386.300 β = 0.014 λ = -1.377	σ = 81.763 μ = 184.300	α = 39.607 β = -0.076 λ = 8.365
4333096	σ = 11.285 μ = 71.416	α = 4.442 β = 0.082 λ = 3.976	σ = 85.715 μ = 218.330	α = 61.980 β = -0.055 λ = 8.947
4334094	σ = 13.099 μ = 67.003	α = 7.961 β = 0.075 λ = 3.694	σ = 104.140 μ = 227.380	α = 16.437 β = 0.106 λ = 3.821

Goodness of Fit

The goodness of fit test is generated using KS and AD test. Both fitness tests are conducted at the significance level of 0.05. Corresponding to the result acquired from the goodness of fit tests; it can be concluded that LPIII distribution is the best probability density function for the analysis at Kemaman. Based on the ranking of KS test, for annual maximum hourly data, 71.43% of stations and 85.71% of stations for annual maximum daily data are best suited by LPIII distribution. In addition, AD test also recommends LPIII distribution, where 85.71% of stations and 100% of stations are the best fit for annual maximum hourly and daily data concatenation, respectively, as shown in Table 7 and 8.

Table 7: Goodness of Fit for Annual Maximum Hourly Data Series

	Kolmogorov-Smirnov Test		Anderson-Darling Test	
Station ID	**Gumbel (Rank)**	**LPIII (Rank)**	**Gumbel (Rank)**	**LPIII (Rank)**
3933001	0.074 (2)	0.062 (1)	0.213 (2)	0.157 (1)
4131001	0.084 (2)	0.073 (1)	0.240 (2)	0.186 (1)
4232002	0.077 (2)	0.076 (1)	0.249 (2)	0.139 (1)
4232104	0.202 (2)	0.195 (1)	0.403 (2)	0.381 (1)
4332001	0.097 (1)	0.098 (2)	0.222 (1)	0.237 (2)
4333096	0.171 (2)	0.147 (1)	0.185 (2)	0.136 (1)
4334094	0.165 (1)	0.166 (2)	0.418 (2)	0.393 (1)

Table 8: Goodness of Fit for Annual Maximum Daily Data Series

	Kolmogorov-Smirnov Test		Anderson-Darling Test	
Station ID	**Gumbel (Rank)**	**LPIII (Rank)**	**Gumbel (Rank)**	**LPIII (Rank)**
3933001	0.191 (2)	0.096 (1)	1.745 (2)	0.337 (1)
4131001	0.111 (1)	0.123 (2)	0.330 (2)	0.315 (1)
4232002	0.134 (2)	0.133 (1)	0.512 (2)	0.422 (1)
4232104	0.157 (2)	0.114 (1)	0.564 (2)	0.252 (1)
4332001	0.223 (2)	0.098 (1)	0.337 (2)	0.254 (1)
4333096	0.176 (2)	0.157 (1)	0.309 (2)	0.226 (1)
4334094	0.155 (2)	0.135 (1)	0.466 (2)	0.280 (1)

Rainfall Intensity Estimation

The annual maximum hourly and daily rainfall intensity for LPIII and Gumbel distributions are calculated with ARI of 2, 10, 25, 50 and 100-year. The results are given in Table 9 and 10, respectively. From the tables, the annual maximum hourly rainfall intensity estimated by Gumbel distribution is the highest at larger ARIs. Meanwhile, for annual maximum daily rainfall intensity, the highest values at larger ARIs are also projected by Gumbel distribution, except for stations 3933001 and 4334094.

Table 9: Hourly Rainfall Intensity for different ARIs

Station ID	Distribution	ARI (Years) versus Rainfall Intensity (mm/hr)				
		2	**10**	**25**	**50**	**100**
3933001	Gumbel	68.783	101.783	118.511	130.862	143.122
	LPIII	68.676	98.162	112.288	122.590	132.783
4131001	Gumbel	66.070	92.476	105.766	115.766	125.412
	LPIII	66.439	89.356	100.054	100.054	115.318
4232002	Gumbel	62.663	86.318	98.223	107.056	115.823
	LPIII	63.532	83.344	81.860	97.753	103.317
4232104	Gumbel	73.332	96.166	107.659	116.185	124.648
	LPIII	73.374	91.467	100.093	106.456	112.620
4332001	Gumbel	65.806	99.900	117.059	129.789	142.426
	LPIII	65.908	95.523	109.858	120.593	130.800
4333096	Gumbel	75.969	104.682	119.135	129.856	140.498
	LPIII	74.784	96.955	109.310	119,003	129.107
4334094	Gumbel	72.176	103.528	119.308	131.014	142.634
	LPIII	71.185	96.716	110.446	121.446	132.684

Table 10: Daily Rainfall Intensity for different ARIs

Station ID	Distribution	ARI (Years) versus Rainfall Intensity (mm/hr)				
		2	**10**	**25**	**50**	**100**
3933001	Gumbel	9.235	20.699	26.469	30.749	34.998
	LPIII	8.202	17.601	25.030	32.116	40.788
4131001	Gumbel	7.741	12.381	14.717	16.450	18.170
	LPIII	7.792	11.806	13.627	14.917	16.155
4232002	Gumbel	8.248	13.871	16.701	18.803	20.884
	LPIII	8.213	13.288	15.779	17.606	19.406
4232104	Gumbel	10.427	17.587	21.190	23.864	26.517
	LPIII	10.635	16.419	18.765	21.320	21.734
4332001	Gumbel	8.979	16.379	20.103	22.866	25.608
	LPIII	8.888	15.801	19.146	21.572	15.520
4333096	Gumbel	10.538	19.625	24.199	27.584	30.960
	LPIII	10.472	17.755	21.227	23.731	26.155
4334094	Gumbel	11.181	21.454	26.624	30.460	34.268
	LPIII	10.599	19.358	24.922	29.614	34.794

Overall, LPIII distribution is recommended for estimating annual maximum hourly and daily rainfall intensity in Kemaman through this study.

Conclusion

The objectives of this study have been achieved by analysing the data series of annual maximum hourly and daily rainfall for seven stations at Kemaman district using LPIII distribution and Gumbel distribution. The statistical characteristics, outliers and parameters are estimated for each data concatenation.

According to the output of the analysis of statistical tests, LPIII distribution is proven to be the most appropriate distribution for annual maximum hourly and daily rainfall for Kemaman district. Based on the KS and AD test, for annual maximum hourly and daily data, it is recommended that LPIII distribution is the best fit distribution for Kemaman.

In general, LPIII distribution is recommended to estimate the annual maximum hourly and daily rainfall intensity in Kemaman. Thus, the rainfall intensity with various ARIs is estimated, which can be used as the basic inputs in hydrologic design, development of water resource planning, forecasting of flood frequency and input to rainfall-runoff models. For recommendation, future research can be carried out at other districts of Terengganu, Malaysia, to verify that LPIII distribution is the recommended distribution for the entire state of Terengganu.

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