ESTIMATING THE R-FACTOR WITH LIMITED RAINFALL DATA IN PENINSULAR MALAYSIA

By

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ABSTRAK

Faktor hakisan akibat daripada air larian (R) daripada rumus RUSLE (*Revised Universal Soil Loss Equation*) adalah salah satu petunjuk yang penting untuk meramal risiko hakisan tanah. Walaubagaimanapun, kekurangan data untuk jangka masa panjang dan yang berterusan menjadi satu masalah dalam menentukan faktor R ini. Masalah ini bukan sahaja berlaku di Malaysia tetapi di negara-negara lain juga. Ini dapat dilihat daripada kajian penyelidik-peyelidik daripada seluruh dunia. Tujuan kajian ini adalah untuk membentuk cara dan rumus-rumus untuk mengira faktor R dengan hanya menggunakan data harian dan bulanan di Semenanjung Malaysia (terutamanya di bahagian utara). Data setiap jam dan harian diambil untuk pengiraan dan membentuk rumus-rumus ini. Salah satu cara digunakan adalah menggunakan Indeks Fournier. Satu perhubungan antara hakisan air larian dan indeks ini didapatkan. Satu lagi cara adalah melibatkan tiga parameter iaitu nilai bulanan hakisan air larian (EI_{30}), jumlah hujan bulanan untuk hari yang nilai hujannya ≥ 10mm dan jumlah bilangan hari dalam satu bulan di mana nilai hujannya juga ≥ 10mm. Rumus-rumus yang terbentuk menggunakan dua cara ini boleh digunakan dengan adanya data hujan harian sahaja. Daripada kajian ini, nilai hakisan air larian (R) yang didapati adalah dalam lingkungan 6576 hingga 9094 MJ mm ha^{-1} h^{-1} $year^{-1}$. Program GIS (*Geographic Information System*) digunakan untuk menginterpolasikan semua nilai yang didapatkan dalam satu peta. Peta bulanan dan tahunan untuk semua nilai ini dibentuk.

ABSTRACT

Rainfall-runoff erosivity factor (R) of the revised universal soil loss equation (RUSLE) is one of the important indicators to predict erosion risks. However, lack of long term and continuous pluviograph data is becoming a problem to determine the R factor. This problem does not only exist in Malaysia but everywhere in the world as shown by researchers around the world. The purpose of this study is to develop models (equations) for calculating the R-factor with only daily and monthly data for Peninsular Malaysia (mainly for the northern part of Peninsular Malaysia). Hourly and daily data of six different stations were used to create these equations. One of the methods used was by using the Fournier index. A relationship between the rainfall erosivity and the Fournier index was determined. Another method was to get a relationship involving three parameters which are the monthly rainfall erosivity (EI_{30}), monthly rainfall for days with ≥ 10mm and monthly number of days with rainfall ≥ 10mm. These two equations which are produced in this study can be used to determine the rainfall-runoff erosivity factor with just daily and monthly data. From this study, the annual rainfall erosivity calculated in northern Peninsular Malaysia ranged from 6576 to 9094 MJ mm ha^{-1} h^{-1} $year^{-1}$. A geographic information system (GIS) was used to interpolate the values and generate a map to show spatial variations of the rainfall erosivity. Maps for monthly and annual rainfall erosivity factor distribution are developed.

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CHAPTER 1

INTRODUCTION

Soil erosion has a long history to it ever since the starting of human development such as in the Mesopotamian and Babylon years. Many of the people then do not know the affects of the development done by them by cutting down forest and clearing lands without a limit. Irrigated fields on the lowland region were not damaged by soil removal but it was ruined by sediment from eroded land above them (Frederick et. al, 1999)

Erosivity is the driving force of erosion agents that causes soil detachment. Erosivity of rainfall happens mainly because of the direct raindrop impact and also the runoff due to the rainfall. The ability of rain to cause the soil erosion is attributed to its rate and also drop size distribution. These two affects the energy load of a rainstorm. Water erosion can be severe in humid places such as Malaysia. This is also true especially for lands with poor soil structure and also lands with steep slopes. Soil erosion is important to be determined because of the loss of soil productivity and costs associated with sedimentation in waterways.

In addition to these effects, chemicals adsorbed to soil particles are also transported to nearby waterways. These are the reasons scientists and engineers are very interested in describing the erosion process. Frederick et. al, 1999 mentioned in his book "*Soil and Water Conservation*" that Asia is one of the places suffering from catastrophic soil erosion. This is due to the long history of land utilization which is responsible for very severe erosion damage. He mentioned also that the extreme population pressure has also caused severe exploitation and considerably increased soil losses. This is very true for China and countries of the south central Asia.

One main important parameter to determine erosivity is the rainfall-runoff erosivity factor, R. It is the average annual summation (EI) values in a normal year's rain or in other words it is the quantitative expression of the erosivity of local average annual precipitation and runoff.

This study addresses the problem of predicting the rainfall-runoff erosivity factor (R) of the Revised Universal Soil Loss Equation (RUSLE) with limited rainfall data. In Malaysia and also in many parts of the world, the problem of lacking long term and continuous pluviograph data is not rare at all. These data are important to calculate the rainfall-runoff factor, R. Hence, this study addresses the difficulty in determining the rainfall-runoff erosivity factor (R) of the Revised Universal Soil Loss Equation because of the lack of continuous pluviograph rainfall data in Peninsular Malaysia.

Therefore, in this study, a new equation will be developed to calculate the R factor even with only daily and monthly rainfall data. This equation would help future calculations of this factor in Malaysia especially in the northern part of Peninsular Malaysia

1.1 OBJECTIVE

This project as a close relationship with the RUSLE equation and it also includes the usage of some other programmes such as Arc View GIS, FORTRAN, Polymath and Microsoft Excel. The objectives of this project are presented below:

- To analyze rainfall data pattern in Seberang Perai according to months and years.
- To determine the relationships between rainfall runoff erosivity factor with Fournier index, monthly rainfall for days with ≥ 10mm and monthly number of days with rainfall ≥ 10mm.
- To compare the results of the above models to find the best one.
- To create rainfall erosivity maps of Seberang Perai area using GIS

1.2 SCOPE

This study is only part of the calculations needed to be done to calculate the annual soil loss of an area. The equation is given as below (Wischmeier and Smith, 1978):

$$A = R*K*L*S*C*P \qquad (1.1)$$

Where A is the computed annual soil loss (kg m^{-2} $year^{-1}$), R is rainfall erosivity factor (dimensionless), K is soil erodibility factor (dimensionless), L is slope length factor (dimensionless), S is slope steepness factor (dimensionless), C is cropping and management factor (dimensionless), P is conservation practices factor (dimensionless). The parameter of this study that is calculated is the rainfall erosivity factor, R

1.3 ORGANIZATION OF REPORT

A good report should consist of many different chapters concerning the research or study. In this report there are five chapters that cover all the information needed in this study.

Chapter 1 is a brief introduction to this study. It explains objective and scope of this study and gives an introduction on the rainfall erosivity factor which is one of the parameter of the RUSLE equation to calculate the soil loss of an area.

As for chapter 2, it informs us on the development on the same kind of study done many other researches before this. This chapter is divided into two parts. One part explains the work done by others in the RUSLE equation and attempts in creating better ways to calculate the R factor (rainfall erosivity factor). The other part is the development in the Geographical Information System (GIS) done by other researches concerning this R factor.

Methodology is an important part of a report on a study or research. Chapter 3 in this report is all on the methodology used in this study. It gives some information on the location of the study area as well as the procedures used. The procedures are divided into three parts which are the data analysis, the R factor equations and also the mappings using GIS (Geographical Information System).

Chapter 4 in this report is the most important chapter. It consists of all the results and discussion for the study. The rainfall data are properly arranged into graphs to see the changing pattern of the rainfall in this area. Equations are derived to calculate the monthly and annual rainfall erosivity factor and the most suitable equation is chosen for the future to calculate the rainfall erosivity. GIS mapping in this chapter shows the outlay of the rainfall erosivity according to months and also annual mean.

Chapter 5 discusses the overall conclusion from this study. Suggestions are made in this chapter to those that are interested in this kind of study or research. These suggestions may help the researcher to develop better ways in calculating the rainfall erosivity factor.

CHAPTER 2

LITERATURE REVIEW

This review consists mainly of two parts. The first section reviews published material dealing with the Revised Universal Soil Loss Equation (RUSLE). The second section addresses the use of geographic information systems (GIS) for producing a map concerning the rainfall-runoff factor R of the RUSLE equation.

2.1 REVISED UNIVERSAL SOIL LOSS EQUATION (USLE/RUSLE)

In their book, Wischmeier and Smith (1978) defined the universal soil loss equation (USLE) as a mathematical model to predict soil loss. This equation has been widely used to predict soil loss and to estimate the numerical values of different components of the erosive process (Alexandre Marco da Silva, 2003). The USLE equation is as below:

$$A = RKLSCP \tag{2.1}$$

where A is the rate of soil loss, rainfall erosivity (R), soil erodibility (K), slope steepness (S), slope length (L), cover management (C), and support practice (P).

The important aspect of this equation to note is the linear relationship between the equation parameters. As any parameter is changed, the resulting erosion yield is similarly changed. Many of the factors of RUSLE will change seasonally, especially corresponding to plant growth and according to changes in rain characteristics (R. Pitt, 2002).

Wischmeier and Smith (1978) also described the erosivity as an interaction between kinetic energy of raindrops and the soil surface. This interaction may result to a greater or lower degree of detachment and down-slope transport of soil particles according to the amount of energy and intensity of rain by considering the same type of soil, topographic conditions, soil cover and management.

USLE model has several shortcomings, two of which are likely to have prominent implications for the model results (Sonneveld and Nearing, 2002). The first shortcoming mentioned was the mathematical form of the USLE is the multiplication of six factors which easily will lead to large errors whenever one of the input data in misspecified. Secondly, the USLE has a modest correlation between observed soil losses and model calculations, even with the same data that was used for its calibration. These shortcomings raise questions about its mathematical model structure and its robustness of the assumed parameter values that are implicitly assigned to the model.

The USLE has some intrinsic model limitations which require attention. This is where RUSLE was produced. The changes from USLE to RUSLE generally fit into two categories: (i) incorporation of new or better data and (ii) consideration of selected erosion processes. But this improvement and other simple improvements in the RUSLE that are based on new data will only benefit for regional or other applications for which the new data is available (Sonneveld et. al, 2002). Many researches then tried to produce improved model or equation for certain regions.

Most runoff and erosion models require rainfall intensity data of considerable to high temporal resolution, which restricts their current application and predictive potential (Dijk, 2002). In his paper, he proposed a simple exponential rainfall depth-intensity distribution involving only two parameters to characteristic storms: rainfall depth (P) and depth-averaged rainfall intensity ($\check{R}$). On the basis of this distribution, analytical expressions were derived for relevant RUSLE and GUEST model parameters. The approach was investigated using tipping bucket rainfall intensity measurements during 30 storms of 33-81 mm. Parameters of both models could be recovered with high accuracy using only P and $\check{R}$. The proposed rainfall depth-intensity distribution combines physically meaningful, clearly defined variables with theoretical simplicity and high descriptive accuracy and provides an excellent scope for use in runoff and erosion modelling.

The rainfall-runoff factor, R is one of the best parameter for the prediction of the erosive potential of raindrop impact. It represents the climatic influence on water related soil erosion and can be used to quantify broad scale, climate driven soil erosion potential (Hashim et. al, 2001).

The original method to calculate the R factor for a storm event needs pluviographical records (Wischmeier and Smith, 1978). Limited long term, continuous pluviograph data makes it difficult to determine the R factor in many parts of the world including Malaysia (Hashim et. al, 2001). Hashim and Eusof, 2001 came up with new values for the unknowns in the equation created by Yu and Rosewell, 1996. The result of their research is an equation to calculate the R factor for Peninsular Malaysia using just monthly rainfall data.

Other researches such as Banasik and Gorski derived new equations to calculate the rainfall erosivity for nine different locations around East and Central Poland. The equation derived using relationships between two parameters which are the rainfall erosivity (EI) and the depth of rainfall (P).

Santos Loureiro et. al, 2001 created a new procedure to estimate the RUSLE EI_{30} index, based on monthly rainfall data and its applied to the Algarve region, Portugal. In their study, a multiple linear regression involving monthly EI_{30}, monthly rainfall for days with $\geq$ 10mm ($rain_{10}$) and monthly number of days with rainfall $\geq$ 10mm ($days_{10}$) were presented for the Algarve region. Twenty-seven years of monthly rainfall erosivity values were computed for 32 standard daily-read raingauge stations. At each of the 17 tipping-bucket raingauges, multiple linear regressions between monthly rainfall erosivity and different rainfall parameters were computed. The use of $rain_{10}$ instead of $rain_{month}$ allows one to eliminate some of the non-erosive precipitation. As for the use of $days_{10}$, it is the best available indicator of monthly rainfall temporal concentration.

According to Alexandre, 2003, many authors have found a good relationship between the Fournier index (Cc) and annual values of rainfall erosivity. The Fournier index represents an equation widely used for the purpose of estimating the R factor with good accuracy, monthly and/or annual values of rainfall erosivity by using pluviometric records. The Fournier index is an equation relating the monthly value of precipitation for a month x and the annual value of precipitation.

2.2 APPLICATION OF GEOGRAPHICAL INFORMATION SYSTEM (GIS)

Geographic Information System (GIS) is an integrated suite of computer based tools which facilitates the input, processing, display and output of spatially referenced data. Benefits of GIS are the ease of data update, data management and data presentation in forms most suited to user requirements. At the same time GIS allows for vast amounts of information of different themes and from different sources to be integrated (Burrough and McDonnell, 1998).

Controlling the erosion of soil dates back early civilizations that realized that the thin, rich, top layer of the earth is detrimental to producing food to feed its inhabitants. Erosion control methods have developed tremendously since the first erosion prevention techniques were implemented and methods causing erosion have gained further understanding. Modeling methods to predict soil erosion are continually being developed (Niedermeier, 1998). In his study, soil erosion is analyzed from a GIS environment using previously developed formulations that produce soil loss.

Niedermeir, 1998 mentioned that the heterogeneity of a soil makes developing a model to study the effects erosion quite difficult. Also the spatial variability in rainfall and wind speeds adds to the complexity in the determination of soil erosion. So by using a GIS environment to model soil erosion, it makes sense due to the tremendous spatial diversity of the natural conditions found at the surface of the earth. A GIS environment one is able to analyze the spatially varying characteristics of land surface, wind, and rainfall by first breaking them down into small cells and modeling each cell independently for soil erosion on an elemental scale. Then the individual cells can be summed up to determine erosion on a regional scale for large areas such as major river basins.

Wan Yusof and M.J Baban, 1999 developed a soil erosion risk map for Langkawi Island, Malaysia using the Universal Soil Loss Equation (USLE), remote sensing and GIS. In their study, they generated representative raster layers based on secondary data for the following parameters; rainfall erosivity, slope length/gradient, soil erodibility and conservation practices. This is for the spatially modeling of soil erosion in the GIS. A Landsat TM imagery dated March 1995 was utilised to produce a land use/cover map of the Island based on the Maximum Likelihood Classification method. This map was then, used to generate the conservation practice factor in the USLE. The analysis was performed using IDRISI, a raster based GIS software. Upon comparison, the produced erosion map showed significant similarities with an erosion risk map of the Island produced by conventional means in 1995. The majority of high erosion risk areas seem to be confined to the highlands. This study demonstrates the effectiveness of remote sensing and GIS in generating soil risk maps. The produced erosion risk map is a valuable resource for planners to minimize soil erosion problems caused by future and ongoing development projects on the Island.

RUSLE-GIS model is a useful tool for resource management and soil conservation planning (Shi et. al, 2002). Shi et. al made a case study in the Three Gorge Area of China using RUSLE and GIS as their main model. The objective of their study was to develop and validate a soil erosion- predicting model based on the revised Universal Soil Loss Equation (RUSLE) in a geographic information systems (GIS) environment. In this study conservation-oriented watershed management strategies using the GIS was develop for the Wangjiaqiao watershed in China.

In an interesting work by Khosrowpanah and Heitz, 2001, they had developed a GIS modeling techniques that will be applicable to any watersheds where similar baseline data is available. This research is done in the Southern of Guam. In their study they have reached their objective to develop a GIS based erosion simulation model suitable for predicting soil erosion for the soils, vegetation and climate conditions of southern Guam and also to examine the relationship between actual sediment production and hydrologic factors such as stream flow and rainfall.

CHAPTER 3

METHODOLOGY

Every research or study has to be done in a proper sequence. Each steps need to be identified and all the processes related to it should be noted down. This is to ensure the work that is done is in a proper manner and easy to follow. These steps are called methodology. Below is the methodology of this study.

3.1 INTRODUCTION

The overall methodology involves the use of RUSLE (Revised Universal Soil Loss Equation) and GIS (Geographical Information System). Generally, the rainfall data needed is already available. Through this data, rainfall analysis is done and the results of this analysis are then used to compute the R-Factor of the RUSLE. New equations are then created using this information. In this study, two types of equation are created. One which uses the Fournier index and the other equation uses the days and rainfall with rain $\geq$ 10mm. After getting the R factor for all the stations, the erosivity map (based on the R factor) is then drawn using the GIS.

3.2 LOCATION

The main location for this study is the South Seberang Perai situated in the Penang, on Malaysia's northwestern coast. Penang is about 370 km from Kuala Lumpur. It consists of an island and also part of the mainland. Its state capital is George Town. Penang is divided into 5 divisions which are Central Seberang Perai, North Seberang Perai, South Seberang Perai, Northeast and Southwest. Refer to Figure 3.1 below for a view of the Penang location.

The area of this state is about 1031 sq km at latitude of 5°8' - 5°35' and longitude of 100°8' - 100°32'. This project is done on the mainland of Penang which is the Seberang Perai. The mainland covers about 738 sq km of the Penang state. The types of industry in Penang are such as the manufacturing, agricultural, forestry, construction, finance, insurance, wholesale and many more. Most of the population is in the manufacturing industry with about 42% (Source of data: *Department of Statistics, Economic Characteristics of the Population, Population Distribution and Basic Demographic, Characteristics, Census 2000*)

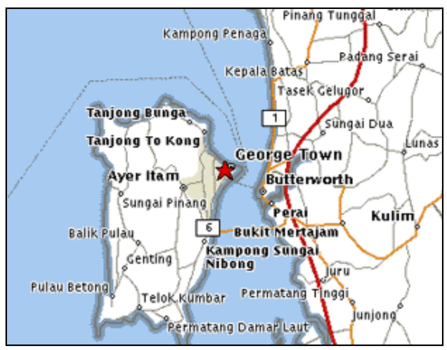


Fig 3.1: Penang State

Six different stations were used to get the rainfall data needed. The stations are Bukit Berapit, Ladang Batu Kawan, Sungai Bakap, Sungai Kulim, Bukit Panchor and Simpang Ampat. These stations cover the area of Seberang Perai. For a clearer view of the area, refer to Figure 3.2 below.

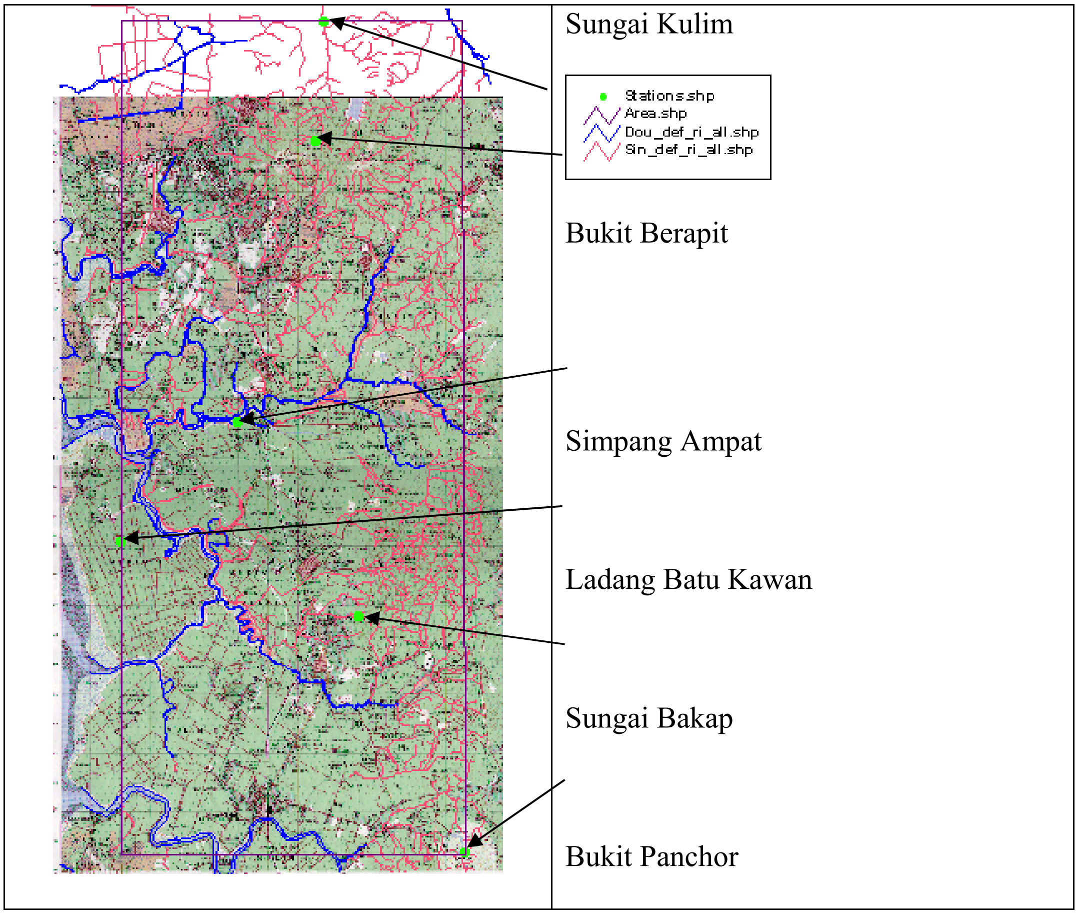


Fig 3.2: Study Area

3.3 MAIN PROCEDURE

The procedures for this study consist of the analyzing rainfall data, R factor Equation (RUSLE) and mapping using the GIS.

3.3.1 DATA ANALYSIS

The given daily rainfall data were arranged into monthly rainfall data for years 1991 to 2003 for most of the stations. The total annual rainfall for each year, the maximum rainfall in a year and the mean monthly rainfall is then shown in graphs.

3.3.2 R FACTOR EQUATIONS

From the hourly data, a few calculations were made. The hourly data that was available are only from years 2000 till 2003 (four years data). These data are used to create equations to calculate the rainfall erosivity factor for places especially in Peninsular Malaysia that has only daily or monthly data. The first calculations made are the estimation of the R factor using the hourly data.

All of the continuous hourly rainfall data have been used to compute rainfall erosivity (EI) for each rainfall event and a relationship between EI and the Fournier index (Cc) is established for each station. Individual rainfall events of less than 10mm were excluded from the computation of EI. The R value is the sum of erosive storm EI_{30} values occurring during a mean year. According to Wischmeier and Smith 1978, individual rainfall events of less than 12.7mm which were separated from other events by more than 6hours without rain should be excluded from the computation of EI values unless the depth of rainfall in 15minutes exceeds 6.3mm. This theory came up after the researches found that rainfall with less than 12.7mm the erosivity affect on the soil is not significant and can be excluded. In this study the threshold value taken is 10mm (which is acceptable because this value is lesser than the suggested value which is 12.7mm). The reason that this value was chosen is because other than getting an equation relating the rainfall erosivity factor and the Fournier index, the values of the rainfall erosivity factor computed is needed for creating another equation based on monthly rainfall days with ≥10mm and monthly number of days with rainfall ≥10mm.

After selecting the erosive rainfall events, there are a few steps of calculations needed. Those steps are as shown below:

A. Relationship between monthly erosivity, R_x and Fournier index, C_c

i. Firstly, the kinetic energy of rainfall (E_j) is computed using the formula derived by Onaga et.al 1998 for eastern Asia

$$E_j = 9.81 + 10.6 \log_{10} I_j \quad (3.1)$$

Where E_j = kinetic energy of rainfall (J/m^2)

I_j = rainfall intensity (mm/h)

ii. The sum of the kinetic energy gives the kinetic energy of the whole rainfall event (E)

$$E = \sum (Ej) \quad (3.2)$$

iii. The rainfall erosivity (EI) is the kinetic energy of the whole rainfall event (E) multiplied by the maximum 30-minute rainfall intensity (I_{30})

$$EI = E \times I_{30} \times 1/100 \quad (3.3)$$

EI = rainfall erosivity ($kJ/m^2.mm/h$)

Take note that $1kJ/m^2 = 10MJ/ha$ (Hashim and Eusof, 2001)

iv. By summing of EI values for each storm, the total erosivity for each month and year is computed. The annual values and mean monthly values were calculated

v. The coefficient of efficiency is then calculated (Ec). This coefficient is an objective measure of "goodness-of-fit" for model validation which is equivalent to the coefficient of determination (r^2) for linear regression models (Hashim and Eusof, 2001)

vi. Fournier indexes (C_c) were then calculated from the monthly and annual values computed in step (iv)

$$C_c = M_x^2/P$$

Where M_x = monthly value of precipitation for month x (mm)

P = annual value of precipitation (mm)

vii. Using the monthly total erosivity from step (iv) and the Fournier index from step (vi), the following relationship between those two parameters were derived (according to accuracy of graphs):

$$R_x = a\,(C_c)^b \quad \text{or} \quad R_x = A(C_c) + B$$

Where a, b, c, A and B are statistically estimated parameters

R_x = total monthly erosivity (MJ/ha.mm/h)

C_c = Fournier index

viii. From the graphs, the coefficient of correlation, r^2 for each graphs were gotten. These values show the accuracy of the graph. This will help to choose which type of equations is the most suitable to calculate the monthly and or annual rainfall erosivity factor for each station.

ix. The overall results were combined to get a common equation for all stations. This is done by combining all the data from all stations (average values from all stations) and create a new graph with a new equation. This equation could then be used to calculate monthly and or annual rainfall erosivity factor,R for the northern part of Peninsular Malaysia.

B. Relationship between monthly rainfall erosivity, Rx, monthly rainfall for days with rainfall ≥10mm, $rain_{10}$ and number of days with rainfall ≥10mm, $days_{10}$

The procedures for this method are as below:

i. The total monthly rainfall for days with rainfall more or equals to 10mm were determined.

ii. The total number of days with rainfall more or equals to 10mm were also determined

iii. The following relationship between three parameters were derived by using multiple linear regression method

$$R_x = p\,(rain_{10}) + q\,(days_{10})$$

Where R_x = monthly rainfall erosivity computed in part A

$Rain_{10}$ = monthly rainfall for days with rainfall ≥10mm

$Days_{10}$ = total number of days with rainfall ≥10mm

p, q = unknowns (multiple regression)

For the calculations done in part A and B, three different computer programmes or software were used in these calculations. They are Microsoft Excel, FORTRAN and Polymath. Excel was used to create all the graphs and calculation of the coefficient of correlation. FORTRAN was used to calculate the total erosivity for each month (EI), total monthly rainfall for days with rainfall more or equals to 10mm and number of days with rainfall more or equals to 10mm. Whereas Polymath was used to calculate the unknowns p and q in part B. the method used is called the multiple regression.

3.3.3 MAPPING USING GIS (Geographical Information System)

Maps to show the distribution of monthly and annual rainfall erosivity are drawn using the ArcView GIS. Example below is for the monthly rainfall erosivity.

i. All the location for the stations are identified and represented by points on the map of the area or the points are drawn using all the coordinates of the stations (as shown in Figure 3.3). The green points in the figure below represent all of the six stations which rainfall data has been used.

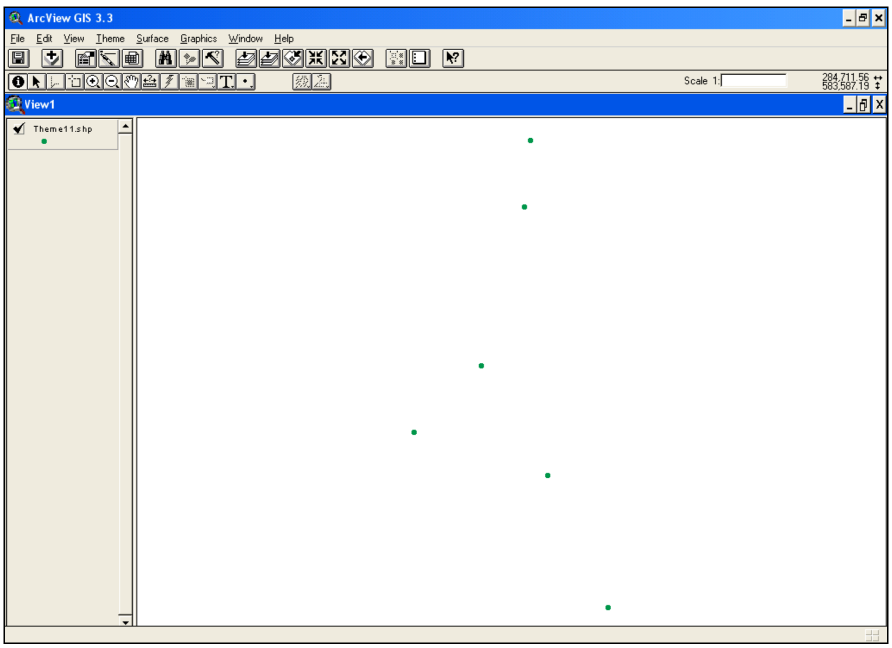


Fig.3.3: Location of stations

ii. A table of all the values of rainfall erosivity factor is created. So now, each point has its own values and data (refer Figure 3.4). As an example, one of the points had been highlighted (Id = 1) and this value represents the EI_{30} value for the station located at the very top (Sungai Kulim station) which is in yellow.

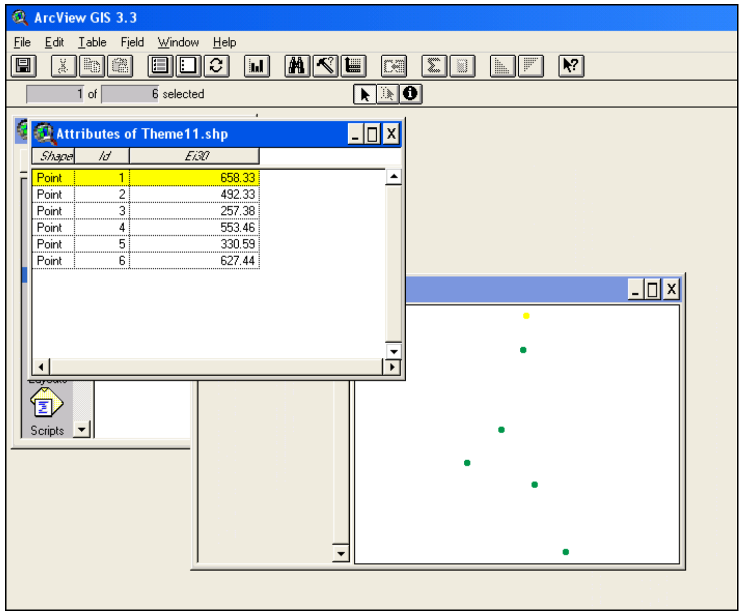


Fig.3.4: Values of EI_{30} according to months

iii. Using interpolation, a map in created according to the values of rainfall erosivity.

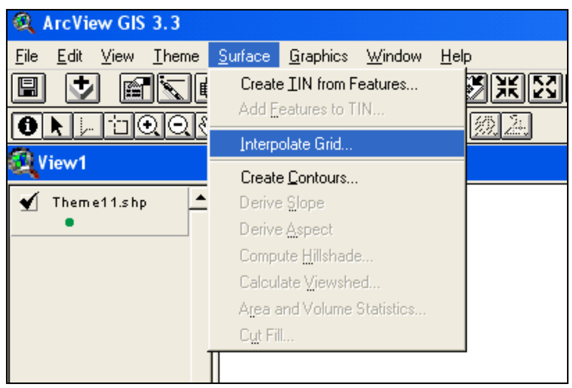


Fig.3.5: Interpolation

iv. The output of the interpolation is shown in Figure 3.6. A contour is created for the values EI30 which is also shown in the same figure.

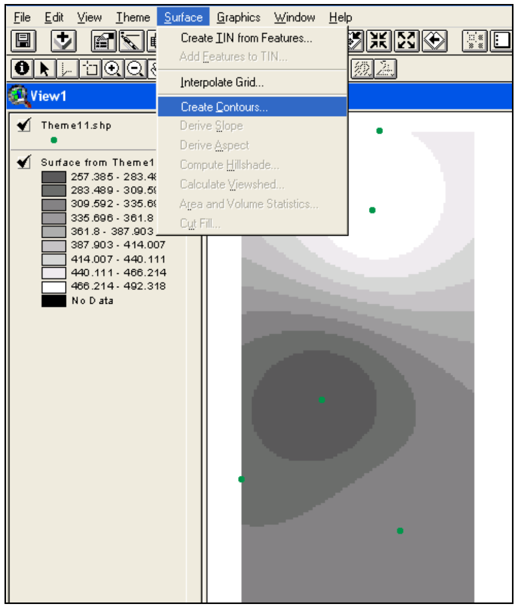


Fig.3.6: Results of interpolation and creating contours

v. Figure 3.7 shows the overall results from the processes (i) to (iv)

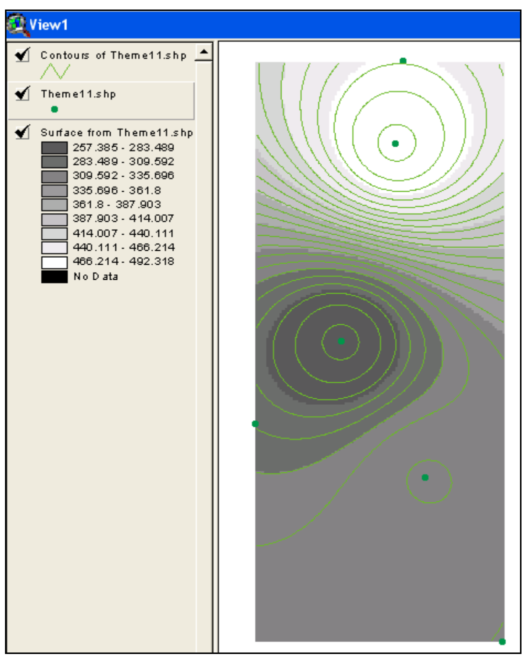


Fig.3.7: Overall map

CHAPTER 4

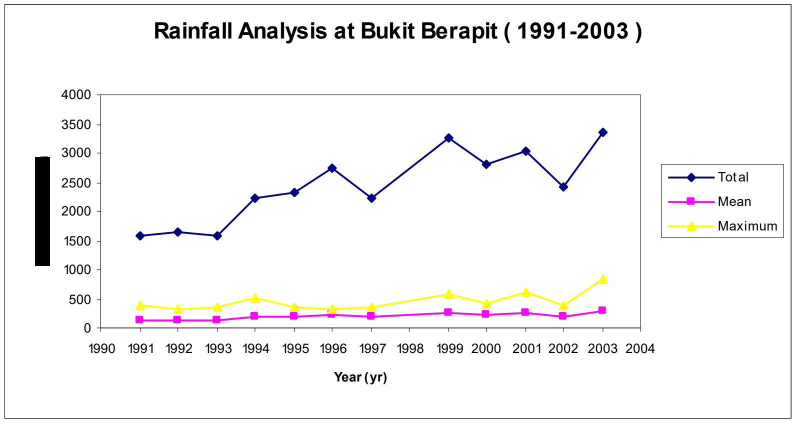
RESULTS AND DISCUSSION

In this chapter, the rainfall data are properly arranged into graphs to see the changing pattern of the rainfall in this area. Suitable equations are derived for future concerning the rainfall erosivity. The GIS mapping in this chapter shows the outlay of the rainfall erosivity according to months and also annual mean.

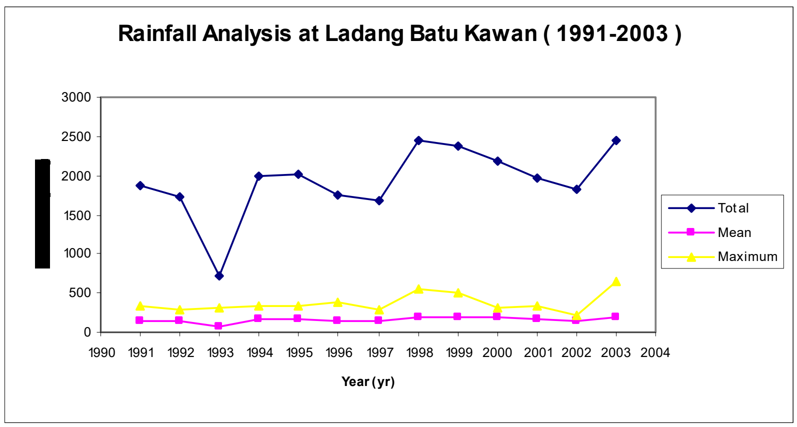
4.0 Rainfall Data Analysis

From all the rainfall data, the pattern of the total, mean and maximum values are shown in graphs in Figure 4.1. From the graphs, we can conclude whether the rainfall pattern is increasing, decreasing or static. These graphs can help predict the kind of values we need in future.

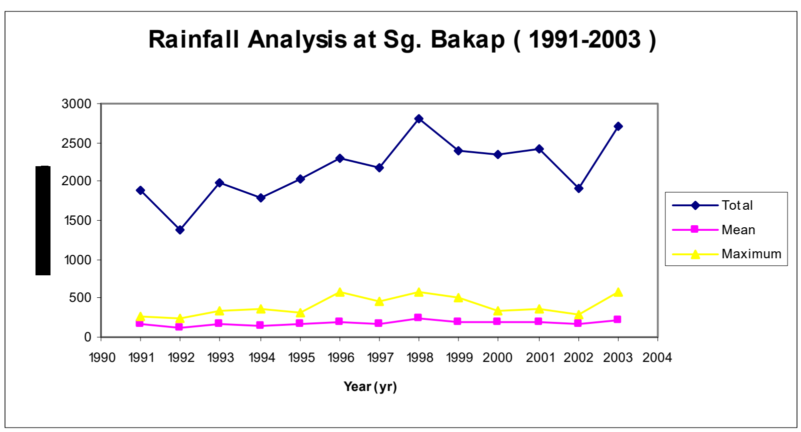
Overall, the rainfall pattern increase with the years but at small amounts. We can see a similar pattern in all the stations for the years 1996, 1997 and 1998. The rainfall decrease from 1996 to 1997 and increase from 1997 to 1998. This pattern is also true for years 2001, 2002 and 2003. For most stations, the rainfall is high in 1999 and 2003 and low in 2002. The mean rainfall yearly is almost the same. The mean rainfall values falls in the range of 100 mm to 250 mm.



(a) Station Bukit Berapit (Annual mean = 2428.8 mm)



(b) Station Ladang Batu Kawan (Annual mean = 1920.4 mm)



(c) Station Sungai Bakap (Annual mean = 2165.1 mm)