FREQUENCY AND TREND ANALYSIS OF HOURLY MAXIMUM RAINFALL AT UNIVERSITI TEKNOLOGI MALAYSIA AREA

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ABSTRACT

Extreme rainfall events are the main cause of flooding. Floods may disrupt academic activities in UTM when heavy rainfall occurs. Extreme precipitation analyses are important for improving flood defense structures and management. The objectives of this research are to identify the trend of precipitation and determine best distribution model for hourly annual maximum rainfall series (AMS) at UTM. The trends are estimated from different rainfall stations around UTM using Mann– Kendall trend test. Frequency analyses were carried out using Easy Fit software to fit the AMS to the best distribution model. It can be concluded that the Generalized Extreme Value (GEV) distribution is the best distribution for describing the hourly AMS in UTM area. The results of Mann-Kendall test for all stations around UTM showed that there are no significant increasing and decreasing trend for precipitation within the year 1971 to 2018. From the result of frequency analysis, the design rainfall and peak discharge (15 to 40 m^3/s for various return periods) were also estimated inside the UTM sub catchment. Identifying the design rainfall and peak discharge will help in modeling possible flood events, thus improving flood management in UTM.

Keywords: *Extreme Rainfall, Trend Analysis, Frequency Analysis, Generalized Extreme Value, Department of Irrigation and Drainage (DID).*

1.0 INTRODUCTION

Recently the changes of the weather and intensity of extreme precipitation events have raised concern that human activity might have resulted to the alteration of the climate. However, climate change may affect the changes of precipitation, evaporation and other hydrological cycle processes.

Extreme rainfall events are the main cause of flooding. The changes in extreme rainfall events, such as heavy precipitation and major flood have attracted a lot of attention because of their devastating consequences on society and economics. In Peninsular Malaysia the extreme rainfall events showed an increasing trend between the years 1975 and 2010 [1]. Thus, extreme rainfall analysis is important to predict the possibilities of extreme event. Such analysis is important in a university as well. Studies related to extreme rainfall involving locations within the university

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campus are limited. It is important to analyze the possibilities of extreme rainfall events inside a university campus such as UTM. Flood may not be large but disruption of academic activities and mobility of residents will be affected. Increasing of the frequency and intensity of extreme rainfall events has raised concerned. It is believed that rise in both frequency and intensity of extreme rainfall events are the major impacts of global warming [2]. Therefore, there is a need to assess the trend and frequency distribution of rainfall. Using this information, flood analysis and simulation may be conducted. This study estimates the design rainfall and peak discharge using the best fit frequency distribution model. Therefore, the trend analysis is aimed at identifying the possibilities of an increase of extreme rainfall intensity and finding solutions to overcome flood problems in UTM such as improving drainage systems so that floods are not too severe.

In a frequency analysis, estimates of the probability of occurrence of future events are based on the analysis of historical rainfall records. Extreme rainfall events are considered as random variables in frequency analysis, which come from identical distribution and are assumed to be independent. The magnitude of the random variables can be related to their frequency of occurrence using probability distribution. There are two forms of probability distribution which is probability density function (PDF) and cumulative distribution function (CDF) [3]. PDF and CDF are described in the following equation:

$$(\boldsymbol{x})=\boldsymbol{P}[\boldsymbol{X}\leq\boldsymbol{x}] \tag{1}$$

$$(\boldsymbol{x})=\int_{-\infty}^{\mathbf{x}} \mathbf{f(x)dx} \tag{2}$$

From equation, F(x) is the cumulative distribution function (CDF) and f(x) is the probability density function (PDF). The CDF is the probability distribution of a random variable x with a given probability, P found at a value less than or equal to x (Eq. 1). It is also regarded as the non-exceedance probability. The CDF is also related to PDF as in (Eq. 2).

There are also several studies investigated on the distribution of rainfall, either hourly, daily or annually. Quantitative goodness of fit tests was done to determine the probability distribution most appropriate for describing annual maximum rainfall series in Peninsular Malaysia. For annually maximum rainfall data in Peninsular Malaysia, generalized extreme value (GEV) distribution is the most suitable to be used [4]. The most common means used in hydrology to show the probability of an event, is to assign a return period or recurrence interval to the event [5]. Return period is an annual maximum event that has a return period (or recurrence interval) of T years, if this value is equalled or exceeded once, on the average, every T year. The reciprocal of T is called the probability of the event or the probability the event is equalled or exceeded in any one year. For example, a 100-year flood has a probability, P =1/T = 1/100 = 0.01 or 1.0 % of being equalled or exceeded in any single year. The concept of a return period is usually found by analysing a series of maximum annual floods, rainfalls, etc. Furthermore, design rainfall is a probabilistic representation of rainfall intensity (depth of rainfall over a time period) at a given location for a given duration and average recurrence interval (ARI). It can be an essential input to a hydrologic model, which is used to estimate design discharge that is needed in the planning and design of many engineering infrastructure projects such as street drainage systems, culverts, bridges and regulators. The peak discharge estimated in the study may be used to design hydrological structure. This estimated will also be useful for risk analysis such as natural, inherent, or hydrologic risk of failure. When dealing with structure design expectations, the peak discharge is useful for calculating the riskiness of the structure.

2.0 Methodology

The present rainfall data are obtained from Department of Irrigation and Drainage (DID) stations having data between 1970 until 2018. The stations are nearest to UTM Skudai area. The rainfall data was obtained in four forms, in hourly, daily, weekly and annual data. From the daily, we can make it to weekly or monthly as well as to annual, but in this study; the estimation uses hourly data. The formation of hourly data was analysed and organize by using Microsoft Excel and from the analysis, the hourly annual maximum series data were collected by classifying the data according to the number of stations nearest UTM area.

These hourly maximum series data were used as input in the trend analysis as well as in the design rainfall based on return period in frequency analysis. In order to determine the design rainfall, frequency analysis is use to predict, so the value of return period is compulsory so that the best distribution model can be described to be developed according to Kolmogorov Smirnov, Anderson Darling and Chi-Squared goodness of fit method. Therefore, the selection of the best-fit distribution is done by examining the average rank produced by the Kolmogorov-Smirnov (KS), Anderson Darling and Chi-Squared.

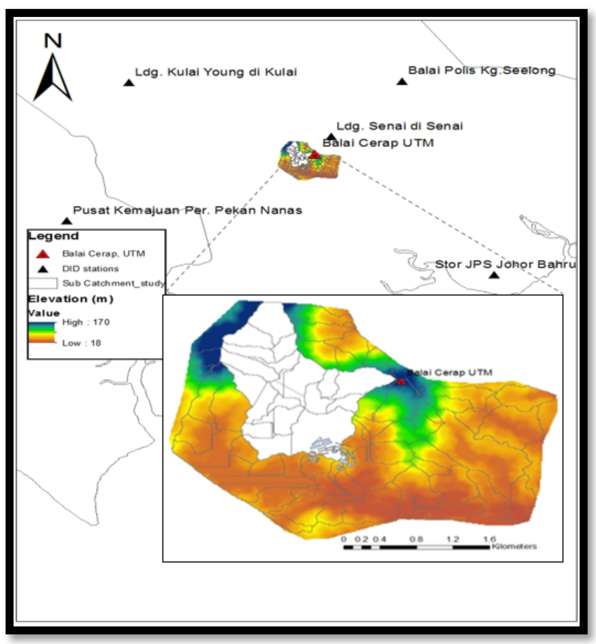


Figure 1: Location of the rainfall station

There are several stations located nearest to UTM area, below is the list of stations:

Table 1: Name of the Rainfall Station and Number Station Rainfall

No.	Name of Station	Station Number
1	Ldg. Kulai Young di Kulai	1635102
2	Balai Polis Kg. Seelong	1636001
3	Ldg. Senai di Senai	1536110
4	Pusat Kemajuan Per. Pekan Nanas	1534002
5	Stor JPS Johor Bahru	1437116

2.1 Correlation Analysis

Correlation analysis is a method of statistical evaluation used to study the strength of a relationship between two, numerically measured, continuous variables. This particular type of analysis is useful when a researcher wants to establish if there are possible connections between variables. In correlation analysis, we estimate a sample correlation coefficient, more specifically have been test about 5 rainfall stations around UTM area. The sample correlation coefficient, denoted r, ranges between -1 and +1 and quantifies the direction and strength of the linear association between the two variables. The correlation between two variables can be positive or negative. The sign of the correlation coefficient indicates the direction of the association. The magnitude of the correlation coefficient indicates the strength of the association. For example, a correlation of r = 0.9 suggests a strong, positive association between two variables, whereas a correlation of r = -0.2 suggest a weak, negative association. A correlation close to zero suggests no linear association between two continuous variables.

2.2 Man's Kendall Trend Test

The Mann-Kendall test is applicable in cases when the data values xi of a time series can be assumed to obey the model

$$x_i = f(t_i) + \varepsilon_i \ , \tag{3}$$

where *f(t)* is a continuous monotonic increasing or decreasing function of time and the residuals ε_i can be assumed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in time. We want to test the null hypothesis of no trend, *Ho*, i.e. the observations *xi* are randomly ordered in time, against the alternative hypothesis, *H1*, where there is an increasing or decreasing monotonic trend.

2.3 Frequency Analysis

Frequency analysis was applied to perform a probabilistic modelling of rainfall records using annual maximum series (1hr-rainfall) data. To construct the distribution model, five model distribution for extreme value or extreme precipitation namely, Generalized Extreme Value (GEV), Log-Pearson 3, Lognormal 3, Gumbel Max and Gamma were selected. the selection of the best-fit distribution is done by examining the average rank produced by the Kolmogorov-Smirnov (KS), Anderson Darling and Chi-Squared. GEV distribution represents the best model for UTM area. Finally, the GEV model was applied to calculate the design rainfall based on various return period such as 2 years, 5 years, 10 years, 20 years, 50 years and 100 years.

2.4 Rational Method (Peak Discharge)

Application of the rational method is based on a simple formula that relates the potential runoff produced in the watershed with, the average intensity of rainfall for a particular length of time (the time of concentration, tc), and the watershed drainage area. The formula is

$$Q = CIA/360 \tag{4}$$

where: Q = design discharge (m^3/s), C = runoff coefficient (dimensionless), I = design rainfall intensity (mm/hr), and A = watershed drainage area (ha).

Table 2: Rational Method Parameter

<table>
<tr><th>Rational Method</th><th>Parameter</th><th>Source</th></tr>
<tr><td>C</td><td><table><tr><th></th><th>n</th><th>Total</th></tr><tr><td>Link and terrace house= 10 %</td><td>0.8</td><td>0.08</td></tr><tr><td>Grass Cover = 30 %</td><td>0.4</td><td>0.12</td></tr><tr><td>Forest Cover = 60 %</td><td>0.3</td><td>0.18</td></tr><tr><td colspan="2">COMPOSITE n</td><td>0.38</td></tr></table></td><td>Satellite Image (Google Earth), DID MSMA 2012.</td></tr>
<tr><td>I</td><td>Design Rainfall Estimated</td><td>Calculation</td></tr>
<tr><td>A</td><td>Catchment Area = 2.351453 km^2 = 235.1453 ha</td><td>Calculated using ArcGIS from DEM Data, (Satellite Alaska,12.5 km)</td></tr>
</table>

3.0 Results and Discussion

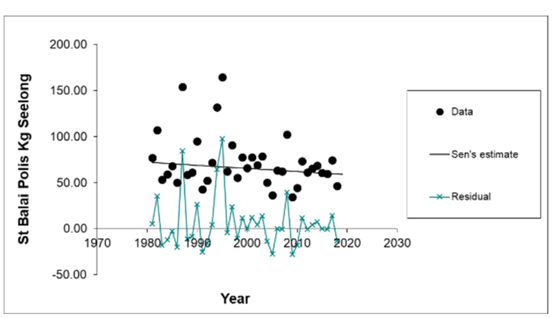
3.1 Correlation Analysis

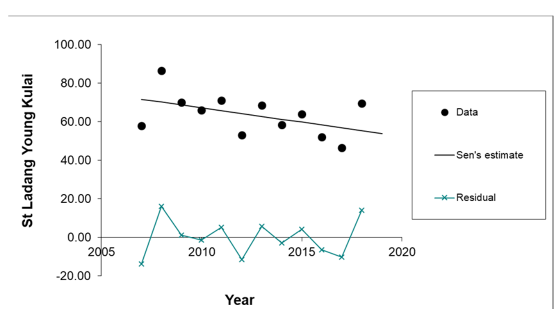
Table 3: Daily Correlation Analysis

	UTM	St Ladang Senai	St Balai Polis Kg Seelong	St Ladang Young Kulai	St Pekan Nanas	St Stor JPS JB
UTM	1.000					
St Ladang Senai	-0.083	1.000				
St Balai Polis Kg Seelong	0.691	-0.095	1.000			
St Ladang Young Kulai	0.575	-0.106	0.447	1.000		
St Pekan Nanas	0.173	-0.053	0.005	0.249	1.000	
St Stor JPS JB	0.614	-0.041	0.381	0.390	0.188	1.000

Based on correlation analysis, we can conclude that St Balai Polis Kg Seelong, St Ladang Young Kulai and St Stor JPS JB are the most suitable JPS rainfall stations to represent UTM area due to strong positive result which is approaching 1.0 indicating high correlation. Thus, the other two station (Station Ladang Senai and Station Pekan Nanas) may not be suitable to represent UTM area as they have low correlation (near to zero).

3.2 Trend Analysis





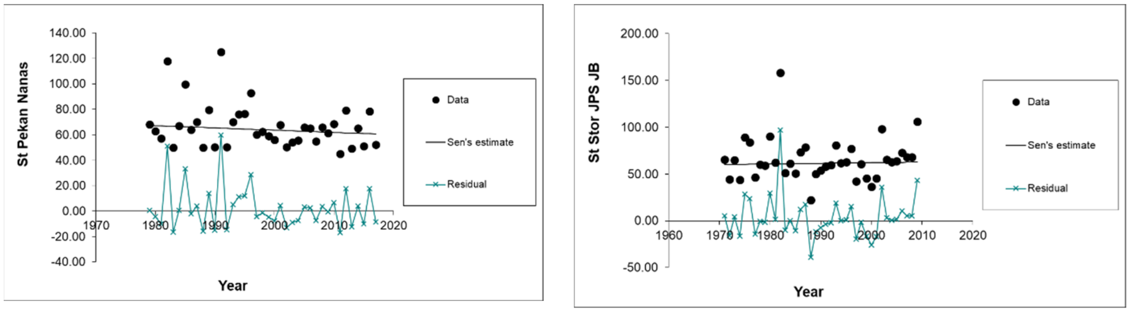


Figure 2: Trend analysis 4 rainfall station

Table 4: Summary of Trend Analysis

Ts Number	1	2	3	4
Name	St Balai Polis Kg Seelong	St Ladang Young Kulai	St Pekan Nanas	St Stor JPS JB
Years	1981 - 2018	2007 - 2018	1979 - 2018	1971 - 2019
n	38	12	40	48
Test Z	-1.08	-1.44	-0.92	0.47
Significant	> 0.1	> 0.1	> 0.1	> 0.1
Q	-3.33E-01	-1.49E+00	-1.76E-01	6.81E-02

The results of Mann-Kendall test for all stations around UTM showed that there are no significant increasing and decreasing trend for precipitation within the year 1971 to 2018. This is due to the significant result for all stations around UTM are greater than 0.1.

3.3 Design Rainfall & Peak Discharge

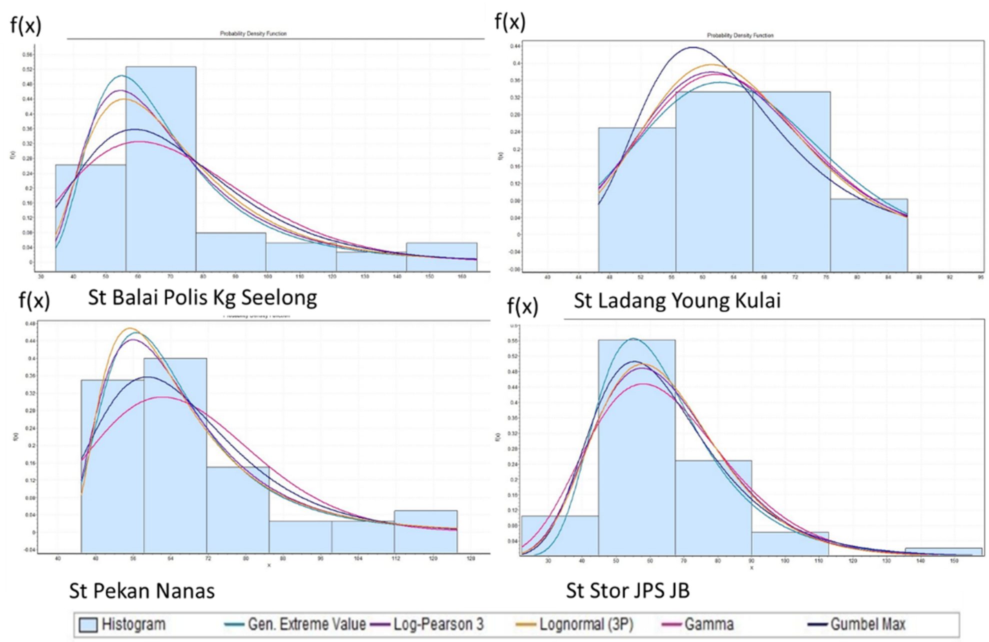


Figure 3: Frequency Analysis of 4 rainfall stations

Table 5: Summary of Design Rainfall & Peak Discharge

Station	Return Period	Distribution Model	Parameter	Design Rainfall	Q= CIA/360
St Stor JPS JB	2	Gen. Extreme Value (Rank 1)	k=0.04251	61.186	15
	5			78.567	20
	10		σ=14.737	90.544	22
	20			102.4	25
	50		μ=55.742	118.29	29
	100			130.62	32
St Pekan Nanas	2	Gen. Extreme Value (Rank 1)	k=0.17708	62.498	16
	5			77.035	19
	10		σ=10.854	88.397	22
	20			100.81	25
	50		μ=58.388	119.41	30
	100			135.51	34
St Ladang Young Kulai	2	Log-Pearson 3 (Rank 1)	α=4021.3	62.616	16
	5			72.16	18
	10		β=-0.00267	77.675	19
	20			82.525	20
	50		γ=14.873	88.322	22
	100			92.396	23
St Balai Polis Kg Seelong	2	Gen. Extreme Value (Rank 1)	k=0.21621	64.229	16
	5			86.783	22
	10		σ=16.222	105.06	26
	20			125.62	31
	50		μ=58.042	157.44	39
	100			185.86	46

Data used in the analysis were annual maximum rainfall series for hourly data. Five probability distribution were investigated as potential candidates to describe the annual extreme rainfall data of UTM area, namely Gamma, Gumbel Max, Generalized Extreme Value (GEV), Log-Pearson 3, and Log-Normal. The combined result obtained suggested the Generalized Extreme Value (GEV) as the most appropriate distribution. The design rainfall and peak discharge have been calculated may be used in hydrological design structure in future in UTM area.

4.0 Conclusion

Outcomes of extreme precipitation analysis influence improvements on flood protection and flood risk management. Our studies were focusing on correlation, trends and frequency analysis around UTM area to identify the design rainfall and peak discharge for the purpose of designing hydrological structures in the future to overcome flood problems. From correlation analysis the station around UTM may be used to represent the rainfall within UTM. Based on the result, Stesen Balai Polis Kg Seelong and Stor JPS JB are the best rain gauge stations to represent UTM due to high correlation of its rainfall data with observed data measured in UTM. Trend analysis in annual maximum rainfall series for all stations around UTM has been carried out by using Man-Kendall's test. The results showed that there are no significant increasing and decreasing trend for precipitation within the year 1971 to 2018. Besides that, the selection of the best-fit distribution is done by examining the average rank produced by the Kolmogorov-Smirnov (KS), Anderson Darling and Chi-Squared. Based on the results of goodness-of-fit test, Generalised Extreme Value (GEV) distribution is the most suitable to describe the annual maximum rainfall series in the UTM area. The frequency analysis was carried out using Easy Fit software. From the result of frequency analysis, the design rainfall and peak discharge were estimated at UTM area for the return periods of; 2 years, 5 years, 10 years, 20 years, 50 years and 100 years. The design rainfall to several return period was estimated according best distribution model and varies depending on the selected distribution. The rational method has been used to estimate the peak discharge depending on the return period. Therefore, identifying the design rainfall and peak discharge will be beneficial in hydraulic structure design. The result from this study can be used for future relating to flood mitigation structure designs.

ACKNOWLEDGEMENTS

The authors wish to convey their appreciation to the Department of Irrigation and Drainage for the rainfall data given and to the School of Civil Engineering which have supported equipment and facilities for this research. Appreciation goes as well to the funders from the Fundamental Research Grant (FRGS) [R.J130000.7851.5F032], and the Malaysian Ministry of Education for GUP 2018 grant [QJ130000.2522.19H68].

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