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Trend Analysis of Rainfall and the Standardised Precipitation Index (SPI) in Johor

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Abstract: Johor has experienced a number of flood events including a recent severe flood. The objectives of this study were to analyse the trend analysis of rainfall at eight (8) selected stations in Johor area and to investigate the annual trend of dry and wet events. Rainfall data from 1980 to 2017 was obtained from the Department of Irrigation and Drainage (DID), Malaysia. Mann-Kendall test is the non-parametric test had been used in this study to analyse the trend analysis of rainfall and Standardised Precipitation index (SPI) was applied to classify the dry and wet events. Temporal trend in the rate of occurrence of dry and wet events (inter-arrival times) were also examined. The results shows that five (5) stations namely Ladang Paya Lang in Segamat, Ladang Sungai Tiram in Johor Bahru, Stor JPS Batu Tiga in Mersing, Ladang Permatang in Kota Tinggi and Stor JPS in Endau stations often having dry events and less wet events. It was observed that most of the stations showed decreasing trend in rainfall and downward trend in SPI analysis. The benefit of investigating the annual trend of dry and wet events is for analysis and comparison with historical events such as drought and flood and community can be prepared and be able to adapt the drought and flood events in the future.

Keywords: Climatic Impact, Trend Analysis, Mann-Kendall, SPI

1. Introduction

Malaysia's climate is characterised during the year by monsoonal sunny and rainy days, with an average annual rainfall of 250 cm. However, the characteristics and patterns of rain have been influenced by global warming, which has resulted in a wide range of meteorological situations [1]. The global warming impacted many natural systems, which include changes in rainfall regime and increase the risks of flooding [2]. The primary factors that control the occurrence and persistence of droughts

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and floods is rainfall. Droughts and floods are extreme events that can have a negative effect on social, economic, political, cultural and others [3].

Malaysia experiences changes in rainfall regimes. The global warming impacted many natural systems and among of the major impacts of global warming are the increased frequency and intensity of extreme rainfall events [4]. Johor is one of the areas in Malaysia that experienced heavy rainfall and affected by floods during monsoon seasons. Johor also often having extreme rainfall that lead to flash flood. Flash flood is common in urban areas including Kuala Lumpur, Butterworth, Kota Bharu, and especially Johor Bahru. Flooding will occur faster and more severely in an urban region than in the suburbs or in the countryside. In urban areas, impervious surfaces prevent water from infiltrating the earth, and water quickly flows off to low regions. The variability of climatic variables such as rain should be studied for better severe weather impact preparedness. The rainfall analysis needs to be studied to find out the trend, hence could be predicted in the future. Therefore, the purposes of this research were to analyse the trend analysis of rainfall at selected rainfall stations in Johor area and to investigate the annual trend of dry and wet events of the selected stations using Standardised Precipitation Index (SPI).

Malaysia as a tropical country has the hydrological system that are very sensitive to the changes in rainfall pattern. It has been recorded that the amount and intensity of rainfall has increased over the years due to climate change in Malaysia. This is already evident in Peninsular Malaysia from the recent episodes of floods [8]. In Johor, flooding is the most common hydro-meteorological hazard, and it occurs regularly during the northeast monsoon (NEM). On 24 Jun 2020, the extreme rainfall resulting in the severe flood in Johor [10]. Then, on 22 Nov 2020, Johor Bahru experienced another severe flooding [11]. Johor has not yet experienced severe drought. However, the Johor River Basin (JRB) has experienced some past hydro-meteorological droughts. JRB's drought experiences are classified as meteorological drought since they lasted between one and three months. The meteorological drought events in JRB have caused a water shortage problem, affecting both Johor and Singapore's growth, due to increased population, economic expansion, and climate change [9].

2. Data and Method

2.1 Study Area

Johor is located in the southern region of the Malaysia, between latitudes 1° 20"N and 2° 35"N. Johor has an area of 19,210 km^2 and has a humid tropical climate that blows from the South China Sea with monsoon rain from November to March. The average annual rainfall received by Johor is 2355 mm with temperatures ranging from 25.5°C to 27.8°C [5]. The daily rainfall was obtained from eight (8) stations in Johor area. The locations and details are shown in Table 1. The amount of missing data was calculated using in-filling missing data methods.

Table 1: Selected rainfall stations in Johor

No	Station	Station Number
1	Kajicuaca Mersing	2438185
2	Ladang Getah Malaya, Kota Tinggi	1738131
3	Ladang Paya Lang, Segamat	2527004
4	Ladang Segamat, Segamat	2428011
5	Stor JPS Batu Tiga, Mersing	2438001
6	Ladang Permatang, Kota Tinggi	1739003
7	Ladang Sungai Tiram, Johor Bahru	1539134
8	Stor JPS Endau	2636170

2.2 In-filling Missing Data Method

There are two commonly used data in-filling methods, which is the arithmetic mean method and the normal ratio method. These methods were applied to calculate the missing monthly rainfall data of the selected rainfall stations.

2.2.1 Arithmetic Mean Method

$$P_x = \frac{1}{n}\sum_{i=1}^{n} P_i \quad \text{Eq.1}$$

Where P_x is the estimate of the missing value (mm), P_i is the rainfall values of rain gauges (mm), and n is the number of surrounding stations.

2.2.2 Normal National Method

$$P_x = \frac{1}{n}\sum_{i=1}^{n} \left[\frac{N_x}{N_i}\right] P_i \quad \text{Eq.2}$$

Where P_x is the estimate of the missing value (mm), P_i is the rainfall values of rain gauges used for estimation (mm), n is the number of surrounding stations, N_x is the mean annual precipitation of X station (mm), and N_i is the mean annual precipitation of surrounding station (mm).

2.3 Mann-Kendall Test

The Mann-Kendall test which is also known as Kendall's tau test is one of the non-parametric tests. This test has been used in various research to see if there is a monotonic pattern in hydro-meteorological data including temperature, rainfall, and streamflow. The benefit of this test is no prior data assumption is needed [4]. One of the advantages of non-parametric test is the data do not require to track any specific distribution. The formulae for this test are as follows:

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} sgn(x_k - x_i) \quad \text{Eq.3}$$

For a time-series { x_i: i = 1, 2, …, $n-1$}, the and { x_k: $k = i+1$, 2, …,n }, where

$$sgn(\theta) = \begin{cases} +1 & ;\theta < 0 \\ 0 & ;\theta = 0 \\ -1 & ;\theta > 0 \end{cases} \quad \text{Eq.4}$$

Normalized test statistic is computed by the follow equation:

$$Z = \begin{cases} \frac{(S-1)}{\sqrt{Var(S)}} & ;S > 0 \\ 0 & ;S = 0 \\ \frac{(S+1)}{\sqrt{Var(S)}} & ;S < 0 \end{cases} \quad \text{Eq.5}$$

The test statistic Z is used to measure the significant of the trend. To test for either a decrease or increase in monotonic trend (two-tailed test) at α level of significance, H_0 should be rejected if the |*Z*| > *Z1-α/2*, where Z1-*α/2* is obtained from the standard normal cumulative distribution tables. For example, at the 5% significance level, the null hypothesis is rejected if |Z| > 1.96.

2.4 Standardised Precipitation Index (SPI)

McKee and his colleagues at Colorado State University created the Standardised Precipitation Index (SPI) to quantify the precipitation deficit over several time scales [6]. In SPI calculations, the gamma distribution is usually assumed to be fitted [6], Weibull distribution is identified as a heavy-tailed distribution in precipitation fitting [3], while the best-fitted distribution for subsequent SPI computation is confirmed to be the lognormal distribution [7]. If the gamma distribution is used:

$$g(x) = \frac{1}{\beta^{\alpha}\,\Gamma(\alpha)}\; x^{a-1}e^{-x/\beta} \qquad \text{Eq.6}$$

In which α is a shape parameter (α>0), β is the scale parameter (β>0), x is the effective precipitation value ($x > 0$) and $\Gamma(\alpha)$ is the gamma function, express as:

$$\int_0^{\infty} y^{\alpha-1}e^{-y}dy \qquad \text{Eq.7}$$

$$\alpha = \frac{1+\sqrt{1+\frac{4A}{3}}}{4A} \qquad \text{Eq.8}$$

$$\beta = \frac{\bar{\mathrm{x}}}{\alpha} \qquad \text{Eq.9}$$

In which,

$$A = ln(\bar{\mathrm{x}}) - \frac{\sum ln(\bar{\mathrm{x}})}{n} \qquad \text{Eq.10}$$

n = the number of observations.

The cumulative probability $G(x)$ of a precipitation event is,

$$G(x) = \int_0^{\infty} g(x)\,dx = \frac{x^{a-1}e^{-x/\beta}dx}{\beta^{\alpha}\,\Gamma(\alpha)} \qquad \text{Eq.11}$$

And letting $t = x/\beta$. Equation (3.14) becomes the incomplete gamma function:

$$G(x) = \frac{\int_0^{\infty} t^{a-1}\, e^{-t}dx}{\Gamma(\alpha)} \qquad \text{Eq.12}$$

Given that gamma distribution is not defined for $x = 0$, the following formulation is used to account for the cumulative probability of zero effective precipitation (q) [6],

$$H\,(x) = q + (1-q)\,G(x) \qquad \text{Eq.13}$$

The cumulative probability distribution is transformed into a normal distribution for the purpose of calculating the SPI using the following approximation:

$$\mathrm{SPI} = -\,(\mathrm{t}-\frac{C_{0+}\,C_1t+\,C_2t^2}{1+d_{1t}+d_2t^2+d_3t^3}),0 < H(x) \leq 0.5 \qquad \text{Eq.14}$$

$$t = \sqrt{\ln(1/H(x)^2} \qquad \text{Eq.15}$$

$$SPI = (\mathrm{t} - \frac{C_{0+}\,C_1t+\,C_2t^2}{1+d_{1t}+d_2t^2+d_3t^3}),\, 0.5 < H(x) \leq 0.5 \qquad \text{Eq.16}$$

$$t = \sqrt{\ln(1/[\,1-H(x)^2]}$$

With the following constant values: Eq.17

C_0= 2.515517, C_1= 0.802853, C_2= 0.010328, d_1= 1.43278, d_2= 0.189269, d_3= 0.001308

The classification system of SPI values shown in the Table 2. A dry event is defined as a time during which the SPI is consistently negative, reaches a value of -1.0 or below, and then returns to a positive value [6]. While, wet event is defined as a time which SPI is consistently positive, reaches a value of 1.0 or above and then returns to a negative value.

Table 2: The Standardised Precipitation Index (SPI) categories based on the initial classification of SPI values

SPI Values	Categories
-2 and less	Extreme Dry
-1.5 to -1.99	Severely Dry
-1.0 to -1.49	Moderate Dry
0.99 to -0.99	Normal
1.0 to 1.49	Moderate Wet
1.5 to 1.99	Severely Wet
2 and above	Extreme Wet

2.5 Software Application

In this study, the technique applied for trend analysis was by using Minitab (Minitab Inc.2017). Trend analysis was performed to determine the trends in the rainfall data. Next, the SPI Generator application serves to generate SPI data. SPI was used to investigate the trend analysis of dry and wet events. The application reads in precipitation data and supports different time scales and data types (weekly, monthly).

3. Results and Discussion

3.1 Trend Analysis of Rainfall

In this study, the trend analysis was carried out by using Minitab (MinitabInc.2017). All monthly rainfall data were collected at all the selected stations. The analyses were carried out using more than 30 years of rainfall data, as well as a short sub-set period (1980-2017).

Table 3 presents the results of rainfall patterns obtained from Mann-Kendall test for all stations. Kajicuaca in Mersing, Ladang Getah Malaya in Kota Tinggi and Ladang Segamat in Segamat stations showed insignificant increasing trends with Kendall's tau (Z) values of 0.694, 0.018 and 0.014, respectively. For Ladang Paya Lang in Segamat, Stor JPS Batu Tiga in Mersing, Ladang Permatang in Kota Tinggi, Ladang Sungai Tiram in Johor Bahru and Stor JPS in Endau stations, there were decreasing trend in rainfall. The Kendall's (Z) values obtained from MK trend test for the stations were -0.234, -0.207, -0.321, -0.027 and -0.081 respectively. Figure 3 presents the trend analysis of rainfall for Station Kajicuaca Mersing.

Table 3: Mann-Kendall test values and trends

No	Stations	Kendall's tau	Trend
1	Kajicuaca Mersing	0.694	Increase
2	Ladang Getah Malaya, Kota Tinggi	0.018	Increase
3	Ladang Paya Lang, Segamat	-0.234	Decrease
4	Ladang Segamat, Segamat	0.014	Increase
5	Stor JPS Batu Tiga, Mersing	-0.207	Decease
6	Ladang Permatang Kota Tinggi	-0.321	Decrease
7	Ladang Sungai Tiram, Johor Bahru	-0.027	Decrease

8	Stor JPS Endau	-0.081	Decrease

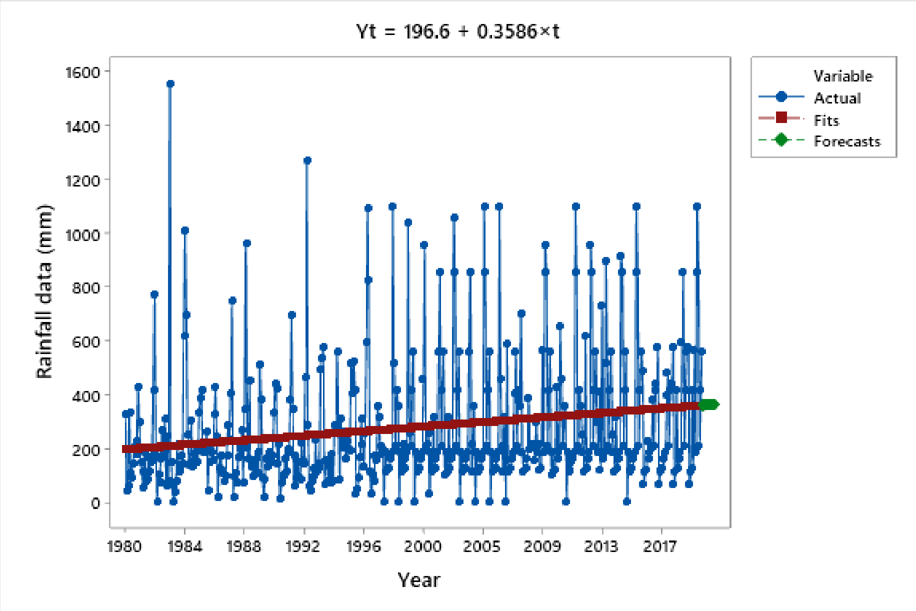

Figure 3: Trend analysis result of rainfall for Station Kajicuaca Mersing

3.2 Trend Analysis of Dry and Wet Events using Standardised Precipitation Index (SPI)

To evaluate if this region has undergone wet or dry events, the trend analysis technique for time scale 12-months of SPI was applied to eight (8) stations in this study. Figure 4 showed the cumulative results of dry and wet conditions based on the SPI values at Station Kajicuaca in Mersing. The two horizontal lines at SPI values of 1.0 and 1.0, respectively, represent thresholds for each dry and wet event. The highest positive SPI values were on November to early March every year. This showed that heavy rainfall often happened during these months every year.

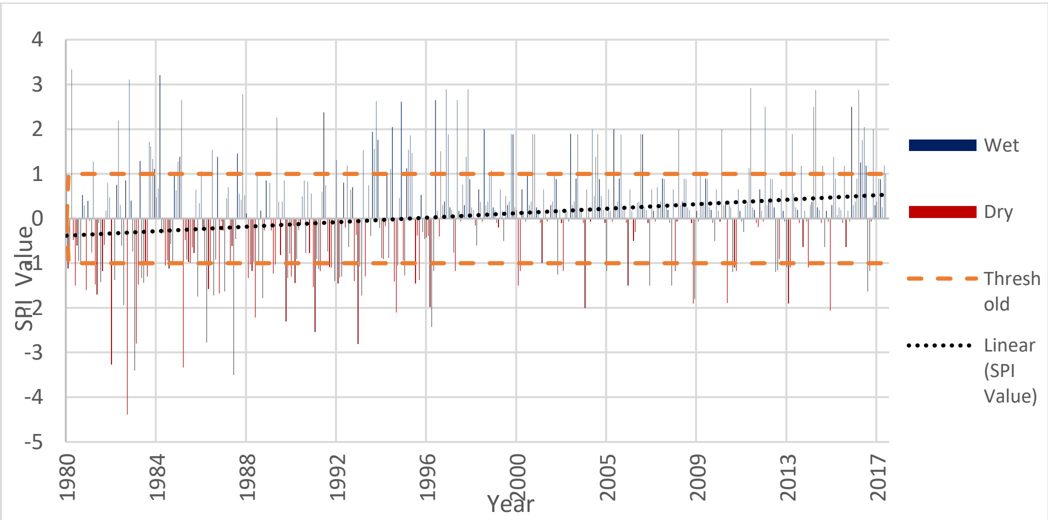

Figure 4: Station Kajicuaca Mersing

Despite the fact that Malaysia has a tropical climate with wet conditions throughout the year, it has been discovered that the percentage of stations with drier conditions ranges from 26 to 27 %, compared to just 20 to 23 % of stations with higher wet conditions. From the analysis, the stations that showed a decreasing trend in SPI indicated an increase in the number of dry events. While, stations which showed upward trend indicated the increasing in the number of wet events. As a result, this condition may imply that severe dry conditions are slightly more common than extreme wet conditions during extreme weather events.

3.3 Temporal Trend in Dry and Wet Events

The dry and wet inter-arrival time was determined for all eight (8) stations. The results of Station Kajicuaca Mersing are plotted in Figures 5 and 6.

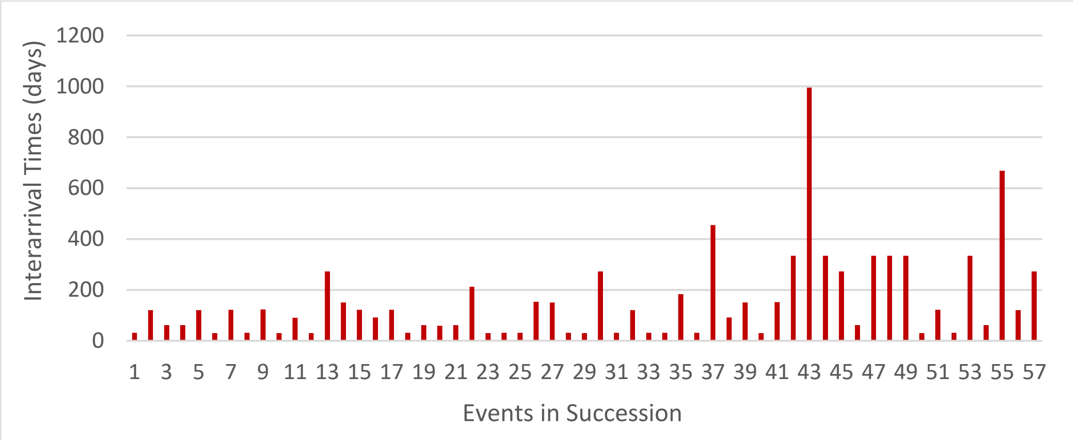

Figure 5: Recurrence intervals of dry events at Station Kajicuaca Mersing

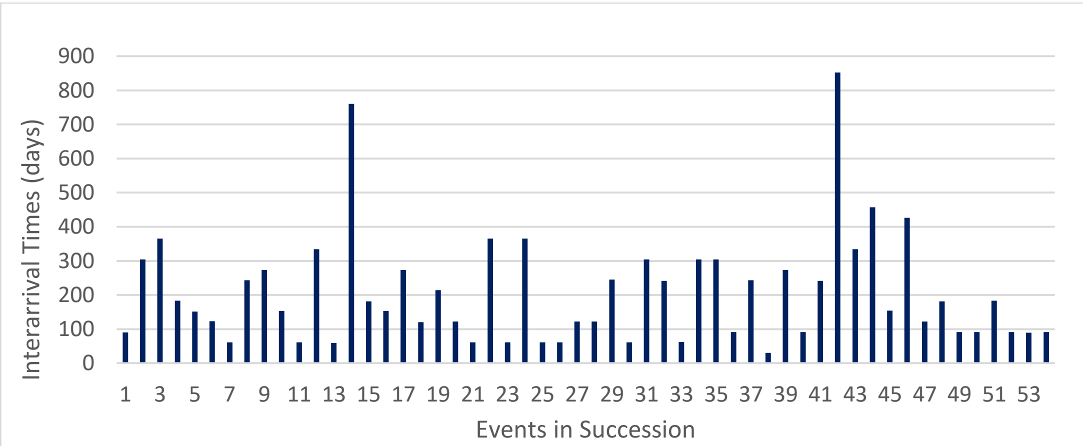

Figure 6: Recurrence interval of wet events at Station Kajicuaca Mersing

Table 4 shows the results of dry and wet inter-arrival times for all stations. Based on the results, the minimum days of inter-arrival for dry and wet events were 28 and 20 days, respectively. While, the maximum days of inter-arrival for dry and wet events were 1034 days for both events.

Table 4: Dry and Wet Inter-arrival Times for all Stations

No	Stations	Dry (days)	Wet (days)
1	Kajicuaca Mersing	30 to 995	30 to 852
2	Ladang Getah Malaya, Kota Tinggi	30 to 1034	28 to 942
3	Ladang Paya Lang, Segamat	28 to 822	20 to 912
4	Ladang Segamat, Segamat	30 to 699	30 to 852
5	Stor JPS Batu Tiga, Mersing	28 to 791	30 to 1034
6	Ladang Permatang Kota Tinggi	30 to 914	30 to 973
7	Ladang Sungai Tiram, Johor Bahru	28 to 699	30 to 833
8	Stor JPS Endau	28 to 791	30 to 852

Figure 7 shows the linear regression of dry events at Station Kajicuaca in Mersing. The result showed increasing frequency. This indicate that dry events occur frequently and extreme at Mersing area.

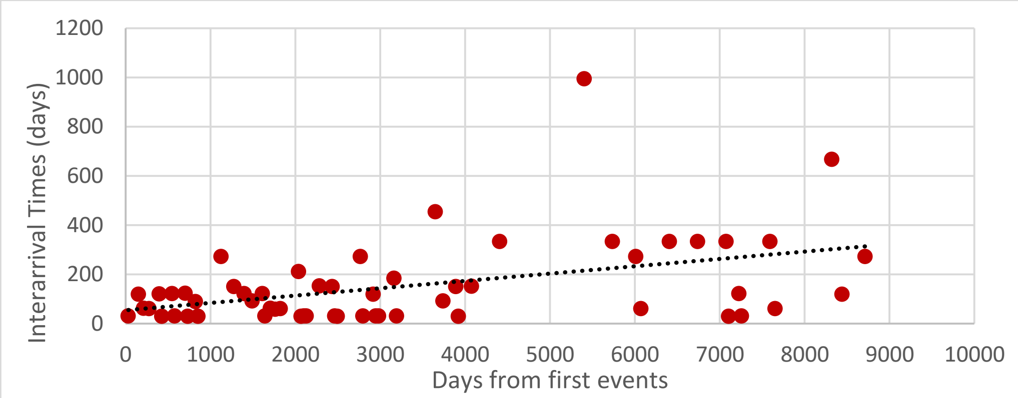

Figure 7: Linear regression of dry events at Station Kajicuaca Mersing

Figure 8 shows the linear regression of wet events at Station Kajicuaca Mersing. The result showed horizontal trend and slightly increasing trend. This indicates that Station Kajicuaca Mersing also having wet events throughout the years.

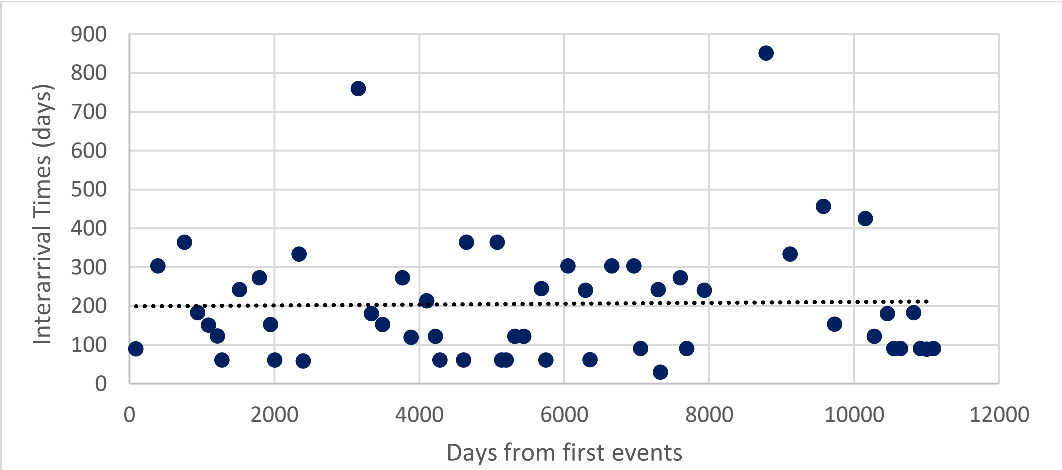

Figure 8: Linear regression of wet events at Station Kajicuaca Mersing

4. Conclusion

In conclusion, based on the analysis, it can be concluded that selected Johor stations tend to having less rainfall every year. It was observed when most of the stations showed negative value of Kendall's tau (Z) and decreasing trend. Increasing trend analysis of rainfall may lead to any natural disaster such as flood and decreasing trend lead to drought events. Rainfall trends are highly dependent on the start and end dates of the data. For the second objectives, the results obtained using SPI 12-month moving cumulative rainfall data. The SPI values range from less than -2, to indicate extremely dry to greater than 2 for extremely wet. The rate of frequency of dry and wet events (inter-arrival times) was also investigated over time. The shorter duration between events indicates that the frequency of dry or wet events is increasing over time. The station that having increasing frequency of dry event were Kajicuaca in Mersing, Ladang Getah Malaya in Kota Tinggi and Ladang Sungai Tiram in Johor Bahru stations. While for decreasing trend were Ladang Paya Lang in Segamat, Ladang Segamat in Segamat, Stor JPS Batu Tiga in Mersing, Ladang Permatang in Kota Tinggi and Stor JPS in Endau stations. Then, the station that having increasing frequency trend in wet events were Kajicuaca in Mersing, Ladang Paya Lang in Segamat, Stor JPS Batu Tiga in Mersing, Ladang Permatang in Kota Tinggi, Ladang

Sungai Tiram in Johor Bahru and Stor JPS in Endau stations, while for decreasing trend were Ladang Segamat in Segamat and Ladang Paya Lang in Segamat stations. Based on the results of this study, several recommendations can be made. Firstly, the analysis of rainfall trends and annual dry and wet events in this study focus only of rainfall stations in Johor area. It is therefore recommended to include stations from other state in Malaysia. With these, the comparison can be made. The results of trend analysis of annual rainfall can determine whether the area stations is going to experience flood or drought events. The results also can help community to be prepared and be able to adapt the extreme future events such as drought and flood.

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References

[1] Md Ali, Z., Tan, L., Daud, I., & Ahmad, N. (2017). Rainfall characteristics of Johor Bahru and Kota Bharu, Malaysia. Journal of Science and Technology, Vol. 9 No. 4 p. 77-83.

[2] Abdul Halim, S., N. S., & Abas, N. (2017). Rainfall analysis in the northern region of Peninsular. International Journal of Advanced and Applied Sciences. 3-4.

[3] Yusof, F., Yee, K. C., Yusop, Z., Suhaila, J., & Mean, F. H. (2013). Rainfall characterisation by application of standardised precipitation index (SPI) in Peninsular Malaysia. 1-25.

[4] Suhaila, J., S.M, D., Wan Zin, W., & Jemain, A. (2010). Spatial patterns and trends of daily rainfall regime in Peninsular Malaysia during the southwest and northwest monsoon: 1975-22004. 1-18.

[5] Nojumuddin, N. S., Yusof, F., & Yusop, Z. (2015). Identification of rainfall patterns in Johor. *Applied Mathematical Sciences*. 2-14.

[6] McKee, T. B., Doesken, N. J. and Kleist, J. (1993). The relationship of drought frequency and duration to time scales. *In: Proc. 8th Conf. on Applied Climatol*, *17-22 January*, *Americ Meteorol Soc, Mass*. 179-184.

[7] Zhang, Y., Guo, F., Meng, W. and Wang, X.-Q. (2009). "Water quality assessment and source identification of Daliao river basin using multivariate statistical methods." *Environmental Monitoring and Assessment* **152**(1): 105-121.

[8] Nashwan, M. N., Ismail, T., Ahmed, K. (2019). Non-stationary analysis of extreme rainfall in peninsular Malaysia. *Volume 14 Number 3, June 2019: 17-34.*

[9] Tan, M. L., Chua, V. P., Li, C., & Brindha, K. (2018). Spatiotemporal analysis of hydro-meteorological drought in. 1-13.

[10] Nordin, R. (2020). More affected by Johor floods. *The Star*. Retrieved April 4, 2021, from https://www.thestar.com.my.

[11] Devi, V. (2020). Flooding in Johor causes 155 people to be evacuated from homes. *The Star*. Retrieved April 4, 2021, from https://www.thestar.com.my.