Rainfall Erosivity Variability for Penang Island

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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 part of Malaysia was considered for two stations, Bukit Berapit and Air Itam. 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 annual rainfall. This was conducted using Mann-Kendall trend analysis and Sen's slope tests. Trend analysis shows that there is negative significant difference in mean annual rainfall for the studied period for Air Itam. The Fournier indexes were used to determine the effect of extreme rainfall events towards soil erosivity. Bukit Berapit recorded 3.33% cases of severe impact using Fournier index and 13.33% cases of high impact using modified Fournier index. The result shows that there is a relationship 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.

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 (Mikhailova et al., 1997). 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 economy depends partly 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 (Potratz et al., 1993). 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 (Ferro et al., 1991). 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 (Fournier, 1960).

The purpose of the USLE is to predict the longterm average annual rate of soil erosion for various land management practices in association with an area's rainfall pattern, specified soil type and topography (Wischmeier and Smith, 1978). Each of the conditions is represented by a different factor in the USLE or RUSLE equation as follows:

$$A = RKLSCP$$

A represents the potential, long term average annual soil loss in tonnes per hectare per year (originally calculated in tons per acre per year). This is the amount which is compared to the "tolerable soil loss" limits.

R is the rainfall factor (MJ mm ha^{-1} h^{-1})

K is the soil erodibility factor (t h MJ^{-1} mm^{-1})

L and ***S*** are the slope length and steepness factors, respectively (dimensionless)

C is the cropping-management factor (dimensionless)

P is the support practice factor (dimensionless)

The USLE, developed by ARS scientists W. Wischmeier and D. Smith, has been the most widely accepted and utilized soil loss equation for over 30 years. Designed as a method to predict average annual soil loss caused by sheet and rill erosion, the USLE is often criticized for its lack of applications. While it can estimate long - term annual soil loss and guide conservationists on proper cropping, management, and conservation practices, it cannot be applied to a specific year or a specific storm. The USLE is a mature technology and enhancements to it are limited by the simple equation structure.

Fournier (1969) 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, Arnoldus (1980) 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. Gocic and Trajkovic (2013) 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 Gemmer et al., (2014) and Xu et al., (2003). 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. Fournier (1960) 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, Arnoldus (1980) proposed the modified Fournier index.

The objective of this study is to analyze the trend of rainfall for the northern 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) part of Peninsula Malaysia was selected to be the study area. Two stations were selected that is Bukit Berapit, located at the mainland and Air Itam, located at the island. Bukit Berapit is located at latitude 05 22' 32" and longitude 100 26' 52" while Air Itam is located at latitude 05 21' 15" and longitude 100 12' 00" as shown in Figure 1.

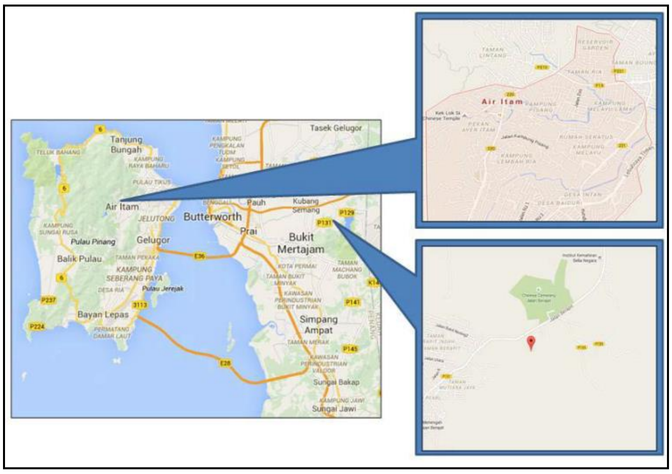

Figure 1 Study area at Air Itam and Bukit Berapit

Air Itam begins west of Masjid Negeri road and Scotland road. Central Air Itam is situated around three main streets: Air Itam road, Pasar road and Balik Pulau road. This area is often overflowing with pedestrian activity and a barrage of traffic courtesy of the popular local markets and businesses that help to congest this major, yet tiny road. To the north, along Bukit Bendera road, is the Penang Hill base funicular train station. Taking a ride on the funicular lifts you up to the top of the hill, offering scenic views and a much cooler climate. Directly to the south of central Air Itam is the township of Bandar Baru Air Itam, more commonly known as Farlim. The climate in Air Itam is very much similar to George Town. Expect year round hot and humid days that are often broken with a cooling afternoon shower. Evenings are much cooler than the daytime, but rarely drop below 20℃. Being further inland than George Town, Air Itam tends to experience slightly less rainfall and lacks the cool breeze that occasionally blows in from the Strait of Malacca.

Bukit Berapit is located in Penang and situated in Seberang Perai, Penang's mainland. Even more specifically, it is in one of Province Wellesley's most famous towns, Bukit Mertajam as it is more affectionately called. Other than the many amenities the core area of Bukit Mertajam has to offer residents of Bukit Berapit, the place is in itself is rather quiet and laid back (Tourism Penang, 2014).

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 Irrigation and Drainage (2003), 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 (Gocic and Trajkovic, 2013 and Helsel and Hirsch, 1992) was used to test for trend. This test is calculated as

$$S = \sum_{i=1}^{n} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \quad (1)$$

where n is the number of rainfall events, x_i and x_j are the observed rainfall events, and sgn is the sign function. The variance is given by

$$\operatorname{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+1)}{18} \quad (2)$$

where n is the number of rainfall events, m is the number of tied events, t_i is the number of 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:

$$Z_s = \begin{cases} \dfrac{S-1}{\sqrt{\operatorname{Var}(S)}} & \text{for } S>0 \\ 0 & \text{for } S=0 \\ \dfrac{S+1}{\sqrt{\operatorname{Var}(S)}} & \text{for } S<0 \end{cases} \quad (3)$$

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 (Gocic and Trajkovic, 2013 and Brauner, 2010) is a nonparametric test for the steepness of the trend. For pair's of data, N

$$Q_i = \frac{x_j - x_k}{j-k} \quad \text{for } i = 1, \cdots, n \quad (4)$$

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

$$Q_{med} = \begin{cases} Q_{\left[(N+1)/2\right]} & \text{for } N \text{ odd} \\ \dfrac{Q_{\left[N/2\right]} + Q_{\left[(N+2)/2\right]}}{2} & \text{for } N \text{ even} \end{cases} \quad (5)$$

The confidence interval for Q_{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:

$$F = \frac{P_{max}}{\overline{P}} \quad (6)$$

With P_{max} = monthly average amount of rainfall of the most rainy month (mm) and $\overline{P}$ = average annual quantity of rainfall.

$$F_M = \frac{1}{\overline{P}}[P_1^2 + P_2^2 \ldots\ldots + P_{12}^2] \quad (7)$$

where P_i is the monthly average amount of rainfall for month *i* (mm), and $\overline{P}$ 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 coefficient of variation for the two stations are given in Table 2. The mean rainfall for Air itam is higher than the mean rainfall for Bukit Berapit. However, the coefficient of variation of Bukit Berapit is higher compared to Air Itam. This shows that the rainfall data in Air Itam is less variable or spread than rainfall data in Bukit Berapit.

Table 2 Descriptive statistics

Station	Mean	Coefficient of Variation
Air itam	6.860	0.1618
Bukit Berapit	5.980	0.2173

Figure 1 and Figure 2 show the time series plot and regression line for stations Bukit Berapit and Air Itam respectively.

From Figure 1, the regression line has a moderate positive 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 Air Itam for the studied period.

4.2 Trend and slope analyses

The trend results for Fournier and Fournier Modified index using Mann-Kendall tau-b and Sen's slope estimator are given in Table 3. For Fournier index, Air itam shows a significant negative trend (*P* value = 0.0322) while Bukit berapit shows a negative trend but not significant (*P* value = 0.6427).

Table 3 The trend results for Fournier and Fournier Modified index

	Station	MK	*P* value	β (unit/year)	CI for β
Fournier	Air Itam	-0.278	0.0322*	-0.4878	(-1.074, -0.077)
	Bukit Berapit	-0.062	0.6427	-0.1050	(-0.580, 0.284)
Fournier Modified	Air Itam	-0.200	0.1249	-0.8577	(-1.915, 0.238)
	Bukit Berapit	0.342	0.0082*	1.0052	(-0.153, 1.896)

**Statistically significant at the 0.05 significant level.*

Sen's slope estimator analysis reveals that the decrement of Air itam is -0.4878 per year. On the other hand, the result of rainfall erosivity using Fournier Modified index recorded a significant positive trend for Bukit Berapit with an increment of 1.0052 per year. Meanwhile, Air Itam shows a negative trend but not significant for Fournier Modified index.

4.3 Erosivity analysis

Figure 3 shows the Fournier index for Bukit Berapit and Air Itam from 1983-2012.

From Figure 3, there are six years that show very low impact (20%), low impact is 53.33% (16 years), while 23.33% and 3.33% of years have moderate and severe impact (seven years and one year) respectively and no record for very severe and extremely severe for Bukit Berapit. For Air Itam, there are also six years with very low impact (20%), 73.33% (22 years) has low impact, 3.33% has moderate impact which is only one years have very severe impact. There are no recorded severe and extremely severe impact years for Air Itam. Thus it can be concluded that for Bukit Berapit, the occurrence of soil erosion is small while for Air Itam there are certain years that soil erosion and ultimately landslide can occur.

Fournier modified index (Figure 4) showed that for Air Itam the highest impact is severe whih makes up 40% from all years. Only five years has low impact (16.67%), and very severe impact is 6.67% which is two years and moderate impact 36.67%. 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.

In geology, denudation is the long term sum of processes that cause the wearing away of the Earth's surface by moving water, ice, wind and waves, leading to a reduction in elevation and relief of landforms and landscapes. The regime of rainfall reflects the aggressiveness of pluvial denudation (the impact from Fournier and Fournier modified index) on the geological substrate and soil through the volume, duration and intensity of rain. The more aggressive they are, especially after long periods of The impact of denudation becomes more aggressive especially after long periods of drought.

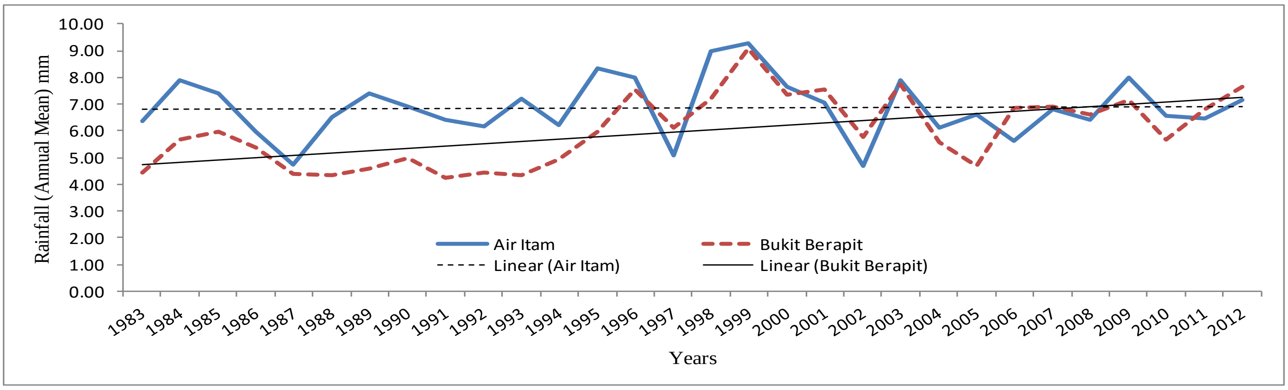

Figure 2 Mean rainfall for Bukit Berapit (1983-2012)

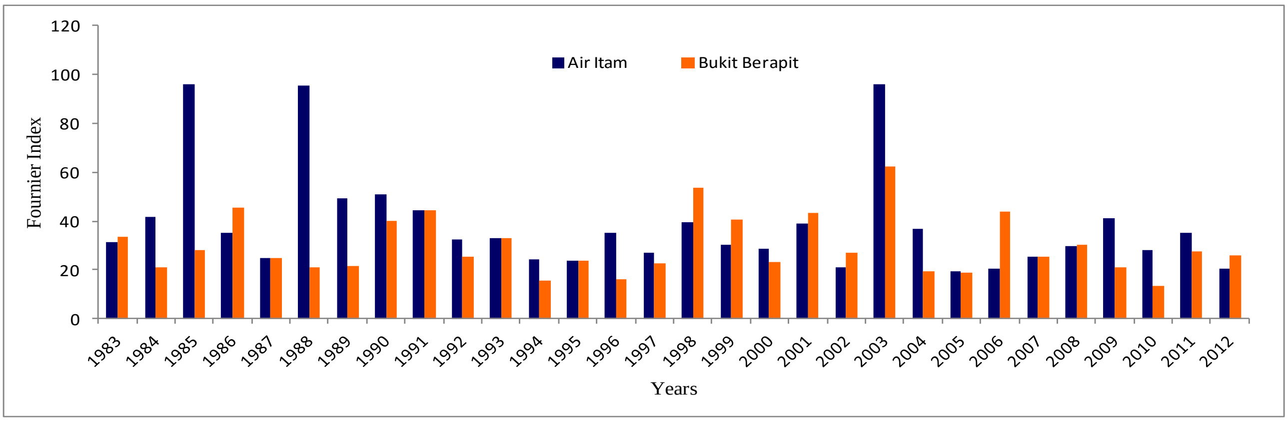

Figure 3 Fournier index variability 1983-2012

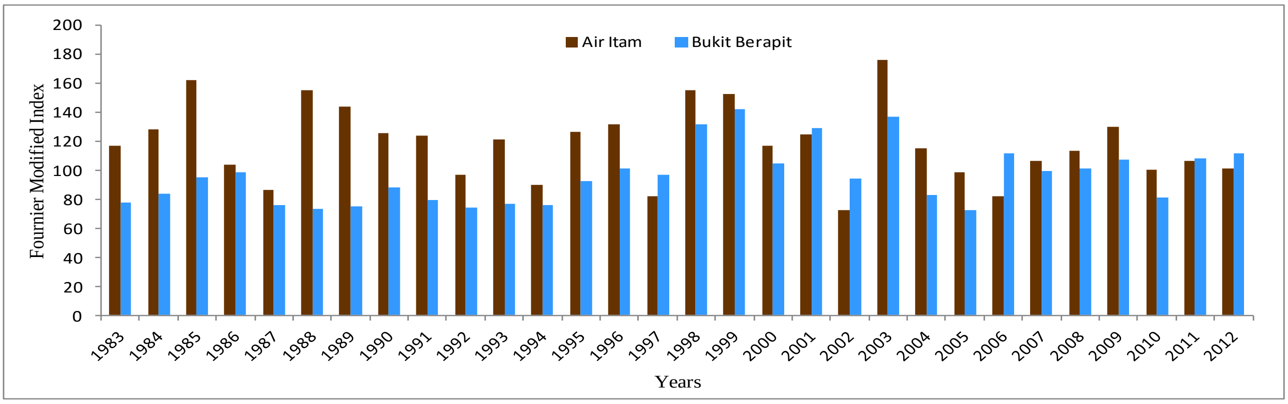

Figure 4 Fournier modified index variability 1983-2012

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 Bukit Berapit and Air Itam, Penang based on the rainfall data from 1983 until 2012. Descriptive statistics show that the mean for mean monthly rainfall for Air Itam were higher compared to Bukit Berapit and for coefficient of variation, Bukit Berapit were higher compared to Air Itam. The time series and regression lines illustrated a very slight upward trend in mean rainfall at Bukit Berapit.

For Air Itam the Mann-Kendall tau-b statistics for trend for Fournier Index show a significant negative trend (p-value = 0.0322) while Bukit Berapit shows negative trend but not significant (p-value = 0.6427). This finding is similar to Gemmer et al., (2004) who has reported that several stations show not significant trends. Fournier Modified Index shows a negative trend and not significant with P value 0.1249 for Air Itam, meanwhile for Bukit Berapit there is significant trend (P value = 0.0082). For Sen's slope estimator analysis reveal that the decrement of Air Itam is -0.4878 per year. On the other hand, the result of rainfall erosivity using Fournier Modified Index recorded a significant positive trend for Bukit Berapit with an increment of 1.0052 per year.

Both Fournier index and Fournier modified index show higher impact for Air Itam compared to Bukit Berapit. For Air Itam, the Fournier modified index show that there are two years where the impact is very severe while for Bukit Berapit shows no year with very severe impact. The result shows that Air Itam 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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7. ACKNOWLEDGEMENT

The authors are indebted to the staff of the Drainage and Irrigation Department of Malaysia for providing the rainfall data for this study and would like to acknowledge the Universiti Sains Malaysia and Ministry of Education for funding this research through the FRGS (203/PAWAM/6740015) grant scheme.