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Research Article

Extreme Rainfall Analysis in the Eastern Region of Peninsular Malaysia

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Abstract. Modeling of rainfall data, particularly rainfall amount, are used for providing input for models of crop growth, design of urban drainage systems, land management systems and other environmental projects. More importantly, in hydrological studies, mathematically simulated data helps in flood prevention and mitigation efforts. In the eastern coast of Peninsular Malaysia, floods have been happening with frightening regularity. This study focuses on the use of a weather generator, known as Advanced Weather Generator to model hourly rainfall series within this region. Five stations with thirty years of data are used in model construction. Two probability distributions, Gamma and Weibull, are individually incorporated in the model to represent rainfall intensity and their performances are compared. The fitting of both model variations are individually conducted at the five stations. The best distribution is then used in generating rainfall series, particularly focusing on extreme rainfall and extreme dry/wet spell lengths. Results indicated that Gamma is the best distribution in simulating hourly rainfall in the east coast as compared to Weibull. The model adequately able to capture the peak/extreme values at the stations. The extreme wet spell length is well simulated although the extreme dry spell is under-estimated at all stations. Rainfall in November was determined as contributing most of the annual rainfall followed by December. This study is relevant and very crucial for a tropical country like Malaysia, which may benefit the policy makers in executing appropriate strategic plans of monsoonal flooding in the regularly affected areas.

Keywords. Extreme event; Rainfall intensity; Gamma; Weibull; Weather generator; Wet spell

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1. Introduction

Extreme events can be defined as maximum values or exceedance above pre-existing high threshold [24]. Large amount of precipitation or extreme precipitation is one of the examples of extreme events. Extreme precipitation events refer to the maximum average precipitation intensities for a given duration, corresponding to the definition of an event in the classical *Intensity-Duration-Frequency* (IDF) relationship used for design of urban drainage system [11, 12]. It is likely that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe [9]. Extreme rainfall is one of the main causes of natural disasters such as flooding. Considerable attention has been paid to the modeling of extreme rainfall for preventive measures of massive flooding as well as for future extreme rainfall's projections [2]. This has led to numerous collaborations between meteorologists and hydrologists to establish a hydrological model of spatial and temporal precipitation extremes. Frequency of heavy precipitation events has found to significantly increase in the eastern parts of North and South America, northern Europe, and northern and central Asia, despite showing a decline in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia between the years of 1900 and 2005 [8, 30].

Small changes in the mean and standard deviation values may contribute to large changes in the probability of extreme events [20]. Severe negative impacts caused by extreme events are becoming more critical nowadays. Around the globe, there is evidence from observations gathered since 1950 of changes in extreme events. Some of the changes are the results of anthropogenic influences, including increases in atmospheric concentrations of greenhouse gases [9], uncontrolled land management and exploitation of land resources. For example, earlier in 1998, the total rainfall amount in Australia had been analysed using daily rainfall records [26]. The study concluded that a general increase of total precipitation was found in most of the region from 1910 to 1990. The trend of extreme indices over eastern and southwestern Australia from 1910 to 1998 was examined [7]. The indices were calculated and divided into three groups which are extreme intensity, extreme frequency and extreme percent. Both extreme frequency and extreme intensity were found to decrease in the southwest coast while extreme percent was found to increase in the east coast. Significant changes in mean precipitation were identified in the mid-1940s while changes in an extreme rainfall intensity index occurred in the late 1970s or early 1980s in the tropical South Pacific [4].

Trends of heavy precipitation over the Czech Republic were also observed between 1961 and 2005 [10]. Most of the indices showed increased trend during winter and decreased trend during spring. In 2010, a study was conducted on spatial patterns of annual and seasonal precipitation trends in Bangladesh over the period of 1958-2007 [23]. The study concluded that the average annual and pre-monsoon precipitations were found to have increased from 1958 to 2007. Similar trends were also found for the number of wet months. Meanwhile in the United States, different trends were found across the regions covering the Baja California peninsular, and some stations in the United States near the Mexican border [5]. Different patterns of trends in precipitation may be due to the systematic changes in climate [26]. Another trend study has been done across the Mediterranean Sea. The trend of maximum daily precipitation from two stations located in the southeastern and northeastern shores of the Mediterranean Sea was investigated [6]. There was no significant trend as well as no periodicity in mean found in the region. This lack of significant trends could be due to the high variability of heavy precipitations in space and time which is difficult to capture by a single rain gauge [21].

Similar to other regions, Malaysia has been experiencing unpredictable rainfall events quite frequently. Although Malaysia is considered to be less prone to natural disasters, the country is more vulnerable to climate change and natural disasters due to the increasing trends in climate-related extreme indices [25]. The increase in massive flood cases, including flash floods, monsoonal floods and landslides in the last decade is often related to the increase in rainfall intensity. The annual spatial pattern of rainfall for Peninsular Malaysia is mostly influenced by the northeast monsoon season where the east coast is most affected during this season [30]. Between 1975 and 2004, Peninsular Malaysia experienced an upward trend of rainfall during the southwest monsoon season. An upward trend in both the aggregate sum of rainfall and the occurrence of wet days were discovered during the northeast monsoon, which gives rise to the increasing trend of rainfall for the period between 1971 and 2004 [25]. In East Malaysia, studies on the trends of monthly, annual and seasonal rainfall was conducted in Kuching, Sarawak based on the observations from 1968 to 2010. Linear regression analysis was used to determine the trends while the Mann-Kendall test was used to calculate the significance of the observed trends. Results showed positive trends during all monsoon seasons except for October.

The east coast of Peninsular Malaysia is most influenced by the northeast monsoon whereby floods triggered by heavy rainfall are frequently occurring (i.e. almost every year). In the last decade, flooding incidences were getting more frequent (in 2009, 2014, 2015, 2016 and 2017) and ferocious. Several factors may contribute to the occurrence of extreme rainfall events within the studied region. The extreme indices could be influenced by El Niño-Southern Oscillation (ENSO) [14], which cause changes in the point of extreme precipitation [30]. Other factors such as the Pacific Decadal Oscillation (PDO) and Southern Oscillation Index (SOI) [29] as well as sea surface temperature (SST) [18] may also be linked to the occurrence of extreme events. Thus, this study has two objectives. First, this study tests and compares the performance of Gamma and Weibull that are incorporated in a weather generator model in simulating extreme rainfall and extreme dry/wet spell lengths at the eastern region of Peninsular Malaysia. In particular, Advanced Weather Generator (AWE-GEN) model is employed in modelling rainfall at hourly scale. Second, hourly scale rainfall series will then be simulated using the identified distribution for each calendar month. Simulation is conducted on a monthly basis to take into account rainfall seasonality. The flow of this paper is as follow. Description of data used in model construction is presented in Section 2. Section 3 presented the adopted methodology. Results are discussed in Section 4 while the analysis of the results is summarized in the final section.

2. Data

Peninsular Malaysia is located between 1° and 6° N in the northern latitude and between 100° to 103° E longitude. The surface climate is influenced by the northeast monsoon season between November and February and by the southwest monsoon season between May and August. The northeast monsoon season is usually associated with heavier rainfall with the eastern and southern regions being the most affected areas. In between these two monsoons are the inter-monsoon seasons occurring in March–April (MA) and September–October (SO), which bring intense convective rainfall to the western coast of Peninsular Malaysia. In this study, the AWE-GEN model is constructed based on 30 years of recorded data (1975-2005). The data needed in building the AWE-GEN model include rainfall, temperature, relative humidity and wind speed at hourly scale. Hourly rainfall data were sourced from the Malaysian Drainage and Irrigation Department (DID) while other meteorological data were from the Malaysian Meteorological Department (MMD). In this study, five stations representing the east coast were selected. Figure 1 shows the location of the rainfall stations whereas Table 1 lists the selected stations used in this study.

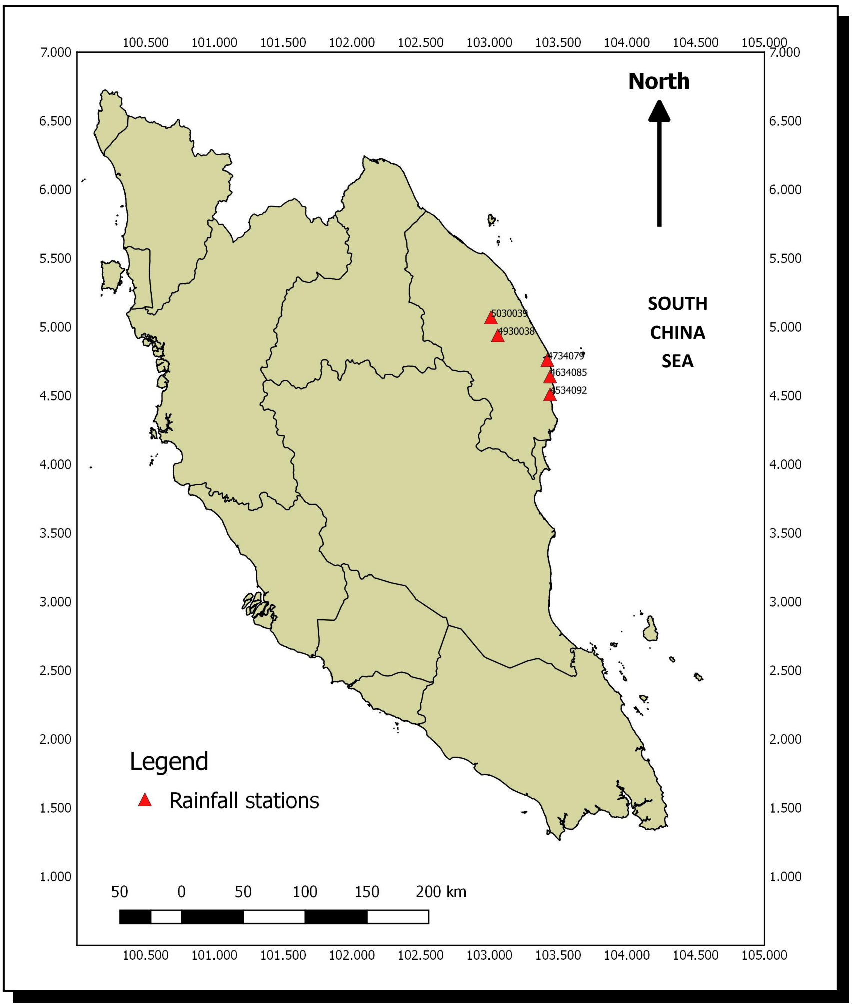

Figure 1. Peninsular Malaysia map with location of rainfall stations

Table 1. Latitude (lat) and Longitude (lon) of Stations

Stations	Lat (°)	Lon (°)
4534092	4.51	103.44
4634085	4.64	103.44
4734079	4.76	103.42
4930038	4.94	103.06
5030039	5.07	103.01

3. Methodology

Within the AWE-GEN model, a stochastic model named Neyman-Scott Rectangular Pulses (NSRP) model is employed to assess the intra-annual variability of rainfall process. Descriptions of the AWE-GEN methodology could be found in [3]. Work by [1, 19] indicates that the NSRP model is suitable to be used to model rainfall distribution in Malaysia. In this study, two distributions, Gamma and Weibull are individually used to represent the parameter representing rainfall intensity. The AWE-GEN model with each distribution is individually fitted to each of the five selected stations. The performances of both Gamma and Weibull are then evaluated and compared using the Root Mean Square Error (RMSE) criteria. The probability density function (pdf) of Gamma distribution is shown below:

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

where θ is the scale parameter ($\theta > 0$), α is the shape parameter ($\alpha > 0$) and x is the hourly rainfall amount. The pdf of Weibull distribution is as follow:

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

where α and β are the scale and shape parameters, respectively.

For the model validation purposes, the simulated hourly rainfall series were segregated into two non-overlapping periods of (i) 1975 to 1989 and (ii) 1990 to 2005. The 1975 to 1989 period was assigned as the reference period where the multiplicative factor was computed based on the simulation output and the high resolution observational data. The changing factors were then applied to improve the biases of the simulation output from 1990 to 2005. The corrected hourly rainfall series was then compared to the observation from the identical period of 1985-1999. To evaluate the performance of both distributions, *Root Mean Square Error* (RMSE) value was estimated to measure models' efficiency for both sets of simulation. Lowest value of RMSE indicates the better distribution at a particular station. Next, the best distribution being identified for each station is used to simulate rainfall series, particularly focusing on the extreme rainfall as well as dry/wet spell lengths.

4. Results and Discussions

Table 2 shows the RMSE values between Gamma and Weibull distributions for all five stations. Overall, Gamma is found to be the better distribution at all five stations as compared to Weibull although the differences are minimal. Hence, Gamma distribution is used to generate hourly rainfall series for each month at each station and the results are aggregated into monthly amount. Figure 2 shows the graphs of simulated mean monthly rainfall amount against the observed values for each station. As seen in the graphs, generally the performance of the model is quite good in simulating the mean amount for all stations except for stations 4534092 and 4734079. The mean rainfall is slightly underestimated in November while for station 4930038, the mean rainfall is slightly overestimated in December.

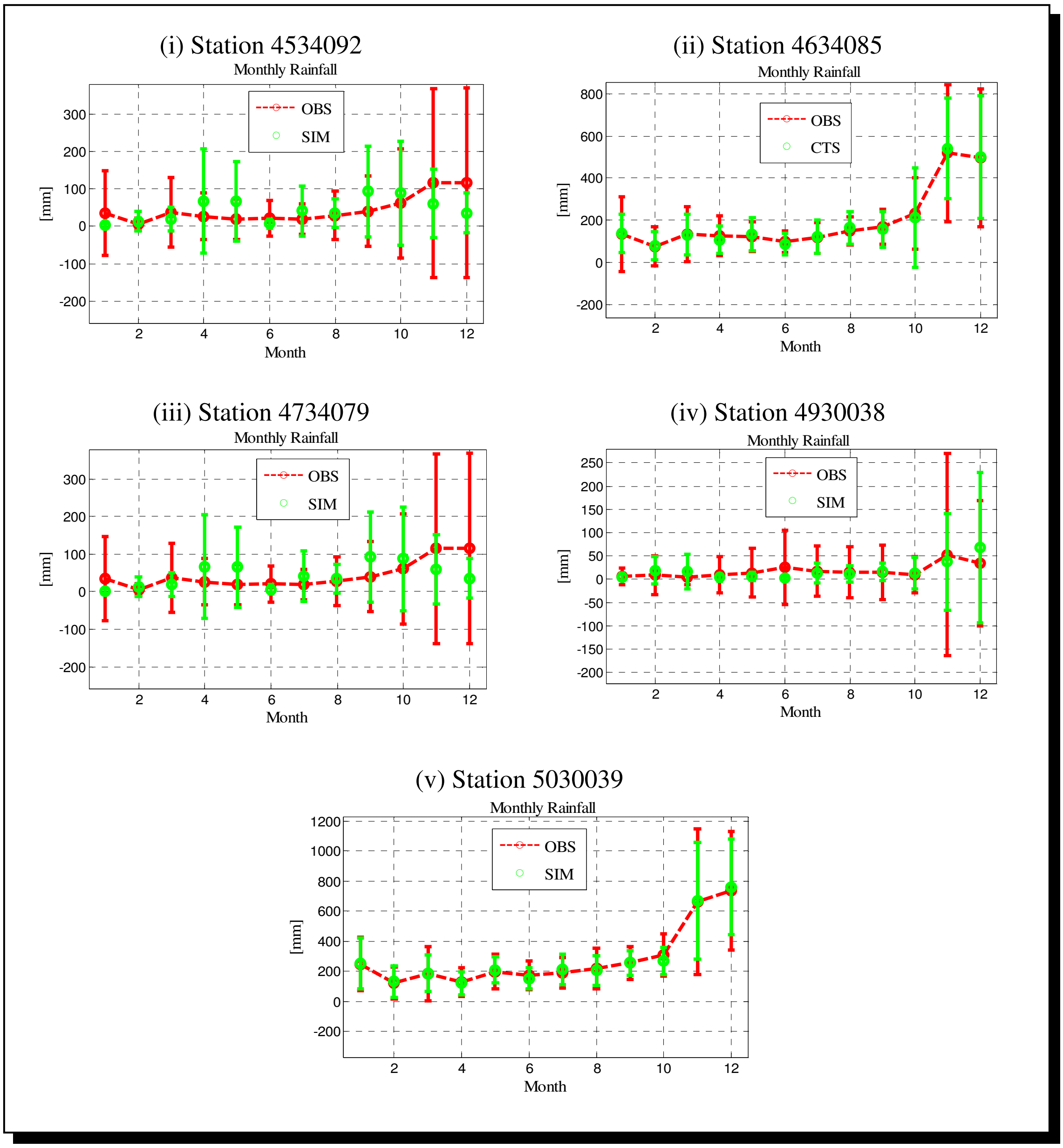

Figure 2. Monthly Rainfall at Each Station

Table 2. RMSE values of hourly rainfall for Gamma and Weibull distributions at each rainfall station (bold font indicates lowest RMSE value)

Stations	RMSE of Gamma	RMSE of Weibull
4534092	**128.0**	130.0
4634085	**128.0**	128.0
4734079	**368.6**	380.6
4930038	**209.2**	235.2
5030039	**326.1**	330.0

For the east coast region, November and December are predominant in the annual rainfall contribution, coinciding with the northeast monsoon period. The monthly rainfall is more variable especially during the northeast monsoon period where east coast is the most affected area during this season. Generally, the AWE-GEN adequately captures the variability of the rainfall in the east coast. This region receives more rainfall than any parts in Peninsular Malaysia. The amount of rainfall could reach up to a range between 1000-1200 mm in a month as can be seen in Figure 2. Such findings are also consistent with other studies such as in [13] and [16]. According to Wong et al. [28], Peninsular Malaysia can be delineated into eight distinct rainfall regions. Rainfall in the east coast region appears to have a single peak during the northeast monsoon which contributes to 85% of the total annual rainfall in this region.

Figure 3 shows the simulation results of hourly and 24-hour extreme rainfall as well as extreme dry/wet spell lengths at the stations. Hourly extreme rainfall seems to be well simulated while 24-hour extreme rainfall is slightly underestimated at all stations except for station 4734079. The extreme wet spell length is well simulated although the extreme dry spell is underestimated at all stations. An upward trend is also observed in the figure. Stations in the east coast region recorded higher values of extreme indices compared to other regions of Peninsular Malaysia [1, 25, 27]. The trend of extreme rainfall events has become more severe between 1960 and 2014 and has increased over the last 40 years [13, 16]. This is consistent with the projects done by [15, 17] in which the trend of rainfall projected by various models continues to increase especially in the east coast of Peninsular Malaysia. Increased number of extreme rainfall events may lead to higher frequency of floods in this region.

As shown in Figure 3, extreme rainfalls (hourly and 24 hour) and dry/wet spell lengths show upward trends for all stations at the east coast of Peninsular Malaysia. The highest amount of rainfall is also recorded in this region during the monsoon season especially northeast monsoon (i.e. November to February) [27]. The northeast monsoon brings higher amount of rainfall compared to other seasons, hence the main contributing factor to the rainfall in Malaysia is the northeasterly winds over the South China Sea which is related to cold surges [22].

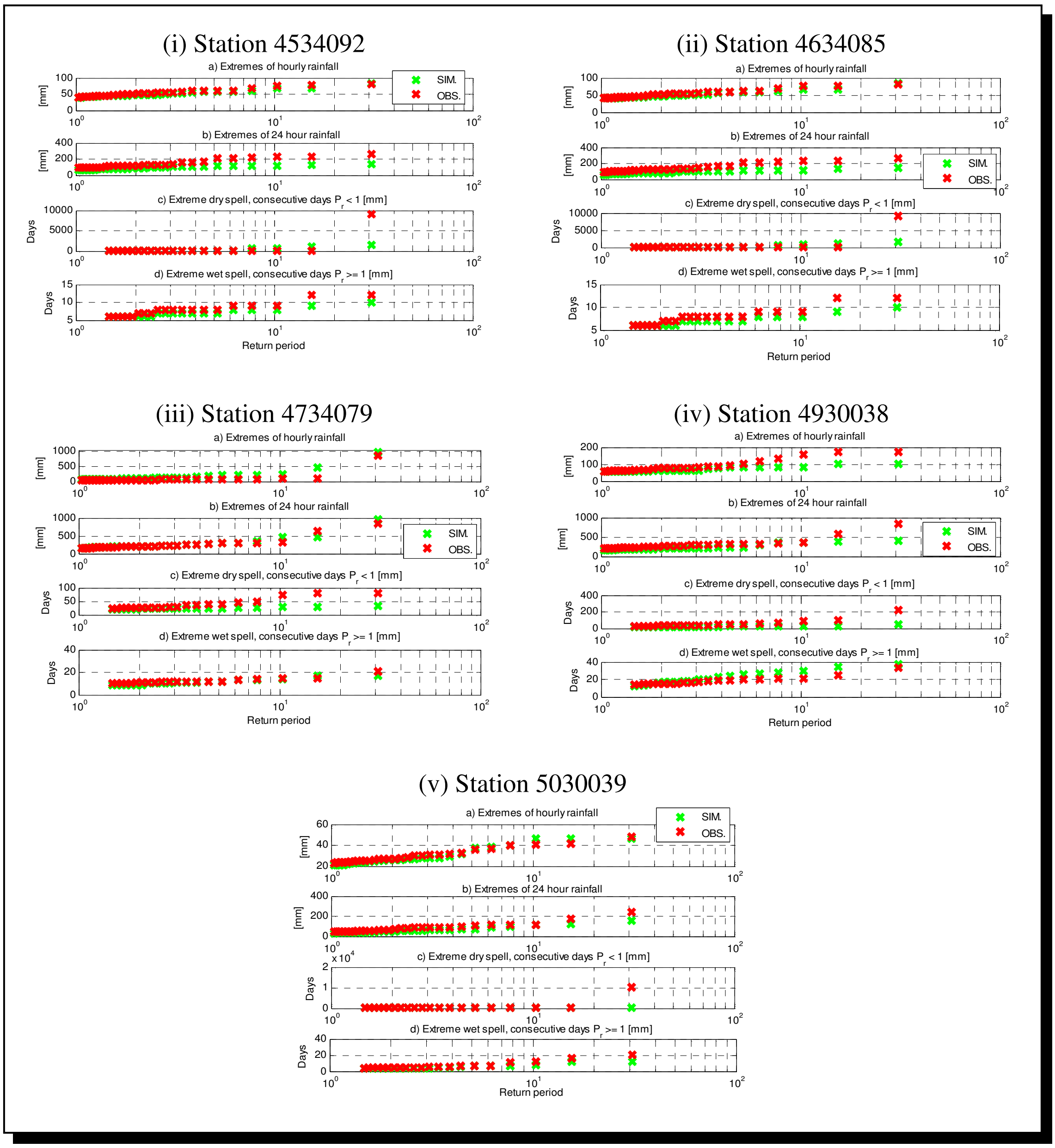

Figure 3. Extreme rainfalls (a) hourly (b) 24 hour and extremes spell length (c) dry consecutive days and (d) wet consecutive days

5. Conclusion

Gamma is identified as the better distribution in simulating hourly rainfall in the eastern coast as compared to Weibull. Despite fairly captures the peak/extreme values at several stations in the eastern partof Peninsular Malaysia, the extreme wet spell length is well simulated. However the extreme dry spell is underestimated at all stations. It was found that rainfall in November is contributing most of the annual rainfall followed by that in December, which coincide with the northeast monsoon season that mostly covers the months of November and December. This region is most influenced by the northeast monsoon in which it receives maximum amount of rainfall, often leading to extreme flood events. Overall, the AWE-GEN model with NSRP model being embedded produces commendable results in simulating extreme rainfall as well as wet spell length throughout the eastern region of the peninsular.

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Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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