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Research paper

Evaluating Extreme Value Rainfall Using Mixed Exponential Distribution with Advanced Weather Generator

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Abstract

Changes in rainfall regime is one of the factors that is used to determine the impact of climate change. Climate change substantially impacted human societies and the natural environment with the many occurences of extreme weather events, namely rainfall variation, floods, droughts and rainstorms. In tropical countries such as Malaysia, the occurrence of extreme rainfalls has become more common in recent decades. Advanced Weather Generator (AWE-GEN) which uses meteorological data as input has the potential in predicting extreme events. The aim of this study is to propose and integrate the mixed exponential distribution in representing rainfall intensity using AWE-GEN model and evaluate the ability of the newly developed model in simulating extreme rainfall. Parameters of mixed exponential distribution theoretically represent light and heavy rainfall. The study site is Kemaman, Malaysia which is often affected by flood. Model input uses historical meteorological variables of forty years (1975 - 2015) at hourly scale, specifically precipitation, air temperature, relative humidity and wind speed. Results indicate the AWE-GEN model with mixed exponential distribution is capable of generating rainfall series very well and also able in capturing extreme rainfall events. The estimated parameters obtained revealed that the wet hourly series at study site is mainly dominated by the heavy rainfall at short duration. The outcome of this study could potentially be used in providing invaluable input to authorities requiring detailed rainfall data for planning and forecasts purposes.

Keywords: *Mixed exponential distribution, weather generator, extreme rainfall, rainfall intensity*

1. Introduction

Climate change possibly imposes one of the critical challenges in the 21st century. Some of the observable effects on the environment include glaciers have reduced in size, ice on rivers and lakes is melting earlier, the global average air and ocean temperatures are rising, and the rising of sea-level. Global warming which is often associated with climate change, is due to the presence of too much carbon dioxide (CO2) in the earth's atmosphere, trapping heat and warming the planet. Around the globe, substantial evidence indicates that global warming influenced precipitation's distributions and patterns and lead to many occurences of extreme weather events, namely rainfall variation, floods, droughts and rainstorms.

Extreme rainfall is one example of devastating weather events, which often occurred here in Malaysia. A study by Syafrina et al. (2015) for the period 1975 -2010 shows the rising trends of extreme rainfall in Peninsular Malaysia. Lately, monsoon floods in Malaysia occur almost on a yearly basis during the northeast monsoon season while flash floods are constantly happening in urban areas during inter-monsoon season. Adverse impacts due to flood include economic loses, displacements of residents, human casualties and biodiversity losses.

Over the years, various rainfall models are developed and improvised with the motivation to accurately replicate rainfall series. Rainfall models based on stochastic approach use past rainfall data of substantial length as input for the generation of synthetic rainfall time series data at specified intervals. An approach known as weather generator, uses existing meteorological data as input to produce series of synthetic rainfall data, ranging from daily to annual periods. (Wilks and Wilby, 1999; Kevin et al., 2005, Kilsby et al., 2007). The underlying concept behind weather generators are based on the cross correlations between the meteorological variables and autocorrelations within the variables themselves. However, the daily weather generators underestimate monthly and inter-annual variances (Khazaei et al., 2013).

An improved version, namely the Advanced Weather Generator (AWE-GEN) is developed by Ivanov et al. (2007) to capture climatic data at hourly scale. The model was constructed based on the fundamental work of Curtis and Eagelson (1982). AWE-GEN was shown able to replicate climatic variables at hourly scale and also contributes low-frequency effects in rainfall process, such as inter-annual variability (Fatichi et. al 2011). In Malaysia, the use of AWE-GEN in generating rainfall series is relatively scarce. Studies conducted by Syafrina et al. (2017) and Syafrina et al. (2018) demonstrated the model's ability in producing rainfall time series at different parts of Peninsular Malaysia. Both studies examine the use of gamma and weibull distributions in representing rainfall intensity within the AWE-GEN model in order to generate rainfall series. The results vary according to the location of studies. It was found gamma distribution gives better results in simulating rainfall series at the outer parts of the northern coast of Peninsular Malaysia whereas weibull distribution is better at the interior parts of the northern coast (Syafrina et al. (2017)). In the western region of the Peninsular, weibull is the better distribution.

The choice of probability distribution to represent model's parameters is therefore critical in determining the competency of a model. There are various studies on Malaysian rainfall which compares the performance of probability distributions representing models' parameters. Study by Yusof et al., (2007) showed that mixed exponential distribution is the better choice in Wilayah Persekutuan. Similar study using Spatial Temporal Neyman Scott model found that mixed exponential distribution is better than weibull in representing rainfall intensity in the Klang Valley (Norzaida A., (2012), Abas et al., (2014) and Norzaida et. al (2017).

2. Research Objective and Data

This study proposed to integrate mixed exponential distribution function as rainfall intensity using AWE-GEN model in modelling hourly rainfall series and assess the ability of the newly developed model in simulating extreme rainfall. The motivation of using mixed exponential distribution is based on the successful use of the said distribution in representing rainfall intensity on Malaysian rainfall. Historical data are obtained from the Malaysian Drainage and Irrigation Department (DID) and the Malaysian Meteorological Department (MMD). The meteorological data of 40 years from 1975 until 2015 are used, particularly hourly rainfall, hourly temperature, hourly relative humidity and hourly wind speed. Once the model is assembled, its ability is tested at a rainfall station located in the east coast of Peninsular Malaysia. The study site is at JPS Kemaman (station 4234109 with Latitude 4.36° Longitude 103.27°), which is located in the state of Terengganu, as shown in Figure 1.

3. Methodology

Generation of hourly rainfall series is conducted using the AWE-GEN model. Description of model methodology is available in Syafrina et al., (2017). In this model, mixed exponential distribution is being proposed in representing the rainfall intensity. Mixed exponential distribution function has three parameters, α, ξ and θ, which are the mixing probability and the scale parameters (light and heavy rainfall), respectively. The probability distribution function is:

$$f(x)= (\alpha/\xi\ e^{(\alpha/\xi)}) +(((1-\alpha))/\theta\ e^{(\alpha/\theta)})$$
$$x>0, 0\leq\alpha\leq1, 0<\xi<\theta \quad (1)$$

where α denotes the mixing probability, ξ and θ represent the scale parameters, while x represents the hourly rainfall amounts.
The intra-annual variability of rainfall within the AWE-GEN model is represented by the Neyman-Scott Rectangular Pulses (NSRP) model. The NSRP model has been successfully used in replicating Malaysia's rainfall series (Norzaida et al., 2016; Abas et al., 2014). The model has seven parameters, which are λ, β, μ_c, η, θ, α, and ξ. The parameters are described in Table 1. Based on Fadhilah (2008), the value of α=0.65 of mixed exponential distribution is suitable for Malaysian rainfall. Hence, only the values of λ, β, μ_c, η, and θ are estimated and the results are given in Table 2. Rainfall series at hourly scale for 40 years' duration is generated at JPS Kemaman station. The simulation is conducted on a monthly basis to make adjustments for rainfall seasonality. Statistical properties are extracted from the simulation results and the properties are then compared to that of the observed data.

Table 1. NSRP model

Parameter	Description
λ	Storm origin arrival rate
β	Waiting time for cell origins after the storm origin
μ_c	Mean number of cells per storm
η	Duration of a cell
θ	Scale parameter (heavy rainfall)
α	Mixing probability
ξ	Scale parameter (light rainfall)

Figure 1. Rainfall station

Results and Discussion
A mixed exponential distribution function is incorporated into the AWE-GEN and used to fit rainfall data. The estimated parameters in Table 2 show that μ_c (representing mean number of cell per storm) recorded higher values in November, December and January. This corresponds to the increased amount of precipitation during northeast monsoon season. Mixed exponential distribution classifies rainfall into two types, light and heavy rainfall. The results reveal that the total estimated mean of the hourly rainfall amount was highly contributed by the heavy rainfall, θ while the remainder was by the light rainfall, ξ. This indicates that the average amount of hourly precipitation at JPS Kemaman is mainly dominated by heavy rainfall. Graph comparing the observed and simulated monthly statistical properties such as means, variance, lag-1 autocorrelation, skewness, frequency of non-prepicitation and transition probability wet-wet were constructed, as shown in Figure 2. All monthly statistics of rainfall are well represented except the transition probability wet-wet was rather underestimated from March to January.
Overall, the mean and standard deviation of monthly rainfall were well preserved with only a slight underestimated in November, December and January. The highest mean rainfall received is during December (600-900mm) as shown in Figure 3. The red and green circles and vertical bars in Figure 3 denote the mean and standard deviation of the monthly values for observed and simulated, respectively. December corresponds to the northeast monsoon season which usually starts in early November and ends in February where it brings more rain in this season. As such, monsoon flooding incidences are common during the northeast monsoon season, especially in Terengganu and Kelantan. On the other hand, the average rainfall received from April to August is lower than in other months. According to Syafrina et al. (2015), west coast region is relatively dry during the southwest monsoon. The southwest monsoon is normally beginning around early June and fade in late September.
The AWE-GEN model is also able to capture the extreme properties as shown in Figure 4. This model is performing quite well in

reproducing the hourly and 24 hours' extremes rainfall up to 40 return period. Similarly, the extreme wet spell is well simulated, however, the extreme dry spell is somewhat underestimated at 40 return period.

Table 2. Estimated parameters of the model

Month	λ	β	μ_c	η	θ	α	ξ
Jan	0.0048	0.0300	14.5134	1.0277	8.9521	0.65	2.2380
Feb	0.0027	0.0200	6.5730	0.5002	7.8285	0.65	1.9571
Mar	0.0061	0.0466	7.7238	1.3753	11.7912	0.65	2.9478
April	0.0076	0.0100	4.4695	1.1329	10.7180	0.65	2.6795
May	0.0159	0.0100	2.2209	1.9690	21.3970	0.65	5.3493
June	0.0125	0.0100	3.0055	1.4299	13.2176	0.65	3.3044
July	0.0116	0.0100	3.3179	1.7555	14.5636	0.65	3.6409
Aug	0.0129	0.0100	3.3751	1.6602	15.5956	0.65	3.8989
Sep	0.0153	0.0495	4.0375	2.3052	17.2776	0.65	4.3194
Oct	0.0121	0.0201	4.8969	1.6374	13.7841	0.65	3.4460
Nov	0.0116	0.0307	11.5086	1.2203	11.8152	0.65	2.9538
Dec	0.0083	0.0313	26.8270	1.2690	8.9985	0.65	2.2496

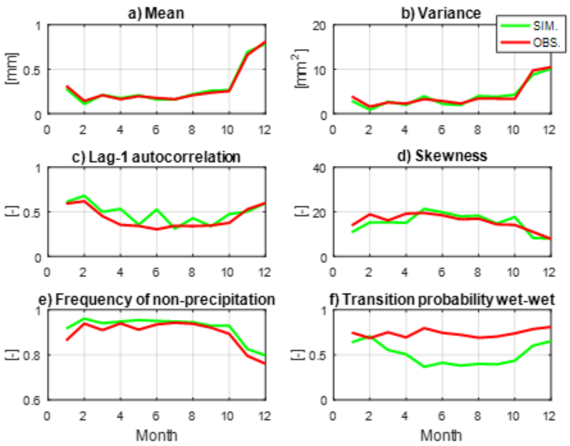

Figure 2. A comparison between observed (red) and simulated (green) monthly statistics of rainfall at hourly.

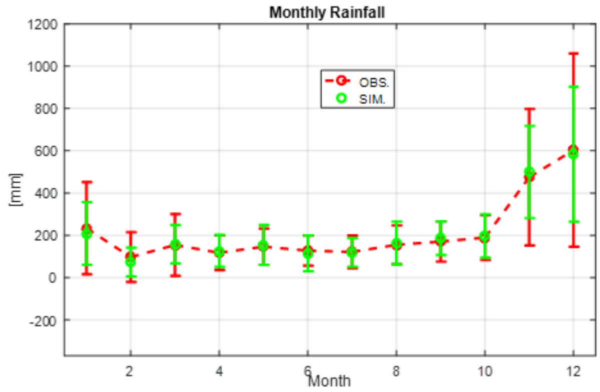

Figure 3. A comparison between observed (red) and simulated (green) monthly rainfall.

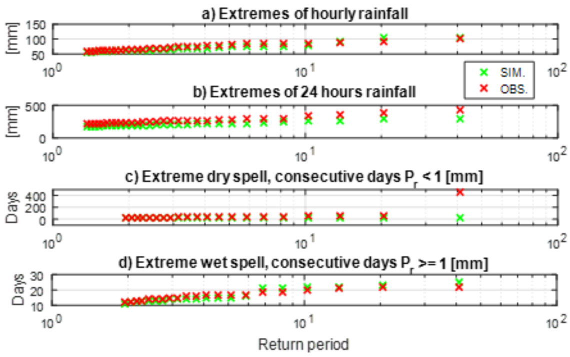

Figure 4. A comparison between values of extreme precipitation at (a) 1 hour and (b) 24 hours' aggregation periods; (c) extremes of dry and (d) wet spell durations.

4. Conclusion

Study findings indicate the usage of mixed exponential distribution in the AWE-GEN model is capable of generating the monthly rainfall at station JPS Kemaman quite well. The estimated parameters imply the wet hourly series is mainly dominated by the heavy rainfall. This indicates that most of the rainfall amount recorded within the study area comprise of heavy rainfall. Furthermore, the simulation results potray that the highest mean rainfall is found to be in December. December corresponds to the northeast monsoon season which usually begins in early November and ends in February. Intense rainfall within short time period is one of the factors contributing to flood events within the study area. The AWE-GEN model is also shown to be able in capturing the extreme properties. The hourly and 24 hours' extremes rainfall are well generated, so does the extreme wet spell and extreme dry spell. Overall, the outcome and the proposed methodology of this study would certainly provide a basis for further studies on conventional rain and floods within other areas within the east coast of the Peninsular. Such knowledge would be crucial in the planning and preparation to help minimize the potential impact of flooding.

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