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Extreme Strom Duration Modelling at Peninsular Malaysia

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Abstract - Occurrence of extreme storm duration can be characterized by their external measures of the annual maximum storm event analysis (AMSEA) namely maximum storm amount (MSA), maximum storm intensity (MSI) and maximum storn duration (MSD). This paper presents the best fitting distribution to describe the siries the MSD only based on hourly rainfall form 1970 to 2008 for 10 rain gauge stations in Peninsular Malaysia. Four three-parameter extreme value distributions which are considered are generalized extreme value (GEV), generalized pareto (GP), generalized logistic (GL) and lognormal (LN3). The parameters of these distributions is determined using the L-moments method. The goodness-of-fit (GOF) between empirical data and theoretical distributions are then evaluated for each of the 10 stations. Although the best fitting distribution may vary according stations considered, in most cases, data for majority of the stations are found to follow the GEV and GL distribution.

Keywords: **AMSEA; GEV; MSA; MSI; MSD**

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1. INTRODUCTION

Extreme rainfall event is often associated with climate change, which may be followed by siries of natural disasters such as flash floods and landslides.
Considering this phenomenon, the analysis of extreme rainfall data can be utilized
for decision makers to set-up measures for reducing or preventing the impact of disasters. In Malaysia, extreme analysis on rainfall data has been explored for all sorts of purposes such as detecting recent changes in extreme rainfall events and fitting probability distributions to annual maximum rainfalls by implementing various methods [1].

In this study, an analysis of extreme rainfall based on annual maximum storm duration (MSD). Previous literatures provide a few methods of viewing storm event analysis (SEA) in their analysis, among them [2],[3]. The analysis involves fitting four extreme values distributions which are considered are generalized extreme value (GEV), generalized pareto (GP), generalized logistic (GL) and lognormal (LN3). The estimation parameters of these distributions is determined using L-moment [4]. Comparison is made to determine the most suitable using goodness-of-fit test. Previous distribution studies on external measures SEA [5], but published studies has yet to be found for MSD for this area.

The contents of the paper are structured as follows. In Section 2, we describe the data and definition of storm. Section 3 describes the statistical models, the L-moments method of parameter estimation, and the goodness-of-fit procedures. Analysis on the MSD series are discussed in Section 4. Finally, a short discussion on the overall findings and conclusion are presented in Section 5.

.2. Data and definition of storm

The data consisting of hourly rainfall data from 10 rain gauge stations in Peninsular Malaysia from 1970 to 2008 have been obtained from the Drainage and Irrigation Department. The name of 10 rain gauge station can be found in table 2

The definition of storm-event depends greatly on the interevent time definition. The inter-event time definition (IETD) is defined as the minimum duration of dry period between two consecutive storm events. Hence, the dry duration between two individual storm events must at least be equal to the IETD value. If not, they would not be considered as two different events but parts of the same storm. For small urban catchments, the IETD is usually taken as 6 h because the time concentration of rainfall which is less than 6 h would make the runoff response of successive storms to appear independent [6]. Storm depth is defined as the accumulated rainfall which begins and ends with at least one wet hour and either contains dry periods with less than or none at all. Storm duration is defined as the time interval for a storm event and storm intensity is the ratio of storm depth to storm duration. The information extracted from the rainfall data is the annual MSA, MSI and MSD. This information and definition of storm can be explained form Fig. 1. let x_{ij} is jth rainfall (mm) on ith storm and n_i is duration (hour) on ith storm, for each storm the MSA, MSI and MSD was obtained from the hourly data as follows

$$\text{MSD} = \text{maximum } (n_i), i = 1,2,3$$

$$\text{MSA} = \text{maximum } \left(\sum_{j=1}^{n_i} x_{ij}\right), \; i = 1,2,3$$

$$\text{MSI} = \text{maximum } \left(\frac{\sum_{j=1}^{n_i} x_{ij}}{n_i}\right), \; i = 1,2,3$$

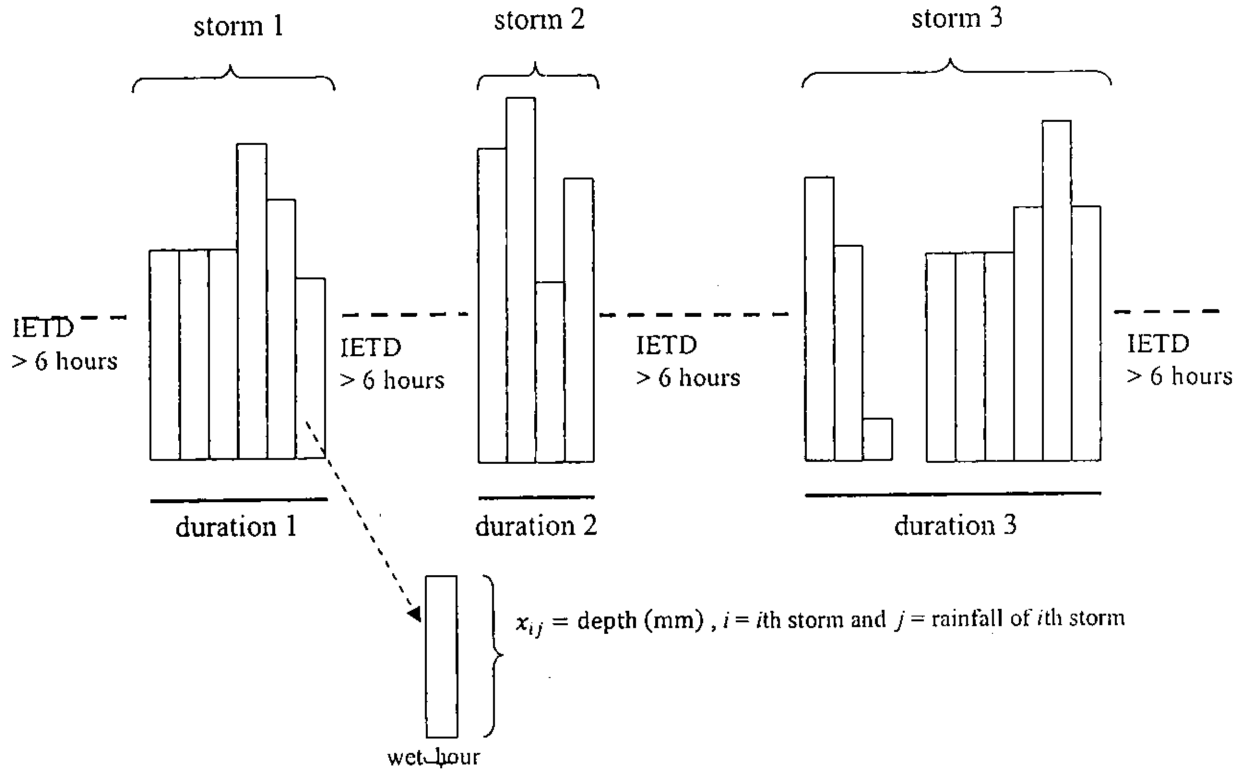

Fig. 1 Definition of storm

3. METHODS

The most common analysis of extreme hydrological events involves the use of annual maximum or annual extreme. When constructing the AMSEA series, the MSA, MSI and MSD for each year in the record is selected; hence, the series obtained would have a length equal to the number of years. Many works that apply the annual maximum series usually involve fitting of a probability model to the rainfall data. Thereafter, several researchers have provided useful applications of annual maximum distributions to rainfall data obtained from different regions of the world. Examples of applications include [7] for applications in Canada; [8] for application in Italy. Four probability distributions associated with modeling extreme events, GEV, GP, GL and LN3 are considered in this paper. The probability density function, probability function and quantile function for each distribution that we consider are as given in Table 1, where x denote the observed values of the random variable representing the event of interest, α is the scale parameter, ε is the location parameter, and κ is the shape parameter.

In order to fit a particular theoretical distribution to the observed distribution of AMSEA, parameters are estimated using the L-moments method.

3.1 Probability distribution

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3.2 L-moment and Goodness-of-fit (GOF)

The L-moments method (LMOM), introduced by [4], is widely applied in the field of applied research such as hydrology, meteorology, and civil engineering for estimating parameters of a distribution. It is based on a linear combination of order statistics where the first-until the fourth-order statistics correspond to measures of location, scale, skewness, and kurtosis, respectively. The rth LMOM, denoted as λ_r is defined as

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

Where $X_{r-k:r}$ is the random variable variable for $(r-k)$ th order statistics. Once the distribution of the observed values is determined for each of the MSA, MSI and MSD series, the expected frequencies under the assumed distribution are computed for each station separately. The most appropriate distribution for each station is identified using results found based on several goodness-of-fit tests.

A numerical GOF tests considered are relative root mean square error (RRMSE). This method involves the assessment on the difference between the observed values and the expected values under the assumed distribution. The formulas for the tests are

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

where $x_{i:n}$ is observed values for ith order statistics of random sample of size n, $\bar{Q}(F_i) = \frac{1}{n}\sum_{i=1}^{n}\hat{Q}(F_i)$ is the estimated quantile values associated with Gringorton plotting position F_i. If RRMSE is used to compare the model, the smallest value of RRMSE will indicate best fitting distribution.

Table 1 List of distributions used in this study

Distribution	Probability density function, *f(x)*	Cumulative distribution, *F(x)*	Quantile function, *Q (F)*	Return Period T-year
GEV	$f(x)=\alpha^{-1}exp\{-(1-\kappa)y - exp(-y)\}$ with $y=\begin{cases}-\kappa^{-1}log\{1-\kappa(x-\xi)/\alpha\}, & \kappa\neq 0\\ (x-\xi)/\alpha, & \kappa=0\end{cases}$ $-\infty<x<\xi+\alpha/\kappa\ for\ \kappa>0$ $-\infty<x<\infty\ for\ \kappa=0$ $\xi+\alpha/\kappa\leq x<\infty\ for\ \kappa<0.$	$F(x)=\begin{cases}exp\left(-\left(1-\frac{\kappa}{\alpha}(x-\xi)\right)^{\frac{1}{\kappa}}\right), if\ \kappa\neq 0\\ exp\left(-exp\left(-\frac{1}{\alpha}(x-\xi)\right)\right), if\ \kappa=0\end{cases}$	$Q(F)=\xi+\frac{1}{\kappa}(1-(-ln(F))^{\kappa})$	$x_T=\xi+\frac{\alpha}{\kappa}\left(1-\left(-ln\left(1-\frac{1}{T}\right)\right)^{\kappa}\right)$
GP	$f(x)=\frac{1}{\alpha}\left(1-\frac{\kappa}{\alpha}(x-\xi)\right)^{\frac{1-\kappa}{\kappa}}$ $\xi\leq x<\infty\ for\ \kappa\leq 0$ $\xi\leq x\leq\xi+\alpha/\kappa\ for\ \kappa>0$	$F(x)=1-\left(1-\frac{\kappa}{\alpha}(x-\xi)\right)^{\frac{1}{\kappa}}$	$Q(F)=\xi+\frac{\alpha}{\kappa}(1-(1-F)^{\kappa})$	$x_T=\xi+\frac{\alpha}{\kappa}(1-T^{-\kappa})$
GL	$f(x)=\frac{\alpha^{-1}exp\{-(1-\kappa)y\}}{(1+exp(-y))^2}$ with $y=\begin{cases}-\kappa^{-1}log\{1-\kappa(x-\xi)/\alpha\}, & \kappa\neq 0\\ (x-\xi)/\alpha, & \kappa=0\end{cases}$ $-\infty<x<\xi+\alpha/\kappa\ for\ \kappa>0$ $-\infty<x<\infty\ for\ \kappa=0$ $\xi+\alpha/\kappa\leq x<\infty\ for\ \kappa<0$	$F(x)=\left(1+\left(1-\kappa\left(\frac{x-\xi}{\alpha}\right)\right)^{\frac{1}{\kappa}}\right)^{-1}$	$Q(F)=\xi+\frac{\alpha}{\kappa}\left(1-\left(\frac{1-F}{F}\right)^{\kappa}\right)$	$x_T=\xi+\frac{\alpha}{\kappa}(1-(T-1)^{-\kappa})$

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LN3	$f(x) = \frac{1}{\alpha\Gamma(\kappa)}\left(\frac{x-\xi}{\alpha}\right)^{\kappa-1} exp\left(-\frac{x-\xi}{\alpha}\right)$ $\xi < x < \infty$	$F(x) = \frac{1}{\alpha\Gamma(\kappa)}\int_0^x \left(\frac{t-\varepsilon}{\alpha}\right)^{\kappa-1} exp\left(-\frac{t-\varepsilon}{\alpha}\right) dt$	$Q(F) = \xi + \frac{\alpha}{\kappa} + \frac{\alpha}{\kappa} Q_0(F,\kappa)$ $Q_0(F,\kappa) = \frac{1}{\sqrt{\kappa}}\left(\left(1 + \frac{\Phi^{-1}(F)}{3\sqrt{\kappa}} - \frac{1}{9\kappa}\right)^3 - 1\right)$	$x_T = \xi + \frac{\alpha}{\kappa}\left(1 - exp\left(-\kappa\Phi^{-1}\left(1 - \frac{1}{T}\right)\right)\right)$

4. RESULT

The characteristics of MSD involving mean, standard deviation, coefficient of variation, skewness and kurtosis for all stations are provided in Table 2. When compared to other region in peninsular, it can be seen that for stations located at small part of the eastern region, including the are of stations Besut, Kemaman, and Batu Hampar also received largest average of annual MSD. These findings suggest that eastern areas are potentially at risk of flooding, landslides, and soil erosion.

The next analysis involves selection of the best fitting distribution for MSD utilizing parameters obtained based on LMOM. Results for the analysis are provided in table 3. Form table 3, it can be concluded that based on LMOM, for GOF tests, The result of estimation using LMOM seem to agree on the best fitting distribution for MSD in most of stations on Peninsular Malaysia, GEV and GL are identified as the most frequently selected best fitting distribution and LN3 as the least frequently selected. These results is supported by [9], they found that GEV is the most frequently selected best fitting distribution for annual maximum rainfall for 13 rain gauge stations in Peninsular Malaysia for the period 1971-1995. [10] found that GL is an appropriate model for annual maximum rainfall using 50 rain gauge stations in Peninsular Malaysia

Table 2 Main characteristics MSD of the rain gauge stations

No.	Station name	Mean	Standard deviation	Coef. of Variation	Skewness	Kurtosis
1	Alorstar	53.82	29.70	0.55	1.56	5.19
2	Ampang	44.62	39.83	0.89	2.44	8.76
3	Batu Hampar	142.29	115.21	0.81	2.59	9.39
4	Bertam	50.51	27.27	0.54	1.47	5.04
5	Besut	108.40	74.45	0.69	2.89	12.31
6	Bukit Bendera	48.76	22.51	0.46	1.28	4.72
7	Chanis	48.41	12.68	0.26	0.61	3.39
8	Chinchin	40.18	29.63	0.74	3.12	14.27
9	Dabong	78.50	54.23	0.69	2.71	11.82
10	Dungun	80.18	37.46	0.47	1.08	4.72

Table 3 Result of best fitting distribution test based on RRMSE for MSD

No.	Station name	GEV	GV	GL	LN3
1	Alorstar	**0.05**	0.07	0.06	0.05
2	Ampang	0.09	0.07	0.10	**0.06**
3	Batu Hampar	0.11	0.14	**0.11**	0.13
4	bertam	0.06	0.08	0.07	**0.06**
5	besut	0.11	0.15	**0.10**	0.13
6	bukit bendera	**0.05**	0.09	0.05	0.05
7	chanis	**0.03**	0.06	0.03	0.03
8	chinchin	0.06	0.06	0.06	**0.06**
9	dabong	**0.05**	0.07	0.06	0.06
10	dungun	0.09	0.19	**0.06**	0.09

bold indicates the smallest test RRMSE value

5. CONCLUSION

The analysis of extreme rainfall based on MSD has been interest to many hydrologist and meteorologist, particularly for the purpose of planning to avoid possible disaster resulting from this extreme event. An important analysis could involve finding the best distribution that can be represent the behavior MSD at a particular location.

This study found that the result of the best fitting distribution may differ for particular station depending on LMOM. However, GEV and GL are identified as the most frequently selected best fitting distribution.

In terms of application, the estimation of MSD could represent a valuable aid for planning and managing the water resources for agricultural use and socioeconomic activity. The decision-making such as construction of a proper drainage system and the management of water resources (reservoirs and ground surface waters) should allow for this prediction in order to be cost-effective. In addition, this information could also facilitate the decisionmakers to prioritize resources accordingly

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