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Rainfall erosivity estimation for Northern and Southern peninsular Malaysia using Fourneir indexes

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Abstract

Rainfall erosivity considers the rainfall amount and its intensity. This is an important parameter for soil erosion risk assessment under future land use and climate change. Comparisons of all climatic parameters show that rainfall is directly involved in the loss of soil quality during torrential rain. The effect of rainfall erosivity in Northern and Southern region of Malaysia was considered for two stations, Bukit Berapit and Johor Bahru. Monthly as well as annual rainfall was obtained from the Department of Drainage and Irrigation, Malaysia for thirty years (1983-2012). Trends analysis of the rainfall data were obtained for 30 years that shows trends for mean monthly rainfall. This was conducted using Mann-Kendall trend analysis and Sen's slope tests. Trend analysis shows that there is no significant difference in mean monthly rainfall for the studied period for Johor Bahru. The Fourneir indexes were used to determine the effect of extreme rainfall events towards soil erosivity. Bukit Berapit recorded 3.33% cases of severe impact using Fourneir index and 13.33% cases of high impact using modified Fourneir index. The result shows that there is a positive correlation between rainfall trends and soil erosivity.

1. Introduction

The global greenhouse effect is expected not only to increase mean global temperatures, but also to influence characteristics of rainfall. Water is related to river flows, and with soil moisture availability for spontaneous vegetation and cultivated species.

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Increased variability of precipitation and a higher amount of erosive rainfall in Malaysia may also increase soil erosion. Rainfall erosivity, the potential ability of rain to cause erosion, is a function of the physical characteristics of rainfall [1]. In the tropics, the rains are comparatively intense and sometimes of long duration. Soil erosion has been of much concern especially to countries like Malaysia whose most economies depend on agriculture. Generalized maps of the geographical distribution of rainfall and wind erosion, puts Malaysia in the area designated as particularly susceptible to rainfall erosion. Population growth, with its attendant increase in development demand for land and agricultural products, is likely to worsen the problem.

Many scientists predict rising atmospheric temperatures and subsequently more intensive hydrologic cycles may also lead to a change of rainfall characteristics and particularly to a higher variability of rainfall. Possible consequences are a decreasing frequency of light and medium rainfalls as well as shorter return periods for intensive rainstorms. A growing frequency of intensive rainstorms may be accompanied by a clustering of dry periods which represent a dangerous combination with regard to water and wind erosion. Dry soils are much more susceptible to water erosion than moist soils because infiltration water compresses the air in soil aggregates, destabilizing them and causing their break-down [2]. Subsequently, the soil particles can easily be carried away by surface runoff.

The universal soil loss equation (USLE) is presently the model most widely applied to estimate soil loss. The simple equation is a multiplicative model in which four non dimensional factors representing the influence of topography, cultural and management practices are used to modify a basic soil loss named potential erosion [3]. Potential erosion is the product of two parameters representing the influence of rainfall and soil characteristics. The rainfall index $R$ is a useful tool for establishing areas of soil erosion risk in which soil conservation structures are necessary. [4] Proposed the index in which the maximum monthly rainfalls (mm) were used. Since Fournier's index does not consider the monthly rainfall distribution during the year, it does not always increase when the number of erosive rainfalls in the year increases. In order to avoid this drawback, [5] proposed the modified Fournier index.

The first part of this research will analyze the trend of rainfall and estimate the steepness of the slope for two areas in Penang. [6] used the Mann-Kendall tau-b for testing trend and Sen’s slope estimator to determine the annual and seasonal trends for several variables in Serbia for the period of 1980-2010. Similar studies using Mann-Kendall trend test were done by [7] and [8]. The Fournier and Fournier’s modified index was used to derive future rainfall erosivity values by the use of average monthly rainfall amounts for elaborating an index in accordance with the universal soil loss equation.

The objective of this study is to analyze the trend of rainfall for the northern and southern region of Peninsular Malaysia and to estimate the erosivity values by the use of Fournier and Fournier Modified Index.

2. Study Area

Pulau Pinang (northern) and Johor Bahru (southern) of Peninsula Malaysia was selected to be the study areas. Two stations were selected that is Bukit Berapit, located at the mainland of Pulau Pinang and Johor Bahru, located at Johor. Bukit Berapit is located at latitude 05° 22' 32" and longitude 100° 26' 52" while Johor Bahru is located at latitude 01° 28' 15" and longitude 103° 45' 10".

3 Data and Methods

This section describes the data used and the methods used in this research.

3.1 Data

The data was obtained from Department of Drainage and Irrigation, Malaysia [9] from 1983 until 2012. The data consist of information on daily rainfall, minimum, maximum and total rainfall per month as well as annual rainfall. The unit of measurement is millimeters. For each month, the total maximum rainfall was divided by the numbers of days in that month to determine the mean monthly rainfall. The analysis was done using the mean monthly rainfall.

3.2 Mann-Kendall test for trend

The Mann-Kendall tau-b nonparametric test [6,10] was used to test for trend. This test is calculated as
\[ S = \sum_{i=1}^{n} \sum_{j=i+1}^{n} \text{sgn}(x_j - x_i) \]  \hspace{1cm} (1)

where \( n \) is the number of rainfall event, \( x_i \) and \( x_j \) are the observed rainfall events, and \( \text{sgn} \) is the sign function.

The variance is given by
\[ \text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 1)}{18} \]  \hspace{1cm} (2)

where \( n \) is the number of rainfall events, \( m \) is the number of tied events, \( t_i \) is the number events that are tied.

For sample size greater than 10, the test can be approximated using the test statistic based on the normal distribution given below:
\[ Z_s = \begin{cases} \frac{S - 1}{\sqrt{\text{Var}(S)}} & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ \frac{S + 1}{\sqrt{\text{Var}(S)}} & \text{for } S < 0 \end{cases} \]  \hspace{1cm} (3)

For increasing rainfall trends, the values of \( Z_s \) is positive and for decreasing rainfall trends the values of \( Z_s \) is negative.

### 3.3 Sen’s estimator for slope

Sen’s slope test [6,11] is a nonparametric test for the steepness of the trend. For \( N \) pair’s of data,
\[ Q_i = \frac{x_j - x_k}{j - k} \text{ for } i = 1, \ldots, n \]  \hspace{1cm} (4)

where \( x_j \) and \( x_k \) are the rainfall values at times \( j \) and \( k \) \((j > k)\) respectively. The \( N \) values of \( Q_i \) are ranked from smallest to largest and the median of the slope or Sen’s slope estimator is given by
\[ Q_{\text{med}} = \begin{cases} Q_{\left\lfloor \frac{N+1}{2} \right\rfloor} & \text{for } N \text{ odd} \\ \frac{Q_{\left\lfloor \frac{N}{2} \right\rfloor} + Q_{\left\lceil \frac{N+2}{2} \right\rceil}}{2} & \text{for } N \text{ even} \end{cases} \]  \hspace{1cm} (5)

The confidence interval for \( Q_{\text{med}} \) was obtained to determine the significance of the slope.

### 3.4 Fournier and Fournier modified index

The Fournier index [4] and the Fournier modified index [5] was calculated according to the equation below:
\[ F = \frac{P_{\text{max}}}{\bar{P}} \]  \hspace{1cm} (6)

with \( P_{\text{max}} \) = monthly average amount of rainfall of the most rainy month (mm) and \( \bar{P} \) = average annual quantity of rainfall
\[ F_M = \frac{1}{\bar{P}}[P_1^2 + P_2^2 + \ldots + P_{12}^2] \]  \hspace{1cm} (7)
where $P_i$ is the monthly average amount of rainfall for month $i$ (mm), and $\bar{P}$ is the average annual quantity of rainfall (mm). Table 1 describes the classifications of erosivity using the Fournier and Fournier modified index.

### Table 1. The erosivity classes by Fournier index ($F$) and Fournier modified index ($F_M$)

| Erosivity class | $F$   | $F_M$ |
|-----------------|-------|-------|
| Very low        | 0-20  | 0-60  |
| Low             | 20-40 | 60-90 |
| Moderate        | 40-60 | 90-120|
| Severe          | 60-80 | 120-160|
| Very severe     | 80-100| >160  |
| Extremely severe| >100  | -     |

### 4 Results and Discussions

#### 4.1 Descriptive Analysis

The mean and standard deviation for the two stations are given in Table 2. For the different time periods, the mean rainfall for Johor Bahru is higher than the mean rainfall for Bukit Berapit. The mean rainfall for Johor Bahru shows a slightly high variability compared to Bukit Berapit.

### Table 2. Descriptive statistics

| Station       | Mean     | Std. deviation |
|---------------|----------|----------------|
| Bukit Berapit | 5.980mm  | 1.30mm         |
| Johor Bahru   | 6.964mm  | 1.28mm         |

Figure 1 and Figure 2 shows the time series plot and regression line for stations Bukit Berapit and Johor Bahru respectively. From Figure 1 and 2, the regression line has a severe slope indicating that there is a very clear upward trend in mean rainfall at Bukit Berapit. Meanwhile, the slope of the regression line shows a slight positive slope indicating that there is a small upward trend in mean rainfall for Johor Bahru for the studied period.
4.2 Trend and slope analyses

The Mann-Kendall tau-b statistics for trend and Sen's slope estimator is given in Table 3 for Bukit Berapit and Johor Bahru. The trend analysis using Mann-Kendall tau-b statistics show that the trend is significant for Bukit Berapit (p-value > 0.05). The Sen's slope estimator show positive slope for the research period.

| Station     | Year      | Z   | p-value | Sen  | CI for Sen          |
|-------------|-----------|-----|---------|------|--------------------|
| Bukit Berapit | 1983-2012 | 0.39| 0.003   | 31.76| (-1.374, 59.682)   |
| Johor Bahru  | 1983-2012 | 0.25| 0.05    | 19.32| (-10.393, 60.216)  |

For Johor Bahru, there is an downward and no significant trend for the research period. There is also same like Bukit Berapit, which is the Sen's slope estimator show positive slope.

4.3 Erosivity analysis

Figure 3 shows the Fournier index for Bukit Berapit and Johor Bahru from 1983-2012.

Six years show very low impact (20%), low impact is 53.33%, while 23.33% and 3.33% of years have moderate and severe impact respectively and no record for very severe and extremely severe for Bukit Berapit. For Johor Bahru, there are also six years very low impact (20%) 73.33% of years has low impact, 3.33% has moderate impact and only 1% of years have very severe impact. There are no recorded severe and extremely severe impact years for Johor Bahru. Thus it can be concluded that for Bukit Berapit, the occurrence of soil erosion is small while for Johor Bahru there are certain years that soil erosion and ultimately landslide can occur.

Fournier modified index (Figure 4) showed that for Johor Bahru the highest impact is moderate which makes up 73.33% from all years. Only five years has high impact (16.67%), and low impact is 10% which is three years. For Bukit Berapit, there is no very high impact recorded. The highest percentage of impact is low and moderate (43.33%) which is 13 years, and only 13.33% has high impact.
5 Conclusions

Rainfall erosivity is the ability of rainfall to cause erosion due to the function of physical characteristic of rainfall (Mikhailova et al., 1997). This study is to determine the rainfall erosivity in northern (Bukit Berapit, Penang) and southern (Johor Bahru, Johor) based on the rainfall data from 1983 until 2012. Descriptive statistics show that the mean for mean monthly rainfall for Johor Bahru were higher compared to Bukit Berapit and for variance, Bukit Berapit were higher compared to Johor Bahru. The time series and regression lines illustrated a very slight upward trend in mean rainfall at Bukit Berapit.

For Bukit Berapit the Mann-Kendall tau-b statistics for trend and Sen's slope estimator show the trend and slope are significant. This finding is in agreement with [8]. Meanwhile for Simpang Ampat, Mann-Kendall tau-b statistics for trend there is an upward and not significant trend for Sen's slope estimator. This finding is similar to [7] who has reported that several stations show not significant trends.

Both Fournier index and Fournier modified index show higher impact for Johor Bahru compared to Bukit Berapit. For Johor Bahru, the Fournier modified index show that there are five years where the impact is high while for Bukit Berapit shows only four years with high impact. The result shows that Johor Bahru is prone to soil erosion incidences that can lead to the possibility of landslide. It also shows that there is a positive correlation between rainfall trends and soil erosivity.

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