Communications in Mathematics and Applications
Vol. 9, No. 4, pp. 593–600, 2018
ISSN 0975-8607 (online); 0976-5905 (print)
Published by RGN Publications

http://www.rgnpublications.com

DOI: 10.26713/cma.v9i4.655

Research Article

Trend of Rainfall Indices at Kg. Kedaik Station, Pahang

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Abstract. Malaysia has been constantly facing massive floods caused by excessive weather events during monsoon and inter-monsoon seasons. Major concerns on the consequences of flood include structural and erosional damage, loss of life and property and disruption of socio-economic activities. Mitigation efforts require proper planning, relying on credible quantification of such changes. The eastern part of Peninsular Malaysia is frequently affected by severe floods especially during north east monsoon season. Affected area includes Pahang state which is located in the middle and more towards the eastern part of Peninsular Malaysia. As such, this study examine the trend of rainfall indices to have a better understanding on rainfall distribution within the area. In particular, the performance of Gamma and Weibull distributions incorporated in Neyman Scott Rectangular Pulse model in reproducing rainfall indices was assessed at Kg. Kedaik station in Pahang. The trends of indices based on thirty years data were calculated and analysed using non-parametric, Mann Kendall test. Performance of both probability distributions was compared using Root Mean Square Error criteria. Results suggest that Gamma is the better distribution in reproducing the hourly rainfall series for Kg. Kedaik station. Further analysis indicate Gamma able to replicate the key rainfall characteristics such as the total amount of rainfall, mean rainfall amount on wet days or rainfall intensity, including the extreme indices; frequency of wet days exceeding the 95th percentile and rainfall intensity exceeding the 95th percentile. Meanwhile, the calculated trend in this study is consistent with previous studies, indicating the presence of positive trend at Kg. Kedaik station.

Keywords. Extreme; Gamma; Mann Kendall; Trend Indices; Weibull

MSC. 91Bxx

Received: September 27, 2017 **Accepted:** October 5, 2017

1. Introduction

In the last decade, Malaysia faces massive floods caused by excessive weather events which occur during monsoon seasons and inter-monsoon seasons [8]. Major concerns on the effect of floods include structural and erosional damage, loss of life and property and disruption of socio-economic activities. Thus, mitigation effort requires proper planning, relying on credible quantification of such changes. For instance, in Malaysia, ever since the calamitous1971 flood, the government took extensive flood control measures by setting up the Permanent Flood Control Commission, creating a flood disaster relief machinery, implementing structural and nonstructural measures and developing flood forecasting and warning systems. Large uncertainties attached to such events make the efforts, a very challenging task. Within Malaysia, the eastern part of the Peninsular is frequently affected by severe floods particularly for the period during the northeast monsoon season. Affected area include the Pahang state, which is located close to the eastern coast of the Peninsular. Some of the worst flooding events in Pahang happen in 2001, 2007, 2013, 2014, 2015 and 2017.

The northeast monsoon season that occurs in South China Sea is believed to be the main contributor to the rainfall trends experienced within the region [6]. Analysis by Sulaiman et al. [7] concluded that unusually high rainfall intensity mainly in highland areas has caused major flood events along the Pahang River basin. A positive correlation between rainfall and water level has also been found in the study, which suggested that increase of rainfall intensity led to an increase of water level of Pahang River basin. Another study on trends of extreme rainfall events in Pahang River basin using Mann Kendall test [4] reveal the presence of positive trend of annual maximum daily rainfall in Pahang River basin between 1970 and 2014. It is also observedthat the proportion of stations with escalating trends for short duration rainfall (10, 30 and 60 minutes) is higher compared to long duration rainfall (6, 12, 24, 48, 120 and 240 hours). This findings indicate that the risk of flash floods occurrence in the future will be higher since the trend for short duration rainfall has been inclining until 2014.

Thus, this study aim to assess the performance of Gamma and Weibull distributions which arebeing incorporated in the Neyman Scott Rectangular Pulse (NSRP) model, in reproducing rainfall indices at a rainfall station in Pahang. The trends of these indices are calculated and analysed between the years of 1975 and 2005 using non-parametric Mann Kendall test. It is anticipated that the same trend prevails as the observed rainfall time series which is more likely to be a positive trend. Description of data is given in Section 2 while the adopted methodology is discussed in Section 3. Results are analysed in Section 4 and 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 mainly shapedby the northeast monsoonoccurring between November and February and by the southwest monsoon, between May and August. The northeast monsoon normally brings heavy rainfall,which makes the eastern and southern regionsvulnerable to flood incidences. Amid these two monsoons are the inter-monsoon seasons occurring in March-April (MA) and September-October (SO), bringing intense convective rainfall to the west of Peninsular Malaysia.

The present study employed a weather generator, the Advanced Weather Generator (AWE-GEN) model in replicating rainfall process. Model development consists of using 30 years of historical data (1975-2005) as input. Among the data used are rainfall, temperature, relative humidity and wind speed at one hour scale. The rainfall data were sourced from the Malaysian Drainage and Irrigation Department (DID) while other meteorological data were sourced from the Malaysian Meteorological Department (MMD). Station 2831179 (Kg. Kedaik) located in Pahang was randomly selected for further analysis as it represents the Pahang state. Figure 1 shows the location of the station.

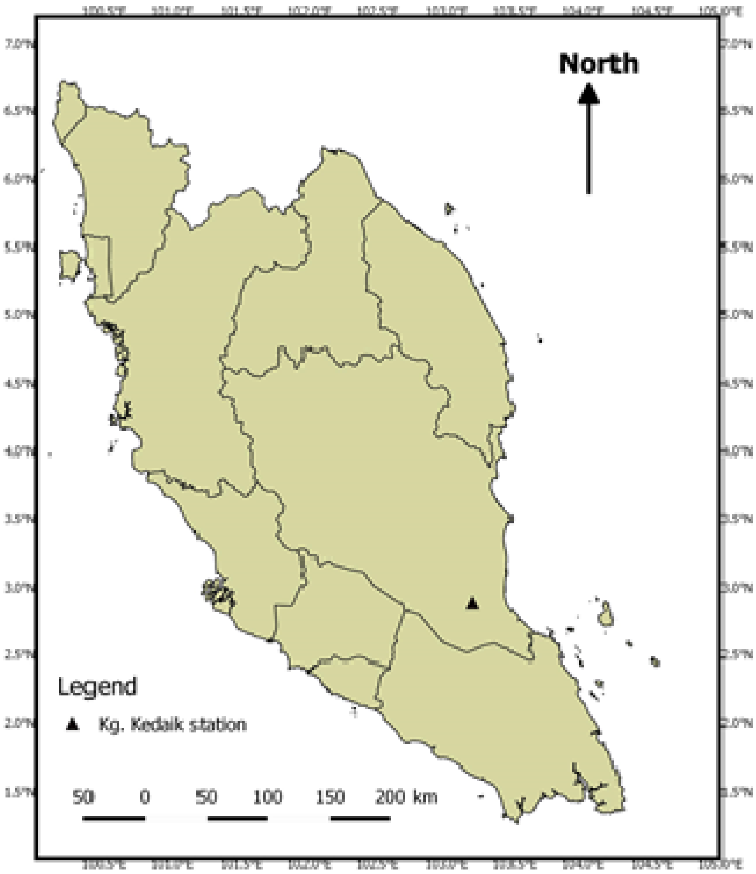

Figure 1. Location of Kg. Kedaik station

3. Methodology

The seasonal variability of rainfall inthe AWE-GEN model is describedby the Neyman-Scott Rectangular Pulses (NSRP) model. In NSRP model, the two proposed distributions, Gamma and Weibull are individually fitted to the intensity of rainfall. NSRP model has been shown capable of mimicking rainfall process in Malaysia [1, 3]. The Gamma distribution, associated in

NSRP model is:

$$P(x) = \begin{cases} \frac{1}{\Gamma(\alpha)\theta^{\alpha}} x^{\alpha-1} e^{\left(\frac{-x}{\theta}\right)}, & x > 0 \\ 0, & x \le 0 \end{cases} \tag{3.1}$$

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

$$P(x) = \left(\frac{\beta}{\alpha}\right)\left(\frac{x}{\alpha}\right)^{\beta-1} \exp^{\left(-\left(\frac{x}{\alpha}\right)^{\beta}\right)} \tag{3.2}$$

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

Model validation involved dividing the resulted simulated hourly rainfall series into two non-overlapping periods of (i) 1975 to 1989 and (ii) 1990 to 2005. The 1975 to 1989 period was chosen as the reference period where the multiplicative factor was computed based on the simulation output and the high resolution observational data. Subsequently changing factors were incorporated to rectify the biases of the simulation output from 1990 to 2005. The rectified hourly rainfall series was then compared to the observation from the identical period of 1985-1999. To compare performance of both distributions, Root Mean Square Error (RMSE) value was estimated for both sets of simulation at Kg. Kedaik station. Lowest value of RMSE indicates the better distribution at the station. Next, best distribution identified was selected for station Kg. Kedaik to simulate hourly rainfall. Rainfall indices were calculated for simulation of rainfall time series and the trends of rainfall indices from simulated time series were calculated using non-parametric Mann Kendall test. Five rainfall indices (see Table 1) on frequency and intensity of extreme rainfall events were chosen based on work by Suhaila et al. [5].

Table 1. Rainfall indices

Description	**Index Name**
Total amount of rainfall	TAR
Frequency of wet days of at least 1 mm of rain	FREQ
Mean rainfall amount on wet days or rainfall intensity	RI
Frequency of wet days exceeding the 95th percentile	XFREQ
Rainfall intensity exceeding the 95th percentile	XI

In Mann-Kendall test,every pair of observed values y_i, y_j $(i > j)$ of the random variable is inspected to find out whether $y_i > y_j$ or $y_i < y_j$. P is the number of the former type of pairs, and M is the number of the latter type of pairs. Then S is defined as follows:

$$S = P - M \tag{3.3}$$

For $n > 10$, the sampling distribution of S is as follows. Z follows the standard normal distribution where:

$$Z = \begin{cases} (S-1)/\sqrt{Var(S)}, & S > 0 \\ 0, & S = 0 \\ (S+1)/\sqrt{Var(S)}, & S < 0 \end{cases} \tag{3.4}$$

4. Results and Discussions

Based on RMSE value, the simulated time series of Gamma distribution gives the lowest RMSE value compared to Weibull distribution. This indicates that Gamma is the better distribution for Kg. Kedaik station. Next, five rainfall indices were calculated for the station and the trend for each index was then calculated using Mann Kendall test. Table 2 compares the test statistics of each index between observed data and simulated data. The null hypothesis for the test is that there is no trend in the series while the alternative hypothesis, there exists trend in the series. The trends were tested at significance level of 0.05. Statement of the null hypothesis is rejected if the p-value is less than the significance level which also means the trend exists in the series.

Table 2. Test statistics of Mann Kendall's test for each rainfall indices, (a) observed time series data, (b) Gamma simulated time series data and (c) Weibull simulated time series data (* indicates significant trend)

Test statistics/Rainfall indices	TAR	FREQ	RI	XFREQ	XI
(a)					
Kendall's tau	0.419	0.425	0.222	0.351	0.354
S	56.54	3	0.21	0.688	0.002
p-value	*0.001	*0.001	0.08	*0.006	*0.006
(b)					
Kendall's tau	0.40	0.23	0.37	0.395	0.395
S	63.51	0.71	0.58	0.571	0.002
p-value	*0.00	0.07	*0.0	*0.002	*0.002
(c)					
Kendall's tau	0.013	-0.013	-0.04	0.044	0.041
Sen	0.37	0	-0.03	0.063	0
p-value	0.932	0.932	0.76	0.746	0.759

As seen in Table 2(a), the p-value for the total amount of rainfall (TAR), frequency of wet days of at least 1 mm of rain (FREQ), frequency of wet days exceeding the 95th percentile (XFREQ) and rainfall intensity exceeding the 95th percentile (XI) indices is found to be less than the significance level, 0.05. Meanwhile, the Sen's slope estimator values for the four indices are positive which indicates significant positive trend between the years 1975 and 2005. However, the p-value for mean rainfall amount on wet days or rainfall intensity (RI) index is greater than the significance level, 0.05. This indicates that no trend exists in the index series.

By comparing the results from Table 2(a) with Table 2(b), the p-value for TAR, RI, XFREQ and XI indices is found to be less than the significance level, 0.05. In contrast, the p-value for FREQ index is greater than the significance level, 0.05. In addition, the positive Sen's slope estimator for these four indices indicate significant positive trend between the years 1975 and 2005. However, Gamma simulated time series seems unable to capture the trend in FREQ index.

A significant trend has also been identified in the RI index which does not exist in the observed data. On top of that, there are slight differences between the Sen's slope estimator values in Gamma simulated time series and observed data.

Next, results from Table 2(a) are compared with Table 2(c). As shown in Table 2(c), the p-values for all indices are greater than the significance level, 0.05 which indicates no trend exists in the rainfall indices. There are also huge differences noted between the Sen's slope estimator in Weibull simulated time series and observed data. Simulations using Weibull distribution seem incapable of capturing the trends of TAR, FREQ, RI, XFREQ and XI indices accurately as compared to Gamma distribution. Such results agree with the earlier finding where Gamma is the best distribution compared to Weibull based on RMSE value. The trends of extreme indices (XFREQ and XI) are also well captured by Gamma distribution compared to Weibull.

The positive trends found in this study are parallel to the study done by Wong et al. [9] where positive trend of annual rainfall was identified between 1976 and 2006 using gridded data. This is also parallel to the study done by Syafrina et al. [8] where the positive trends of extreme intensity and extreme frequency indices have been detected during monsoon and inter-monsoon seasons throughout Peninsular Malaysia [8] between 1975 and 2005. Studies by Othman et al. [4] concluded that the same trend was identified in the following year until 2014. The results implied that heavy rainfall events within the region will continue to increase, resulting in more recurrent hydrologic extreme events such as floods. According to Wong et al. [9], Peninsular Malaysia can be delineated into eight distinct rainfall regions and the east coast is divided into two zones; northeastern and southeastern. Kg. Kedaik station is located in the southeastern zone. The spatial rainfall variation for both regions is more uniform throughout the year. However, it is interesting to note that the difference between the southeast zone and northeast zone occurs in the lower monsoon rainfall during November-December over the southeastern coast region.

Over the southeastern region, the flat terrain allows the storm systems to reach further inland [9], hence resulting in higher inland rainfall. Topography and location of a river could be factors that contribute to extreme rainfall event at Kg. Kedaik station. Heavy rainfall on a higher area will flow to the lower area like Kg. Kedaik station. Rivers tend to flow more slowly in low-lying areas. If the water volume suddenly escalates, the percentage of floods occurring would be high. Water level caused by the heavy rainfall will rise. If the water level exceeds the river bank or the dams, water will over flow, resulting in flooding [7].

5. Conclusion

This study demonstrates that Gamma distribution is able to reproduce hourly rainfall for Kg. Kedaik station quite well compared to Weibull distribution. Gamma distribution is also shown to be better at capturing the variation of monsoon rainfall which frequently occurs in Pahang and the eastern coast of Peninsular Malaysia. Moreover, Gamma distribution able to reproducesstatistical characteristics of rainfall such as total amount of rainfall (TAR), mean rainfall amount on wet days or rainfall intensity (RI), including the extreme indices; frequency of wet days exceeding the 95th percentile (XFREQ) and rainfall intensity exceeding the 95th percentile (XI) rather well. Meanwhile, the positive trend derived from this study is consistent with the results from previous studies at Kg. Kedaik station.

The rising occurrence of heavy rainfall events may increase the recurrence of flood which is already a major problem in the eastern region of the Peninsular. Significant increase of heavy rainfall events and rainfall intensity may also trigger landslide occurrences due to excessive runoff water. Other major sectors such as economic, public health, coastal environment and urban drainage will be impacted both directly and indirectly, especially areas within the east coast. Thus, results from this study could be used to provide valuable information and guidance to relevant parties in better understanding of the ongoing changes in rainfall as well as extreme rainfall. In turn, this would help in the adaptation and mitigation risk efforts in facing negative impacts of climate change within the east coastal region of Peninsular Malaysia.

Acknowledgement

We thank the Malaysian Department of Drainage and Irrigation (DID) and the Malaysian Meteorological Department (MMD) for providing the rainfall data and other meteorological data. We also thank IIUM and UTM for supporting this research. This research is funded by the Research Initiative Grant Scheme (Project ID: RIGS16-079-0243) and UTM GUP Vote 15H74.

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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