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# TREND ANALYSIS OF PRECIPITATION DATA IN FLOOD SOURCE AREAS OF KELANTAN RIVER BASIN

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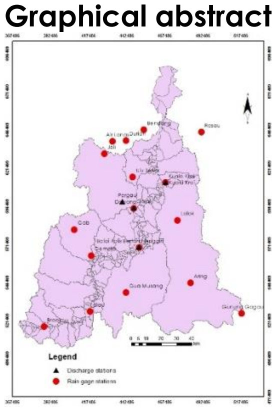
Jabir Haruna Abdulkareem[a,b*], Wan Nor Azmin Sulaiman[b]

[a]Department of Soil Science, Institute for Agricultural Research, Faculty of Agriculture, Ahmadu Bello University, Zaria
[b]Department of Environmental Science, Faculty of Environmental Studies, Universiti Putra Malaysia

*Corresponding author
jhabdulkareem@abu.edu.ng

## Graphical abstract




## Abstract

Rainfall is one of the most important climatic elements that influence both the spatial and temporal water availability. Therefore, identification of its trend over years is vital for detection of extreme climatic changes. The purpose of this study is to investigate the variability of precipitation in flood source areas of Kelantan river basin by detecting precipitation flood changes in the temporal structure for the period of 1984-2014. A total of 17 rain gage stations with at least 25 years' records in the temporal structure for the period 1984-2014 were selected. For the AMF data, 4 gauging stations were selected for the analysis. Mann-Kendall and Sen slope estimator tests were used to detect possible precipitation trend. This resulted in the detection of non-statistically significant trend in the annual maximum series of 24-hr precipitation in 12 of the 17 selected rain gauge locations and statistically significant trend in 5 locations for the period under study. Whereas, the AMF series signaled significance at 5% level in all the stations. This may be as a result of watershed characteristics such as land use changes soil, topography, of the study area which needs to be studied in detail.

*Keywords*: trend analysis, precipitation, annual maximum series of 24-hour precipitation, annual maximum flood, goodness of fit

## Abstrak

Hujan adalah salah satu daripada unsur-unsur iklim yang paling penting yang mempengaruhi kedua-dua ketersediaan air ruang dan masa. Oleh itu, pengenalan trend ke atas tahun adalah penting untuk mengesan perubahan iklim yang melampau. Tujuan kajian ini adalah untuk mengkaji perubahan hujan di kawasan berisko banjir di lembangan Sungai Kelantan dengan mengesan perubahan hujan dalam struktur variasi masa bagi tempoh dari tahun 1984 hingga 2014. Sebanyak 17 stesen hujan yang mempunyai rekod bacaan sekurangnya 25 tahun bagi data dalam struktur variasi masa bagi tempoh dari tahun 1984 hingga telah dipilih. Data untuk AMF pula, empat stesen luahan air telah dipilih untuk dianalisa. Analisa statististik Mann-Kendall dan Sen penganggar cerun ujian bukan parametrik telah digunakan untuk mengesan kemungkinan aliran hujan. Hasil penggunaan kaedah ini mendapati bahawa tiada pengesanan trend statistik yang signifikan dalam siri maksimum tahunan 24-jam hujan di 12 lokasi dari 17 stesen hujan terpilih manakala terdapat trend statistik yang signifikan bagi 5 stesen lokasi bagi jangkawaktu yang dikaji. Manakala, bagi analisis data AMF, terdapat pengesanan signifikan pada tahap 5% di semua stesen. Hal ini mungkin disebabkan oleh ciri-ciri kawasan lembangan seperti perubahan penggunaan tanah, tanah, topografi, yang yang memerlukan kajian terperinci.

*Kata kunci*: analisis trend, hujan, siri maksimum tahunan 24 jam hujan, banjir maksimum tahunan.

## 1.0 INTRODUCTION

Majority of hydrologic time series statistical analyses faced in a typical scale in water resources management (either monthly or annually) are centered on certain fundamental assumptions. These assumptions include; the time series is free from missing data, consistent, free from trends, non-periodic with no persistence, stationary and constitutes a stochastic process whose random component follows the appropriate probability distribution function [1,2].

These assumptions are not always true. For example; missing data which is a common setback faced by hydrologists mainly due to a number of reasons. Random and systematic errors are almost always certain during measurement of hydrologic variables such as precipitation and stream flow [3,4,5,6,7]. These necessitates the call for missing data analysis in hydrological time series analysis prior to hydrological analyses such as trend detection.

Trend detection in long time series of hydrological data is an important and difficult issue, of increasing interest for both hydrology and climatology over three decades. It is paramount in order to examine climate changes scenarios and enhance climate impact research [8,9,10,11]. The majority of water resources projects are planned, designed and operated based on the historical prototype of water availability, quality and demand, assuming constant climatic behavior. It is therefore essential to investigate present and probable future climatic change patterns and their impacts on water resources so that appropriate adaptation strategies may be implemented [12]. This makes trend detection in long time series data vital for better planning and designing regional water resources management. Trend analysis is widely implemented to analyse hydrological variables such as precipitation, stream flow and river discharge. For example, several researchers found that trends in observed daily precipitation are generally a complex function of the climatic environment, precipitation intensity and season [13,14,15,16]. Relevant reviews on trend analysis in precipitation time series include the studies of [17,18,19,20,21].

There exist a great number of probability distributions that were used for testing the goodness of fit in hydrologic data. Some of these distributions that were used and described in various literatures include; Normal family, Generalized Extreme Value family and Pearson Type III family.

Flood is a natural disaster that occurs in several countries in the world. It has been demonstrated that changes in the magnitude and frequency of flooding can be attributed to climate change, particularly precipitation, temperature and sea level change [22,23,24,25,26]. More intense precipitation may lead to increases in flood peaks and may subsequently cause increases in the extent of flood inundation. Much research has been carried out to demonstrate how variation in precipitation may contribute to changes in flood frequency [27,28].

Flood is the major natural disaster in several parts of the east coast states of Peninsula Malaysia, Kelantan river basin inclusive. The Kelantan river basin is one of the largest basins in Malaysia which is known to be flood prone. During early December, 2014, heavy precipitation occurred for many days that lead to disastrous flooding in several parts of the east coast state of Kelantan flooding the entire river basin. The flood was considered to be the greatest in history that happens in the Kelantan Rivers and its tributaries which drains about 13,100 $km^2$ watersheds affecting more than 200, 000 people. It causes damage to lives and properties worth several millions of Malaysian ringgits.

Although several researches have been conducted that involved trend analysis of hydrological data in recent years, none of these researches use a combination of precipitation data and AMF data. While other studies focus only on the 2014 flood, this research attempted to analysed the variability of precipitation and AMF over the period of 1984-2014 for possible climate change. More so, apart from identifying the possible trend in the hydrological data, data preparation involving missing data analysis as well as fitting the data into the best probability distribution was carried out in this study.

The aim of the current study is to identify the variability of precipitation in flood source areas of Kelantan river basin by detecting precipitation and AMF changes in the temporal structure for the period of 1984-2014. In order to contribute for a better interpretation of its hydrological status using Mann-Kendall test and Sen's slope estimator. The precipitation regime features a high seasonal and annual variability in both temporal and spatial domains, providing the incentives for assessing the precipitation variability and by extension on climate change.

**Table 1** Spatial and temporal information of 17 precipitation gauge stations and four discharge gauging stations

| No | Station No. | Precipitation Station | Latitude (°N) | Longitude (°E) | Period of record |
|---|---|---|---|---|---|
| 1 | 4614001 | Brook | 04° 40’ 35” | 101° 29’ 05” | 1984-2014 |
| 2 | 4717001 | Blau | 04° 36’ 00’’ | 101° 24’ 00’’ | 1984-2014 |
| 3 | 4726001 | Gunung Gagau | 04° 45’ 25’’ | 102° 39’ 20’’ | 1984-2014 |
| 4 | 4819027 | Gua Musang | 04° 52’ 45’’ | 101° 58’ 10’’ | 1984-2014 |
| 5 | 4923001 | Aring | 04°56’ 15’’ | 102° 21’ 10’’ | 1984-2014 |
| 6 | 5017001 | Gemala | 05° 05’ 55’’ | 101° 45’ 45’’ | 1984-2014 |
| 7 | 5120052 | Balai Polis | 05° 08’ 45’’ | 102° 02’ 55’’ | 1984-2014 |
| 8 | 5216001 | Gob | 05° 15’ 05” | 101° 39’ 45’’ | 1984-2014 |
| 9 | 5320038 | Dabong | 05° 22’ 40” | 102° 00’ 55’’ | 1984-2014 |
| 10 | 5322044 | Kg. Laloh | 05° 18’ 30’’ | 102° 16’ 30’’ | 1984-2014 |
| 11 | 5520001 | Ulu Sekor | 05° 33’ 50’’ | 102° 00’ 30’’ | 1984-2014 |
| 12 | 5521044 | Kuala Krai | 05° 32' 00" | 102° 10' 00" | 1984-2014 |
| 13 | 5718033 | Kg. Jeli | 05° 42’ 05’’ | 101° 50’ 20’’ | 1984-2014 |
| 14 | 5719001 | Kg. Durian | 05° 46’ 50’’ | 101° 58’ 05’’ | 1984-2014 |
| 15 | 5820006 | Bendang Nyior | 05° 50’ 40’’ | 102° 04’ 25’’ | 1984-2014 |
| 16 | 6019004 | Rumah | 06° 01’ 25’’ | 101° 58’ 45’’ | 1984-2014 |
| 17 | 6122064 | Air Lanas | 05° 46’ 30’’ | 101° 53’ 20’’ | 1984-2014 |
| | | Discharge Station | | | |
| 1 | 5521444 | Kuala Krai | 05° 32 00’’ | 102° 10 00’’ | 1984-2014 |
| 2 | 5320443 | Galas | 05° 22 55’’ | 102° 00 55’’ | 1984-2014 |
| 3 | 5419401 | Pergau | 05° 25 05’’ | 101° 56 45’’ | 1984-2014 |
| 4 | 5120401 | Nenggiri | 05° 08 55’’ | 102° 02 45’’ | 1984-2014 |

**Table 2** Missing Data Analysis; Summary statistics (Before treatment)

| Station | Number of Observ | Observ with missing data | Observ without missing data | Minimum (mm) | Maximum (mm) | Mean (mm) | Standard deviation (mm) |
|---|---|---|---|---|---|---|---|
| Brook | 31 | 0 | 31 | 749.00 | 4183.00 | 2146.20 | 683.81 |
| Blau | 31 | 0 | 31 | 470.00 | 2725.50 | 1880.94 | 594.12 |
| Gunung Gagau | 31 | 0 | 31 | 391.00 | 5396.50 | 3648.65 | 1122.10 |
| Gua Musang | 31 | 0 | 31 | 1376.00 | 3082.00 | 2269.89 | 387.01 |
| Aring | 31 | 1 | 30 | 1318.00 | 3266.50 | 2532.47 | 464.53 |
| Gemala | 31 | 0 | 31 | 114.00 | 3468.00 | 1747.54 | 702.72 |
| Balai Polis | 31 | 0 | 31 | 646.00 | 2975.50 | 2034.55 | 537.10 |
| Gob | 31 | 1 | 30 | 590.00 | 3329.50 | 2039.20 | 796.08 |
| Dabong | 31 | 0 | 31 | 766.00 | 3111.50 | 2214.19 | 569.20 |
| Laloh | 31 | 0 | 31 | 698.00 | 3068.50 | 2197.34 | 675.65 |
| Ulu Sekor | 31 | 0 | 31 | 910.00 | 3752.00 | 2557.53 | 713.88 |
| Kuala Krai | 31 | 0 | 31 | 532.00 | 3339.50 | 2130.01 | 747.24 |
| Jeli | 31 | 3 | 28 | 284.00 | 4359.50 | 3061.42 | 1047.62 |
| Durian | 31 | 0 | 31 | 1397.00 | 4396.50 | 3290.20 | 776.44 |
| Bendang | 31 | 0 | 31 | 1161.00 | 4578.50 | 2717.38 | 902.54 |
| Rumah | 31 | 0 | 31 | 1605.00 | 4642.00 | 2871.73 | 955.00 |
| Air Lanas | 31 | 0 | 31 | 689.00 | 4578.50 | 3145.31 | 969.75 |

**Table 3** Missing Data Analysis; Summary statistics (After treatment)

| Station | Number of Observations | Observations with missing data | Observations without missing data | Minimum (mm) | Maximum (mm) | Mean (mm) | Standard deviation (mm) |
|---|---|---|---|---|---|---|---|
| Brook | 31 | 0 | 31 | 749.00 | 4183.00 | 2146.20 | 683.81 |
| Blau | 31 | 0 | 31 | 470.00 | 2725.50 | 1880.94 | 594.12 |
| Gunung Gagau | 31 | 0 | 31 | 391.00 | 5396.50 | 3648.65 | 1122.10 |
| Gua Musang | 31 | 0 | 31 | 1376.50 | 3082.00 | 2269.89 | 387.01 |
| Aring | 31 | 0 | 31 | 1318.00 | 3266.50 | 2547.22 | 464.05 |
| Gemala | 31 | 0 | 31 | 114.00 | 3468.00 | 1747.54 | 702.72 |
| Balai Polis | 31 | 0 | 31 | 646.00 | 2975.50 | 2034.55 | 537.10 |
| Gob | 31 | 0 | 31 | 590.00 | 3329.50 | 2026.74 | 785.77 |
| Dabong | 31 | 0 | 31 | 766.00 | 3111.50 | 2214.19 | 569.20 |
| Laloh | 31 | 0 | 31 | 698.00 | 3068.50 | 2197.34 | 675.65 |
| Ulu Sekor | 31 | 0 | 31 | 910.00 | 3752.00 | 2557.53 | 713.88 |
| Kuala Krai | 31 | 0 | 31 | 532.80 | 3339.50 | 2130.03 | 747.24 |
| Jeli | 31 | 0 | 31 | 284.00 | 4359.50 | 3088.87 | 1001.82 |
| Durian | 31 | 0 | 31 | 1397.50 | 4396.50 | 3290.20 | 776.44 |
| Bendang | 31 | 0 | 31 | 1161.00 | 4578.50 | 2717.38 | 902.54 |
| Rumah | 31 | 0 | 31 | 1605.00 | 4642.00 | 2871.73 | 955.00 |
| Air Lanas | 31 | 0 | 31 | 689.00 | 4578.50 | 3145.31 | 969.75 |

## 2.0 METHODOLOGY

### 2.1 Study Location

Kelantan River basin is located in the north eastern part of Peninsular Malaysia between latitudes 4° 40' and 6° 12' north, and longitudes 101° 20' and 102° 20' east. The maximum length and breadth of the catchment are 150 km and 140 km respectively. The main river is about 248 km long and drains an area of 13,100 $km^2$, occupying more than 85% of the State of Kelantan. Kelantan river basin has an annual precipitation of about 2383±120 mm, a large amount of which occurs during the North-East Monsoon between mid-October and mid-January.The estimated runoff for this area is 500 $m^3\ s^{-1}$ [29]. The mean annual temperature at Kota Bharu is 27.5° C with mean relative humidity of 81%. The mean flow of the Kelantan River measured at Guillemard Bridge is 557.5 $m^3\ s^{-1}$.

There are six major sub-basins in Kelantan River basin namely Galas, Nenggiri, Pergau, Guillemard Bridge, Kuala Krai and Lebir. The eastern and western portions, consisting of mountain ranges have a granitic soil cover encompassing a mixture of fine to coarse sand and clay. The soil cover is a metre or so deep but depths of more than 18 m may be encountered in localised areas. A fine sandy loam soil is found in the extreme east and west of the southern half of the basin. Its depth seldom exceeds a few metres. The remaining fraction, comprising almost one-third of the catchment, is cloaked by a variable soil cover that varies in depth, from a few metres to more than 9 m.

### 2.2 Missing Data Analysis

Missing data analysis was conducted using normal ratio method which is the most commonly used method for estimation of missing rainfall data in hydrological analyses. According to the method the missing rainfall is given as:

$$P_x = \frac{1}{n}\sum_{i=1}^{i=n}\frac{N_x}{N_i}P_i 1) \quad (1)$$

Where $P_x$ is the missing rainfall for any storm at the interpolation station 'x', *Pi* is the rainfall for the same period and the same storm at the "*ith*" station of a group of index stations, $N_x$ the normal annual rainfall value for the 'x' station and *N* is the normal annual rainfall value for '*ith*' station.

### 2.3 Testing the goodness of fit

Goodness of fit is used to quantify how compatible a random simple is with the theoretical probability distribution. The Chi-Square, Anderson-Darlington and Kolmogorov-Smirnov tests were used in this study to determine the best fit probability distribution using Gumbel distribution, General extreme values (GEV), Lognormal III Pearson (LN III) and Log Pearson III (LP III) as the distribution parameters.

#### 2.3.1 *Chi-square Test*

This test is use to test if a sample of data are from a population with a specific distribution. The chi-square test is an alternative to the Anderson-Darling and Kolmogorov-Smirnov goodness-of-fit tests. The chi-square statistic in this study was calculated using the equation below;

$$x^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)}{E_i} \quad (2)$$

Where
$O_i$ = observed frequency
$E_i$ = expected frequency
$i$ = number of observations (1,2,….k) and is calculated as follows;

$$E_i = F(x_2) - F(x_1) \quad (3)$$

Where
F = cumulative distribution function of the probability distribution
$x_1$, $x_2$ = limits for bin $i$

### 2.3.2 Anderson-Darlington Test (A-D)

This is used to test if a sample of data are from a population with an explicit distribution. It compares the fit of an observed cumulative distribution function to an expected cumulative distribution function. Anderson-Darlington test is an alteration of the Kolmogorov-Smirnov test and therefore infer more weight to the tails than does the Kolmogorov-Smirnov test. This test was calculated using the equation below;

$$A^2 = -N - S$$

Where

$$S = \sum_{i=1}^{N} \frac{2i-1}{N} [lnF(Y_i) + \ln(1 - F(Y_{N+1-i}))] \quad (4)$$

F = cumulative function of the distribution

### 2.3.2 Kolmogorov-Smirnov Test (K-S)

The Kolmogorov-Smirnov statistic is used to decide if a sample comes from a population with a specific distribution. It is given as the largest vertical difference between the theoretical and the empirical cumulative distribution function (ECDF); Given $N$ ordered data points $Y_1$, $Y_2$,….$Y_N$.

**Table 4** Descriptive statistics of rainfall from rainfall stations in Kelantan

| Rainfall Station | Number of observation | $P_r$ (mm) | 1st Quartile (mm) | $P_m$ (mm) | 3rd Quartile (mm) | V | $C_s$ (F test) | $C_k$ (F test) | SEM |
|---|---|---|---|---|---|---|---|---|---|
| Brook | 31 | 3434.00 | 1756.25 | 2163.50 | 2511.00 | 467600.51 | 0.41 | 1.68 | 122.82 |
| Blau | 31 | 2255.50 | 1635.50 | 2045.00 | 2248.50 | 352976.49 | -1.06 | 0.49 | 106.71 |
| Gunung Gagau | 31 | 5005.50 | 3137.45 | 3814.70 | 4374.25 | 1259100.39 | -0.99 | 1.34 | 201.53 |
| Gua Musang | 31 | 1705.50 | 2019.25 | 2340.00 | 2492.00 | 149780.08 | -0.36 | 0.12 | 69.51 |
| Aring | 31 | 1948.50 | 2295.25 | 2565.00 | 2871.00 | 215340.40 | -0.73 | 0.51 | 83.35 |
| Gemala | 31 | 3354.00 | 1355.50 | 1732.50 | 2136.00 | 493810.81 | -0.02 | 0.53 | 126.21 |
| Balai Polis | 31 | 2329.50 | 1664.25 | 1732.50 | 2424.75 | 288478.62 | -0.41 | 0.14 | 96.47 |
| Gob | 31 | 2739.50 | 1626.73 | 2183.00 | 2567.50 | 617427.55 | -0.35 | -0.71 | 141.13 |
| Dabong | 31 | 2345.50 | 1917.75 | 2272.00 | 2710.05 | 323985.81 | -0.72 | 0.04 | 102.23 |
| Laloh | 31 | 2370.50 | 1838.50 | 2274.00 | 2778.25 | 456506.38 | -0.72 | -0.23 | 121.35 |
| Ulu Sekor | 31 | 2842.00 | 2221.25 | 2477.00 | 3049.25 | 509624.75 | -0.265 | -0.36 | 128.22 |
| Kuala Krai | 31 | 2806.70 | 1576.25 | 2151.50 | 2702.25 | 558364.65 | -0.31 | -0.60 | 134.21 |
| Jeli | 31 | 4075.50 | 2809.75 | 3444.00 | 3800.75 | 1003637.71 | -1.42 | 1.70 | 179.93 |
| Durian | 31 | 2999.00 | 2693.50 | 3446.00 | 3831.55 | 602865.02 | -0.48 | -0.33 | 139.45 |
| Bendang | 31 | 3417.50 | 2197.25 | 2739.20 | 3450.50 | 814578.84 | -0.15 | -0.61 | 162.10 |

$P_r$ =Range; $P_m$ = Mean; V=Variance; $C_s$ =Skewness; $C_k$ =Kurtosis; SEM=standard error of mean

**Table 5** Descriptive statistics of the Annual maximum flood data

| Stations | $P_r$ (mm) | 1st quartile | $P_e$ (mm) | 3rd quartile | SD (mm) | $C_s$ (F test) | $C_k$ | SEM |
|---|---|---|---|---|---|---|---|---|
| Kuala Krai | 10.47 | 21.78 | 24.08 | 26.02 | 2.6816 | -0.1474 | -0.24125 | 0.59 |
| Galas | 11.70 | 33.58 | 35.15 | 36.63 | 2.94 | 0.10 | 0.1277 | 0.57 |
| Pergau | 7.63 | 37.13 | 38.91 | 40.41 | 1.919 | -0.28486 | -0.34609 | 0.45 |
| Nenggiri | 8.66 | 51.08 | 53.22 | 54.69 | 2.50 | 0.52 | -0.3042 | 0.63 |

$P_r$ =Range; $P_m$ = mean; SD=standard deviation; $C_s$ =Skewness; $C_k$ =Kurtosis; SEM=standard error of mean

$$E_N = n(i)/N \quad (5)$$

where $n(i)$ is the number of points less than $Y_i$ and the $Y_i$ are ordered from smallest to largest value. This is a step function that increases by 1/$N$ at the value of each ordered data point.

### 2.4 Mann–Kendall Test and Sen Slope Estimator

Secondary data for AMS of 24-hour precipitation from three stations and that of AMF from four discharge gauging stations distributed across the Kelantan river basin were obtained for the trend analyses. The trend analyses were conducted using Mann–Kendall nonparametric test. This test has been widely used in hydrological studies to test for trend in the time series data. It is a rank-based procedure, robust to the influence of extremes and suitable for application with skewed variables widely used to test the normality of hydrologic variables [30,31]. More particularly, this technique can be adopted in cases with distribution-free data containing outliers and non-linear trends [32,33]. According to this test the null hypothesis ($H_0$) indicates that the annual distribution of the data ($x_1$....$x_n$) is a sample of $n$ independent and identically distributed random variables [34]. The alternative hypothesis $H_1$ of a two sided test is that the distribution of $x_k$ and $x_j$ are not identical for all $k,j \leq n$ with $k \neq j$. The test statistic is given below [35].

The null and the alternative hypothesis of the Mann-Kendall test for trend in the random variable x are:

$$H_0 : \Pr(x_j > x_i = 0.5, j > i, \quad (6)$$
$$H_A \Pr(x_j > x_i \neq 0.5, \text{ (two-sided test)}$$

The Mann-kendall statistic $S$ was calculated as;

$$S = \sum_{k=1}^{n=1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad (7)$$

Where $x_j$ and $x_k$ are the data values in years $j$ and $k$ respectively, with $j>k$, and sgn () is the signum function:

$$\text{sgn } (x_j - x_k = \begin{cases} 1 \;\; If \; x_j - x_k > 0 \\ 0 \;\; If \; x_j - x_k = 0 \\ -1 \; If \; x_j - x_k < 0 \end{cases} \quad (8)$$

Under the null hypothesis the distribution of $S$ can be approximated well by a normal distribution (for large sample sizes $n$), with mean $\mu_S$ and variance $\delta^2{}_S$ given by:

$$\mu_S = 0,$$

**Table 6** Summary statistic of PDP

| Distribution | Chi-square | | Anderson-Darlington | | Kolmogorov-Smirnov | |
|---|---|---|---|---|---|---|
| | | | Blau | | | |
| | Statistic | Rank | Statistic | Rank | Statistic | Rank |
| Gumbel | 1.7858 | 2 | 0.43937 | 1 | 0.13346 | 2 |
| GEV | NA | NA | 7.7308 | 4 | 0.12432 | 1 |
| LN III | 6.0275 | 3 | 1.3347 | 3 | 0.20594 | 3 |
| LP III | 0.09035 | 1 | 0.89096 | 2 | 0.14651 | 4 |
| | | | Brook | | | |
| | Statistic | Rank | Statistic | Rank | Statistic | Rank |
| Gumbel | 1.0148 | 2 | 1.0292 | 3 | 0.12718 | 4 |
| GEV | 0.84669 | 1 | 0.47191 | 2 | 0.10752 | 2 |
| LN III | 1.1862 | 3 | 0.31243 | 1 | 0.09363 | 1 |
| LP III | NA | NA | 4.1473 | 4 | 0.11909 | 3 |
| | | | Gua Musang | | | |
| | Statistic | Rank | Statistic | Rank | Statistic | Rank |
| Gumbel | 0.98147 | 1 | 0.0812 | 1 | 0.34077 | 4 |
| GEV | 1.0082 | 2 | 0.28614 | 3 | 0.07504 | 2 |
| LN III | 2.389 | 4 | 0.29646 | 4 | 0.10155 | 3 |
| LP III | 1.0312 | 3 | 0.21466 | 2 | 0.07437 | 1 |
| | | | Gunung Gagau | | | |
| | Statistic | Rank | Statistic | Rank | Statistic | Rank |
| Gumbel | 2.0104 | 1 | 0.20493 | 1 | 0.08367 | 1 |
| GEV | 3.1977 | 3 | 0.72627 | 3 | 0.09779 | 2 |
| LN III | 2.1623 | 2 | 0.67623 | 2 | 0.13818 | 3 |
| LP III | NA | NA | 14.979 | 4 | 0.16664 | 4 |
| | | | Dabong | | | |
| | Statistic | Rank | Statistic | Rank | Statistic | Rank |
| Gumbel | 0.20871 | 2 | 0.30217 | 3 | 0.10716 | 3 |
| GEV | 0.30021 | 3 | 0.22381 | 1 | 0.07641 | 1 |
| LN III | 0.13472 | 1 | 0.53294 | 4 | 0.11266 | 4 |
| LP III | 0.40135 | 4 | 0.23859 | 2 | 0.08969 | 2 |
| | | | Gob | | | |
| | Statistic | Rank | Statistic | Rank | Statistic | Rank |
| Gumbel | 1.07340 | 3 | 0.41658 | 2 | 0.07808 | 1 |
| GEV | 0.16408 | 2 | 0.29230 | 1 | 0.08797 | 2 |
| LN III | 0.15854 | 1 | 0.57801 | 3 | 0.10428 | 3 |
| LP III | 4.33760 | 4 | 0.59337 | 4 | 0.11686 | 4 |

| | Statistic | Rank | Statistic | Rank | Statistic | Rank |
|---|---|---|---|---|---|---|
| **Balai Polis** | | | | | | |
| Gumbel | 2.1324 | 3 | 1.1832 | 3 | 0.16477 | 4 |
| GEV | 0.56441 | 1 | 0.27232 | 2 | 0.12047 | 2 |
| LN III | 1.1282 | 2 | 0.31838 | 1 | 0.11003 | 1 |
| LP III | NA | NA | 4.5982 | 4 | 0.12923 | 3 |
| **Gemala** | | | | | | |
| Gumbel | 0.68357 | 3 | 0.62265 | 3 | 0.12054 | 3 |
| GEV | 0.39036 | 2 | 0.28992 | 2 | 0.08899 | 1 |
| LN III | 0.35129 | 1 | 0.22867 | 1 | 0.0941 | 2 |
| LP III | NA | NA | 11.462 | 4 | 0.15068 | 4 |
| **Aring** | | | | | | |
| Gumbel | 1.3629 | 4 | 0.3038 | 4 | 0.09153 | 3 |
| GEV | 0.70617 | 1 | 0.17893 | 1 | 0.08823 | 2 |
| LN III | 0.76292 | 2 | 0.29573 | 3 | 0.09525 | 4 |
| LP III | 1.3014 | 3 | 0.21392 | 2 | 0.08561 | 1 |
| **Laloh** | | | | | | |
| Gumbel | 0.47239 | 1 | 0.31804 | 2 | 0.09554 | 4 |
| GEV | 0.54835 | 2 | 0.21489 | 1 | 0.06562 | 3 |
| LN III | 0.95823 | 4 | 0.70164 | 4 | 0.10971 | 2 |
| LP III | 0.70147 | 3 | 0.4321 | 3 | 0.10757 | 1 |
| **Ulu Sekor** | | | | | | |
| Gumbel | 4.09 | 4 | 0.64273 | 4 | 0.13132 | 4 |
| GEV | 1.5348 | 3 | 0.18024 | 1 | 0.08074 | 1 |
| LN III | 0.1895 | 1 | 0.23191 | 3 | 0.08179 | 3 |
| LP III | 0.94395 | 2 | 0.18451 | 2 | 0.08142 | 2 |
| **Kuala Krai** | | | | | | |
| Gumbel | 0.84624 | 3 | 0.43593 | 4 | 0.09522 | 4 |
| GEV | 0.10066 | 1 | 0.11066 | 1 | 0.05782 | 1 |
| LN III | 0.75174 | 2 | 0.23921 | 3 | 0.08127 | 3 |
| LP III | 1.0355 | 4 | 0.12711 | 2 | 0.07119 | 2 |
| **Jeli** | | | | | | |
| Gumbel | 6.202 | 2 | 0.69774 | 2 | 0.12026 | 1 |
| GEV | NA | NA | 0.09641 | 1 | 4.0506 | 4 |
| LN III | 1.7025 | 1 | 1.7034 | 3 | 0.1742 | 2 |
| LP III | NA | NA | 5.5432 | 4 | 0.22144 | 3 |
| **Durian** | | | | | | |
| Gumbel | 1.24470 | 4 | 0.43812 | 3 | 0.10224 | 3 |
| GEV | 0.63269 | 2 | 0.18809 | 1 | 0.06136 | 1 |
| LN III | 0.65593 | 3 | 0.68442 | 4 | 0.13228 | 4 |
| LP III | 0.46422 | 1 | 0.19223 | 2 | 0.06572 | 2 |
| **Bendang** | | | | | | |
| Gumbel | 0.97656 | 1 | 0.64703 | 4 | 0.14037 | 3 |
| GEV | 4.0103 | 4 | 0.37096 | 1 | 0.09140 | 1 |
| LN III | 3.1962 | 3 | 0.49600 | 3 | 0.84893 | 4 |
| LP III | 2.5475 | 2 | 0.49394 | 2 | 0.11038 | 2 |
| **Air Lanas** | | | | | | |
| Gumbel | 0.80590 | 2 | 0.25018 | 3 | 0.08874 | 3 |
| GEV | 0.72678 | 1 | 0.15256 | 1 | 0.06691 | 1 |
| LN III | 0.95158 | 3 | 0.52347 | 4 | 0.74801 | 4 |
| LP III | 0.97433 | 4 | 0.18143 | 2 | 0.08155 | 2 |
| **Rumah** | | | | | | |
| Gumbel | 1.09720 | 4 | 1.09130 | 4 | 0.13194 | 4 |
| GEV | 0.15123 | 3 | 0.16855 | 1 | 0.08147 | 1 |
| LN III | 0.13973 | 2 | 0.21310 | 3 | 0.08460 | 2 |
| LP III | 0.12582 | 1 | 0.20893 | 2 | 0.09334 | 3 |

$$\delta^2{}_S = [n(n-1)(2n+5) - \sum_{i=I}^{m} t(i)(i-1)(2i+5)]/18 \quad (9)$$

Eq. (9) gives the variance of $S$ with a correction for ties in data with $t_i$ denoting the number of ties of extent $i$. The standard normal variate is then used for hypothesis testing, and is called here the trend test statistic $Z$.

$$Z = \begin{cases} \frac{S-1}{\sigma_S}\ If\ S > 0 \\ 0\ If\ S = 0 \\ \frac{S+1}{\sigma_S}\ If\ S < 0 \end{cases} \quad (10)$$

the slope. Sen slope estimator is used to quantify the slope of the trend, if the null hypothesis is rejected. [36] and [37] reported that the estimator can be used to depict the quantification of change per unit time. The slope estimates $Q_i$ of $N$ pairs of data are calculated as equation below:

$$Q_i = (x_j - x_k)/(j - k) \quad (11)$$

Where $N$ is the values of slopes ranked from the smallest to the largest. If $N$ is odd, Sen's slope is calculated as follows:

$$Q_{median} = Q(N+1)/2 \quad (12)$$

If $N$ is even, the estimator arises from the equation below;

$$Q_{medium} = Q = [Q_{\frac{N}{2}} + Q_N + \tfrac{2}{2}] \quad (13)$$

## 3.0 RESULTS AND DISCUSSION

### 3.1 Missing Data Analysis

The normal ratio method was used to compute the missing data in this study. Results for this analysis are presented in Tables 1-3. Of the seventeen rainfall stations used in this study, only 3 stations were found with missing data namely; Jeli with three years missing data while Aring and Gob both have a year missing from the rainfall record. Completed data after treatment is presented in Table 3. The minimum and maximum rainfall over the period of 31 years in all the stations before and after treating the missing data were found in both Gemala (114.00 mm) and Gunung Gagau (5396.50 mm) respectively as shown in table 1 and 2. Mean values of both pre-treated and post treated data in all the stations ranged from 1747.50-3648.65 mm with treated stations having slightly higher values compared to the untreated station. In the case of standard deviation, values obtained from Jeli (station with the highest missing value) higher record were recorded in 'before treatment' scenario (1047.62 mm) than 'after treatment' scenario (1001.82 mm). The same applies to Aring and Gob, which are also stations with missing data.

For a two-tailed test, the null hypothesis is rejected at significance level '$a$' (Type I error). If $|Z| > Z_{\propto/2}$, where $Z_{\propto/2}$ is the value of the standard normal distribution with an exceedance probability $a/2$. If the null hypothesis is rejected, the Man-Kendall test revealed that there is upward trend then the true slope may be estimated by computing the least square estimate of

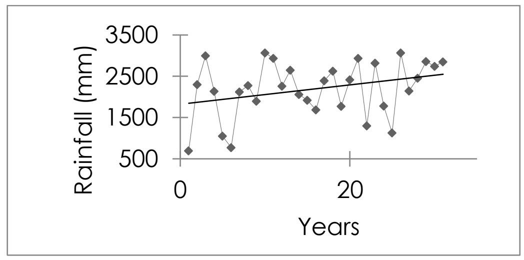



**Figure 1** Graph showing precipitation trend from Laloh

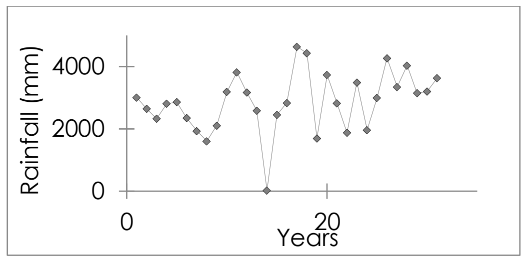



**Figure 2** Graph showing precipitation trend from Rumah

### 3.2 Descriptive Statistics

Descriptive analysis was carried out on the treated data after missing data analysis and the results obtained are presented in Table 4. The thirty-one rainfall data was analyzed for descriptive statistics such as range, first quartile, median, third quartile, variance, skewness ($C_s$), kurtosis ($C_k$) and standard error of mean (SEM). Data quality control such as mean and standard deviation were carried out as an essential step before analyses, because erroneous outliers can seriously have an effect on the trends [38]. Range value for Blau, Bali Polis, Gob, Dabong, Laloh, Ulu Sekor and Kuala Krai are all in the window of 2255.50-2842.00 mm. In Gua Musang and Aring stations, range values of 1705.50 mm and 1948.50 mm were obtained respectively. The highest and the lowest values for the first quartile, median and third quartiles were obtained from Gunung Gagau (3137.45 mm, 3814.70 mm and 4374.25 mm) and Gemala stations (1355.50 mm, 1732.50 mm and 2424.75 mm respectively) in that order. These stations are free from missing data. Results of the $C_s$ performed using $F$ test revealed that all the stations give a positive skewness with exception of Brook (-0.41) where a negative skewness was obtained. In the case of $C_k$ which was also calculated using $F$ test, values obtained in most of the stations are predominantly positive with few exceptions where negative values were recorded. These exceptions include Gob (-0.71), Laloh (-0.23), Ulu

Sekor (-0.36), Kuala Krai (-0.60), Durian (-0.33), Bendang (-0.61) and Air Lanas (-0.08). SEM values for all the stations are in the class of 69.51-201.53. Gunung Gagau (201.53) having the highest and Gua Musang (69.51) being the lowest.

In the case of AMF data (Table 5) a negative $C_s$ and kurtosis were obtained from Kuala Krai and Pergau and a positive $C_s$ for Galas and Nenggiri. Data quality control such as mean and standard deviation were also carried out on this data as an essential step before analyses, because erroneous outliers can seriously have an effect on the trends [39].

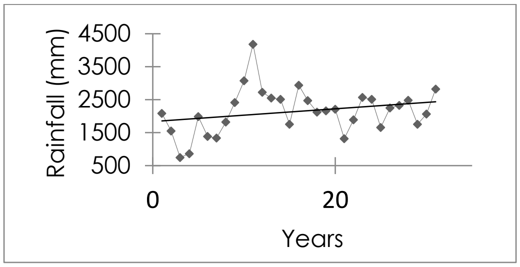



**Figure 3** Graph showing precipitation trend from Brook

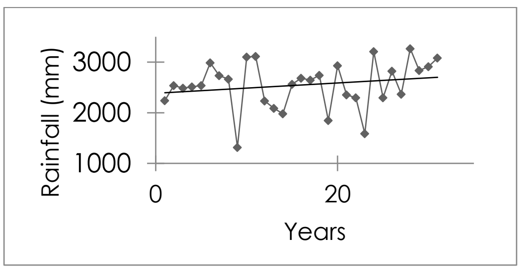



**Figure 4** Graph showing precipitation trend from Aring

### 3.3 Identification of best fit probability distribution

The results of the three goodness of fit mentioned above were fitted on the annual maximum rainfall data and the results are shown on Table 6. It was observed that all distributions were acceptable to fit to the data at the significant level, $\alpha$ of 0.05. Even though, there is no clear trend as to which distribution parameter was found to be dominant in all other locations. While Gumbel fitted well in some locations, GEV, LN III, LP III fitted better in other locations. In Table 6 where the results of 6 stations were reported namely; Blau, Brook, Gua Musang, Gunung Gagau, Dabong and Gob. It was observed in Blau LP III ranked first in chi-square, while it was in Brook GEV for Brook. For A-D test, Gumbel fitted better for Blau and GEV for K-S. In Brook, LN III distribution parameter fitted better for both A-D and K-S test. With the exception of K-S both chi-square and A-D tests were ranked first by Gumbel distribution parameter in both Gua Musang and Gunung Gagau. The results of both chi-square, A-D and K-S were similar to each other in both Dabong and Gob (Table 6). In these locations, LN III fitted best in chi-square, GEV in A-D and K-S for Dabong and Gumbel distribution was found to fit better in Gob.

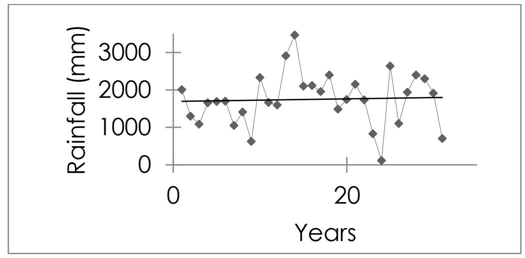



**Figure 5** Graph showing precipitation trend from Gemala

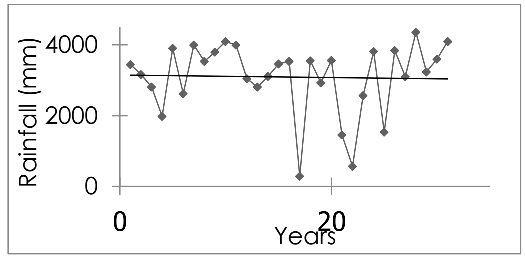



**Figure 6** Graph showing precipitation trend from Jeli

### 3.4 Precipitation Trend Analysis Using Mann-Kendall test and Sen Slope Estimator

Mann-Kendall non-parametric test was applied to the annual maximum series of 24-hour precipitation and the AMF data to verify increasing or decreasing trends. The Kendall *S* and *Z* statistics were calculated on the 31-year annual data (1984-2010). Figures 1-17 and 18-21 shows the graphical presentation of annual maximum series of 24-hour precipitation and the AMF data respectively. Table 7 and 8 present the Mann-Kendall's non-parametric tests results, as well as an estimate in the computed test statistics and its associated *P* value. *P* values are the smallest level of significance (5%) at which null hypothesis will be rejected. In this study, the null hypothesis is that there is no trend in the available data.

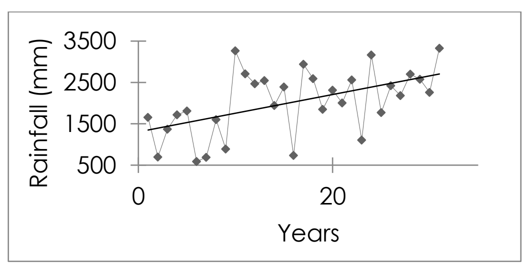



**Figure 7** Graph showing precipitation trend from Gob

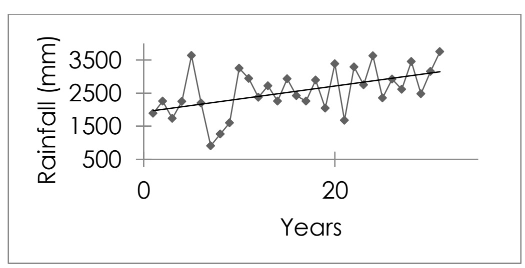



**Figure 8** Graph showing precipitation trend from Ulu Sekor

Trend analysis for the rainfall data (Table 7) was found to be statistically non-significant in twelve of the seventeen stations analysed in this study (Brook, Blau, Gunung Gagau, Gua Musang, Aring, Gemala, Balai Polis, Dabong, Laloh, Kuala Krai, Jeli and Durian). While a statistically significant trend (95%) was obtained for the five stations. These results coincide with the findings of previous researchers in the same location who obtained similar findings of non-significant trends on stations located on the downstream of Kelantan river basin namely Gunung Gagau, Aring, Laloh and Kuala Krai [39]. All the values for Kendall's tau were recorded to be positive except for Gua Musang which was found to be -0.002. Highest value was found in Gob (0.36) while the lowest was found in Balai Polis (0.03).

**Table 7** Mann-Kendall results for the Annual maximum 24-hour precipitation data

| Rainfall Stations | Unit | Kendall's tau | *S* | p-value (two-tailed) | Sen's slope | Level of significance |
|---|---|---|---|---|---|---|
| Brook | mm | 0.17 | 77.00 | 0.20 | 18.52 | NS |
| Blau | mm | 0.14 | 66.00 | 0.27 | 10.24 | NS |
| Gunung Gagau | mm | 0.23 | 108.00 | 0.07 | 42.83 | NS |
| Gua Musang | mm | -0.00 | -1.00 | 1.00 | -0.18 | NS |
| Aring | mm | 0.19 | 87.00 | 0.15 | 13.18 | NS |
| Gemala | mm | 0.10 | 45.00 | 0.46 | 9.58 | NS |
| Balai Polis | mm | 0.03 | 12.00 | 0.85 | 1.80 | NS |
| Gob | mm | 0.36 | 165.00 | 0.01 | 42.03 | * |
| Dabong | mm | 0.23 | 107.00 | 0.07 | 25.88 | NS |
| Laloh | mm | 0.19 | 89.00 | 0.14 | 20.69 | NS |
| Lulu Sekor | mm | 0.35 | 161.00 | 0.01 | 41.50 | * |
| Kuala Krai | mm | 0.13 | 59.00 | 0.33 | 18.11 | NS |
| Jeli | mm | 0.08 | 35.00 | 0.57 | 5.10 | NS |
| Durian | mm | 0.23 | 105.00 | 0.08 | 31.28 | NS |
| Bendang | mm | 0.33 | 151.00 | 0.01 | 48.50 | * |
| Rumah | mm | 0.25 | 115.00 | 0.05 | 34.59 | * |
| Air Lanas | mm | 0.25 | 117.00 | 0.05 | 39.28 | * |

*S*=Mann Kendal statistics or Kendall score; NS = not significant at 5% level probability *= significant at 5% level probability

**Table 8** Mann-Kendall results for the AMF data

| Stations | Unit | Kendall tau | *S* | p-value (two-tailed) | *Q* | Level of significance |
|---|---|---|---|---|---|---|
| Kuala Krai | $m^3/s$ | 0.398 | 10.47 | 0.003 | 0.45 | * |
| Galas | $m^3/s$ | 0.214 | 11.70 | 0.095 | 0.35 | * |
| Pergau | $m^3/s$ | 0.479 | 7.73 | 0.0004 | 0.30 | * |
| Nenggiri | $m^3/s$ | 0.587 | 8.66 | 0.00001 | 0.21 | * |

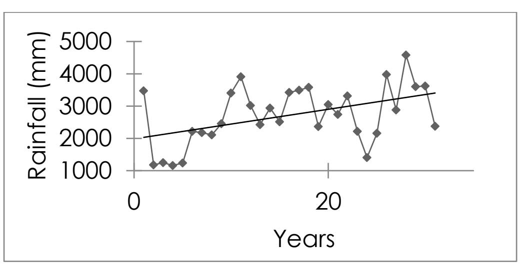



**Figure 9** Graph showing precipitation trend from Bendang

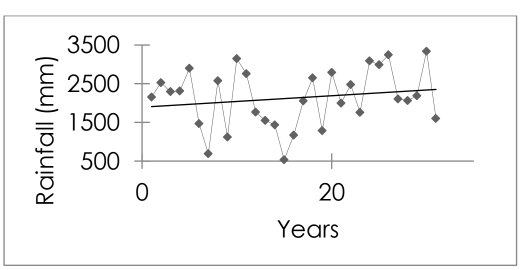



**Figure 10** Graph showing precipitation trend from Kuala Krai

Trend analysis for the AMF data is presented in Table 7. An increasing trend which is statistically significant (5% probability level) was obtained for all the locations under study. The Kendall tau values for the AMF data were all positive. The values obtained ranged from 0.214-0.587. The highest and lowest *S* values were obtained from Pergau (7.73) and Galas (11.70) respectively.

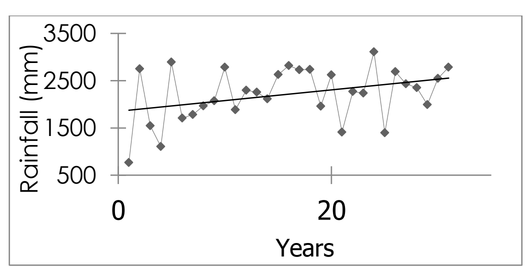



**Figure 11** Graph showing precipitation trend from Dabong

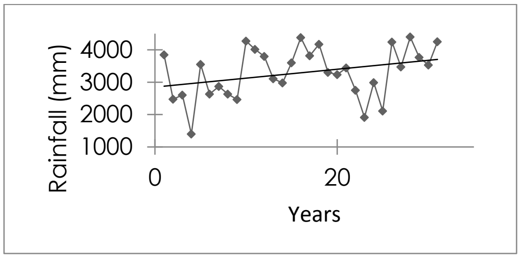



**Figure 12** Graph showing precipitation trend from Durian

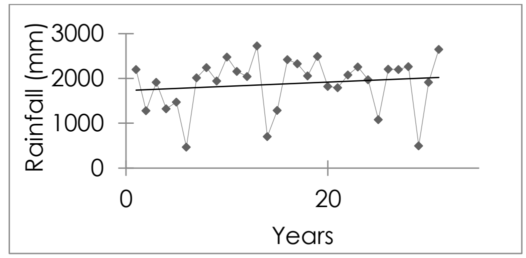



**Figure 15** Graph showing precipitation trend from Blau

Sen slope estimator was employed following the Mann Kendall test to figure out the change per unit time of the trends observed in all precipitation time series. Outputs are presented in Table 7 and 8 for the AMS of 24-hour precipitation and AMF data. A negative Q value represents a downward slope and a positive sign indicates an upward one. With the exception of Gua Musang, all other sixteen stations exhibit an upward trend in the 24-hour precipitation. A statistically non-significant upward slope approximates an increase of 42.83 mm/hydrologic year in Gunung Gagau while statistically non-significant upward slope of 48.50 mm/hydrologic year is estimated in Bendang. In Gua Musang where the Sen's slope value is negative, statistically non-significant reduction in rainfall of about -0.18 mm/hydrologic year is expected from that station.

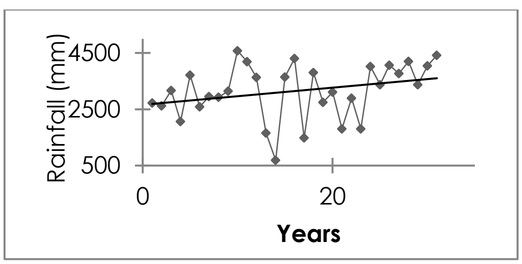



**Figure 13** Graph showing precipitation trend from Air Lanas

While in the case of AMF data where a statistically significant upward slope was obtained. An increase of 0.39 mm/hydrologic year from Kuala Krai and 0.24 mm/hydrologic year for Galas represents the approximate annual maximum flood increase.

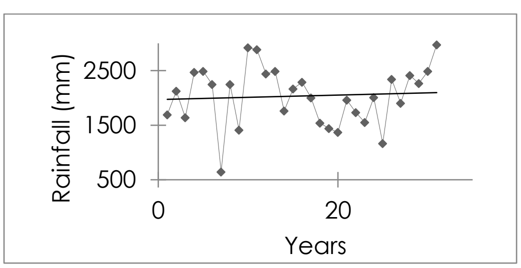



**Figure 14** Graph showing precipitation trend from Balai Polis

## 4.0 CONCLUSIONS

The results of rainfall analysis for identifying the best fit probability distribution revealed that the distribution pattern for different data sets can be identified out of a large number of commonly used probability distributions by using different goodness of fit tests. Owing to the fact that no clear PDP appears to be the dominant one in all the stations, all data from all the stations fitted well with both chi-square, A-D and K-S tests.

The Mann–Kendall test was employed to detect annual trends in precipitation and AMF data. Both statistically non-significant increasing and statistically significant increasing trends were obtained for the annual maximum series of 24-hour precipitation and statistically significant increasing trends AMF data respectively. This confirms the increasing flood prone nature of these locations.

Twelve of the seventeen precipitation stations analyzed for trend analysis were found be statistically non-significant at 95% level of probability. The other 5 were found to be statistically significant also at 95% level of probability.

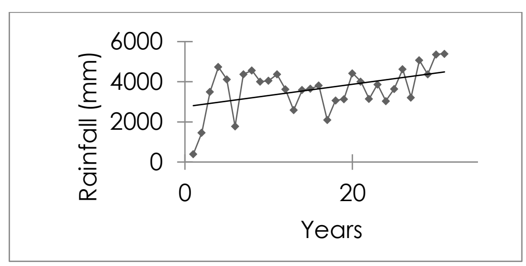



**Figure 16** Graph showing precipitation trend from Gunung Gagau

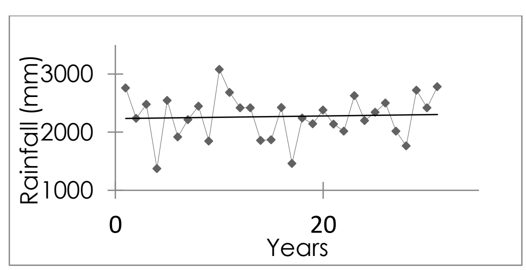



**Figure 17** Graph showing precipitation trend from Gua Musang

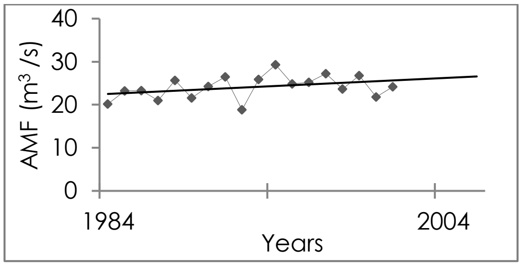



**Figure 18** Graph showing trend of AMF from Kuala Krai

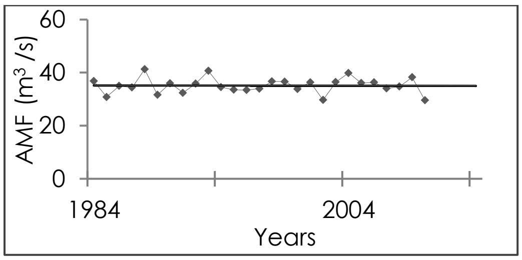



**Figure 19** Graph showing trend of AMF from Galas

The statistically non-significant increasing slope of the precipitation data in most of the stations signifies no climate change occurrence that will significantly influence the rainfall regime in these locations during the period under review. While statistically significant increasing slope of the rainfall data in some few stations will make us to suggest climate change occurrence. The 2014 flood which is a rare extreme event caused by large amount of precipitation, one event is not enough to draw conclusions about the possible occurrence of climate change. As several studies have reported topography, soil and land use/land cover (LULC) as the most significant factors influencing rainfall-runoff patterns for a single flood event in drainage basins. While soil and topography appeared to have insignificant effect in the short term flood event, LULC are considered to be the most significant and key factors affecting rainfall-runoff behavior over a long period. Thus, some uncertainty still remains until a comprehensive LULC study of the area under study and its impact on the hydrologic regimes is carried out (a study currently undergoing by the authors). As LULC may have played a key role in the recent floods that have occurred in the Kelantan river basin. Owing to the claims made by several people that illegal logging and unrestricted land cover conversion without consideration of environmental repercussions, has alters natural hydrologic systems of the basin.

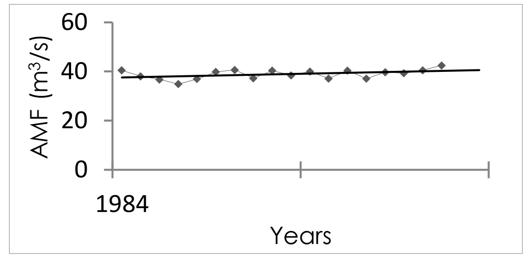



**Figure 20** Graph showing trend of AMF from Pergau

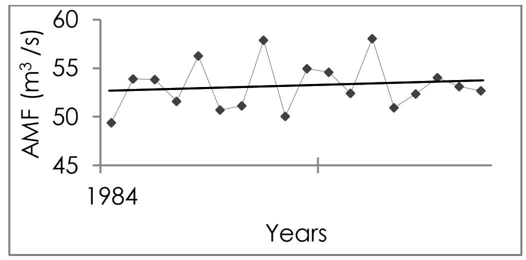



**Figure 21** Graph showing trend of AMF from Nenggiri

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