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COMPARISON OF GAMMA AND WEIBULL DISTRIBUTIONS IN SIMULATING HOURLY RAINFALL IN PENINSULAR MALAYSIA

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ABSTRACT

Prior knowledge of rainfall is essential in the planning and lessening of the risks associated with extreme events such as floods, landslides and erosions. The development of a reliable model is therefore, crucial in predicting rainfall series that is parallel to the local climate. In this study, a weather generator is chosen to model hourly rainfall time series in Peninsular Malaysia. Short duration rainfall such as hourly scale is an inherent aspect of tropical rainfall, and instigates many flooding events, especially in the western part of the peninsular. Two distributions, Gamma and Weibull are incorporated into the rainfall generator and their performances in generating rainfall series are then compared. Simulations using both Gamma and Weibull distributions are individually conducted at forty stations across the peninsular. Results reveal that both Gamma and Weibull distributions are able to capture rainfall characteristics at the study sites. However, Gamma is found best to represent rainfall at sites located in eastern and southern parts of the peninsular whilst Weibull is more suitable for western and northern parts. Hence, Gamma is more suitable for representing monsoon rainfall while Weibull is more appropriate for inter-monsoon rainfall.

Keywords: Rainfall intensity; Gamma; Weibull; hourly rainfall.

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1. INTRODUCTION

Extreme rainfall events are shown to be on the rise globally. Being one of the most important impacts of climate change, increasing events of high intensity rainfall could be disastrous to any country. Flash floods caused by high intensity rainfall may occur within minutes or hours of raining, depending on the intensity and duration of the rain, the topography, soil conditions, and ground cover. Stochastic weather generators are commonly relied on to simulate daily time series of weather, including elements such as minimum and maximum temperature and rainfall amount [7]. Such simulations are sometimes intended to reflect solely natural variations under the present climate or, alternatively, to be consistent with large-scale global change [3,6]. These simulations are typically used as inputs in assessments of the societal impacts of variations in weather and climate, for example, in statistical downscaling of the output from a general circulation model. Therefore, the realistic modeling of the intensity (and frequency) of rainfall and severity of extreme weather events (e.g., hot or cold spells or high rainfall amounts) is essential.

Rainfall intensity is defined as the ratio of the total amount of rain (rainfall depth) during a given period to the duration of the period. It is expressed in depth units per unit time, usually as mm per hour (mm/h). The statistical characteristics of high intensity, short duration convective rainfall are essentially independent of locations within a region. Preliminary assessment on spatial distribution of hourly maximum index (Hr-Max) for Peninsular Malaysia is computed for the interval of 1975 and 2010. It is shown that the Hr-Max recorded a higher value in this season compared to other seasons, with amount of rainfall reaching up to 49.93mm. This is in agreement with the general assumption that convective rain occurring during the inter-monsoon period has higher intensities compared to stratiform rain which occurs during the monsoon season.The maximum rainfall for convective rain tends to depict higher values in a relatively shorter time frame. Such results cannot be captured using daily data, as portrayed by the results of [8], in which the highest extreme intensities occur during NEM season. While most weather generator used meteorological data at daily scale as input, the Advanced Weather Generator (AWE-GEN), developed by [2], enable the use of data at hourly scale. High resolution data such as hourly scale are more sensitive towards high intensity convective rain, a common feature of tropical rainfall within urban areas [5]. Besides capable of simulating the inter-annual variability of rainfall process, AWE-GEN could also capture extreme values. In this study, Gamma and Weibull distributions are individually incorporated into the AWE-GEN to determine which distribution is better at capturing hourly rainfall patterns across the peninsular. The present AWE-GEN model uses Gamma distribution and this study proposes the use of Weibull based on the fact past studies indicate that Weibull is also able to represent rainfall process and capture extreme values.

2. DATA

In this study, the AWE-GEN model is constructed based on 30 years of historical data (1975-2005). The input data required by AWE-GEN are hourly rainfall, hourly temperature, hourly relative humidity and hourly wind speed. These input data are gathered from 40 rainfall stations across Peninsular Malaysia. The rainfall stations are selected based on two criteria: (1) adequacy of data and length of record, and (2) even distribution of rainfall stations across the peninsular. Stations with missing values, greater than 2% of the total record hours between 1st January 1975 and 31st December 2010 are excluded. The Average Nearest Neighbour is used in ensuring the stations chosen are sufficiently spaced out over Peninsular Malaysia.

3. METHODS

Thirty years of hourly rainfall series are generated at each of the 40 rainfall stations using Gamma distributions that are incorporated in AWE-GEN. The same process is repeated using Weibull distribution. In AWE-GEN, the intra-annual variability of rainfall is represented by the Neyman-Scott Rectangular Pulses (NSRP) model. Work by [1,4] indicates that the NSRP model is suitable to be used in Malaysia. The Gamma distribution that is associated in NSRP is as follows:

$$P(x) = 0\begin{cases} \dfrac{1}{\alpha\Gamma(\alpha)}\exp^{\left(\frac{x-\theta}{\sigma}\right)}, & x > 0 \\ 0, & x \le 0 \end{cases}$$

where σ is the scale parameter $(\sigma > 0)$, α is the shape parameter $(\alpha > 0)$, x is the hourly rainfall amount and θ is the threshold parameter which is less than x.

The Weibull distribution is as follows:

$$P(x) = \left(\frac{\beta}{\alpha}\right)\left(\frac{x}{\alpha}\right)^{\beta-1}\exp^{\left(-\left(\frac{x}{\alpha}\right)^{\beta}\right)}$$

where σ and β are the scale and shape parameters, respectively.To compare performance of both distribution, Root Mean Square Error (RMSE) valueis estimated for both sets of simulations at each rainfall station. Lowest value of RMSE indicates better distribution at a particular station.For validation of model, the simulated hourly rainfall series is divided into two non-overlapping period of i) 1975 to 1989 and ii) 1990 to 2005. The 1975 to 1989 is used as the reference period where the multiplicative factor is calculated based on the simulation output and the high resolution observational data. The changing factors are then used to correct the biases of the simulation output from 1990 to 2005. The corrected hourly rainfall is then compared to the observation from the identical period of 1985-1999.

4. RESULTS AND DISCUSSION

Table 1 shows the values of RMSE whereas Figure 1 shows the best distribution for each rainfall station across Peninsular Malaysia. Results show that Gamma is the best distribution mostly for stations located in eastern and southern parts of the peninsular while Weibull is the best distribution mostly for those in western and northern parts of the peninsular. A few stations within the middle part of the peninsular show that both distributions are well performed. Western region is most affected by the inter-monsoon season where convective rain brings high intense rainfall in a short duration (i.e. hourly) during this season. On the other hand, eastern region is most affected by the Northeast monsoon rainfall where stratiform rain brings long duration (i.e. daily) extreme rainfall during this season [5]. Thus, this indicates that Gamma is the best distribution in representing monsoon rainfall while Weibull is the best distribution for the inter-monsoon rainfall. In addition, Weibull also seems to be able to simulate rainfall in a drier region (i.e. northern part).

Table 1. RMSE values of hourly rainfall for Gamma and Weibull distributions at each rainfall station (bold fonts indicate lowest RMSE value)

Station	RMSE		Station	RMSE		Station	RMSE	
	Gamma	Weibull		Gamma	Weibull		Gamma	Weibull
1	**248.8**	258.8	16	217.1	**210.8**	31	238.6	**228.3**
2	226.3	**224.7**	17	203.6	**199.4**	32	**204.7**	206.7
3	**254.1**	281.1	18	**237.0**	239.2	33	205.5	205.5
4	237.8	**237.7**	19	**205.4**	205.6	34	**228.2**	239.5
5	**218.2**	235.6	20	234.7	**233.3**	35	**128.0**	130.0
6	**233.6**	236.6	21	**266.2**	270.2	36	**246.6**	324.6
7	**236.7**	237.0	22	128.0	128.0	37	**250.2**	251.0
8	286.5	**275.6**	23	**368.6**	380.6	38	366.3	**213.4**
9	298.0	**294.2**	24	270.3	**270.2**	39	**238.7**	240.0
10	**252.0**	259.3	25	**326.1**	330.0	40	667.2	**590.0**
11	241.1	**237.5**	26	**209.2**	235.2			
12	235.3	**232.6**	27	**216.0**	224.7			
13	255.2	**251.8**	28	404.1	**325.3**			
14	**264.3**	271.4	29	417.4	**252.6**			
15	**296.3**	301.0	30	229.0	**212.0**			

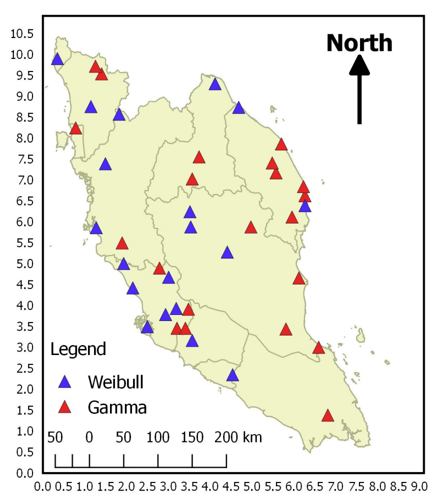

Fig.1. Best distribution of rainfall intensity for each rainfall station

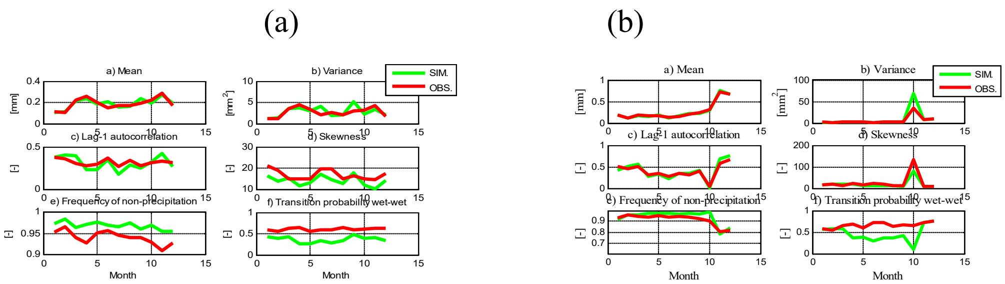

Fig.2. A comparison between observed (OBS) and simulated (SIM) monthly statistics at 1-hour aggregation period, (a) Weibull and (b) Gamma distributions

The capability of the model to reproduce the main statistics of the rainfall process at different aggregation periods is tested. The simulated mean, variance, lag-1 autocorrelation, skewness, frequency of no rainfall, and the transition probability from a wet spell are compared with observations at the monthly scale.Two stations representing Gamma and Weibull distributions are selected for comparison of monthly statistics between simulated and observed.The comparison at 1-hour aggregation period is shown in Figure 2. All monthly statistics of rainfall are well simulated (i.e. are still preserved) at 1-hour aggregation period.

5. CONCLUSION

This study aims to determine the best probability distribution to represent extreme rainfall events in Peninsular Malaysia. The study results have shown that both Gamma and Weibull distributions performed rather well at all study sites. RMSE value shows only minimal difference between the two distributions. All monthly statistics of rainfall are well preserved at the 1-hour aggregation period.Further analysis indicates that different seasonal variations of rainfall is best represented by different types of distribution.The outputs from this study could be used as a basis in providing inputs for various hydrological applications,especially those related to management of flooding in urban areas, hence aiding theMalaysiangovernment in integrating hazard mitigation and risk adaptation planning.

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