

# **Rainfall erosivity attributes on central and western Mauritius**

by

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## Abstract

Rainfall can be the most erosive agent with respect to rainfall induced erosion, particularly within the context of a tropical maritime environment. Mauritius provides an example of such an environment, which, due to its location and elevated topography, is subject to frequent erosive rainfall events as well as occasional cyclones which potentially threaten loss of soil and may accelerate land degradation. Such intense rainfall forms a key part of the “*R*-factor” in the USLE and RUSLE soil loss equations, which are commonly used worldwide in deriving the soil loss of an area. This project focuses on various attributes of rainfall erosivity on the central and western parts of Mauritius over a six year assessment period. A steep rainfall gradient exists; 600mm in the western plains and 4000mm per year in the higher central region. Rainfall and erosivity attributes are investigated in these two regions on the island to assess the role that topographic elevation has on rainfall erosivity. Using the  $EI_{30}$  method to find the “*R*-factor”, erosivity is calculated for the period of 2003 – 2008. Varying time intervals were used in calculating  $EI_{30}$  to determine the value that high resolution data has in erosivity calculations and is compared to the use of the Modified Fournier Index. This project also speculates on the potential impacts of changing rainfall intensity and erosivity associated with climate change in the future.

A difference was found in the erosivity experienced in the elevated central interior and the rain-shadowed western lava plains. Stations on the western plains recorded 25% of the erosivity experienced by stations in the interior and large differences were found in the number of erosive events, rainfall, erosive rainfall totals, seasonality, and annual erosivity totals of erosivity. The central interior showed greater variability in *R*-factor values; however these remained similar in extent despite the large difference in total annual rainfall and the number of events that each station recorded. High resolution data did account for erosivity that lower resolution does not, but the extent of erosivity for all stations within the respective regions were markedly similar. Use of the Modified Fournier Index caused erosivity to be overestimated on the island when compared to the  $EI_{30}$  method. Changes in erosivity are speculated to occur with changes in rainfall intensities but the central interior of the island will notice fluctuations in climate (with respect to rainfall erosivity) more than the western plains.

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*“Study to show yourself approved unto God, a workman that needs not to be ashamed, rightly dividing the word of truth.”*

-2 Timothy 2:15

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## Chapter One: Introduction

Among the factors initializing and determining soil erosion rates, rainfall erosivity is the one natural factor that is not directly influenced by human action and is potentially the most devastating. Soil erosion rates induced by rainfall are high in tropical environments and at particular risk to the impact of rainfall induced soil erosion are small island environments (Salako *et al.*, 1995; Lal *et al.*, 2002; Nigel & Rughooputh, 2010a). With limited land resources and often large populations, these island environments, which are often found within the tropical regions of the planet, are vulnerable to land degradation resulting from erosion. Areas in tropical regions are subject to intense rainfall which triggers and/or accelerates erosion processes. Key to these processes, rainfall erosivity plays a vital role in determining the soil loss that can occur due to intense rainfall events (Nigel & Rughooputh, 2010a). Compounding the issue, future climate change is likely to change rainfall regimes and intensities which may potentially alter erosion rates and vulnerability to soil degradation (Lal *et al.*, 2002).

Mauritius is an example of a small island state that faces erosion from intense rainfall. The island's elevated topography has created a steep rainfall gradient where the western edge of the island receives just 600mm of rainfall per year but the center has up to 4000mm, creating an environment where the interior of the island is subject to potentially very high erosion (Nigel & Rughooputh, 2010a). In addition, Mauritius had a 2006 population of 1.23 million people which equates to around 630 people per km<sup>2</sup>. With 41% of the population living in cities and the remaining population in the rural areas, the land is under pressure from agriculture and land use change (Ramalanjaona & Brogan, 2009). Apart from the large population of the island, its economy, along with tourism and industry, is based largely on agriculture and more particularly the sugarcane industry. Approximately 90% of arable land on Mauritius is used in the cultivation of sugarcane (Cheeroo-Nayamuth *et al.*, 2000; Deepchand, 2001).

Population growth, the small size of the island and a restrictive topography has forced the changes of formerly natural land to agriculture, urban areas and industry. This has placed pressure on the existing land resources of the island (Finn, 1983). Complicating the matter are the threats of climate change, rising sea levels and changing in rainfall regimes. The limited land resources of Mauritius need to be preserved and managed properly, as soil loss will compound the above concerns further. With its tropical climate, rugged terrain, and large sugarcane industry, soil loss poses a threat to the island's environment, economy and people (Nigel & Rughooputh, 2010a). In a world where land resources are increasingly coming under pressure, a need remains to better understand and quantify soil loss and erosion due to erosive rainfall, particularly within the context of climate change and changing rainfall regimes.

## 1.1 Land degradation and soil erosion

As much as 15% of the Earth's ice-free land surface has been historically affected by some form of land degradation, 56% of which comes as a result of water erosion in the form of rainfall, rivers, and oceans (GLASOD, 1990). This is a concern for land as Khanbilvardi & Rogowski (1986) reveal that erosion of the landscape results in the loss of fertile topsoil and a decrease in soil depth, increased crusting, as well as rill and gully development. If left unchecked, this can lead to poor fertility, poor infiltration, increased runoff and land degradation, affecting the region's economy and environment. Severe soil loss is most often irreversible and difficult to prevent (Chapman, 2005).

Soil erosion is one of the most widespread form of land degradation, particularly when associated with changes in land use and is of particular concern in areas of expanding agricultural activity (Southgate, 1990). Agriculture, changing land use, soil degradation (Cotler & Ortega-Larrocea, 2006; Szilassi *et al.*, 2006) and poor land management are key elements of soil erosion (Thornes, 1990; Kosmas *et al.*, 1997; García-Ruiz, 2010). Attempts to model soil loss and erosion (Wischmeier & Smith, 1978; Renard *et al.*, 1997) has led to the suggested inclusion of environmental and agricultural policy in Mexico at a legislative level to control changes in land use and type in an attempt to mitigate erosion (Cotler & Ortega-Larrocea, 2006; Bakker *et al.*, 2008). Climate change can potentially offset any positive changes that have taken place in land cover and erosion (Cebecauer & Hofierka, 2008).

Erosion is the natural detachment and transport of particles by erosive agents such as the movement of wind, water and ice, from one area to another but can be accelerated by anthropogenic influences (Govers *et al.*, 1990; Flanagan, 2002). The process is made complex by the numerous mutually interacting factors that can affect it (Cebecauer & Hofierka, 2008). This creates problems for the 'on-site' area as well as the area where sediment is deposited (Lal, 2001). Atawoo & Heerasing (1997) point out that the erosion of soil depends on a number of factors which include erosivity of the rain, erodibility of the soil, slope length and steepness, crop practice and conservation practice.

There has been a growing awareness over the past years of the potential impact that climate change will have on soil erosion and its many aspects. Cebecauer & Hofierka (2008) state that changes in temperature, precipitation and evapotranspiration resulting from climate change can lead to a change in land cover type, vegetation and hydrological regimes which will affect the ability of soil particles to be eroded and transported. Although the general relationship between climate and erosion is long understood (Langbein & Schumm, 1958), there are a

number of challenges to consider when investigating climate change and its impact on erosion. These include issues of spatial and temporal scale, temporal discontinuities, and anthropogenic influences (Imeson & Lavee, 1998).

Within the context of climate change and soil loss, erosion resulting from rainfall is complex. Rainfall amounts, intensities and precipitation days may change and can indirectly affect vegetation and land cover. When considering climate change, Boardman & Favis-Mortlock (1993) note that higher rainfall amounts and intensities, and not higher temperatures are what threaten to increase the potential of soil erosion (see also O'Neal *et al.*, 2005). With respect to the island of Mauritius, this is a concern as Yang *et al.* (2003) show that regions with an increasing trend of precipitation and a simultaneous increase in population would face serious soil erosion problems resulting from land use change by humans and agriculture. There is a need to quantify soil erosion to aid in better understanding and managing soil loss.

The Universal Soil Loss Equation and its subsequent version, the Revised Universal Soil Loss Equation, created by Wischmeier & Smith (1978) and Renard *et al.* (1994, 1997) respectively, were developed to quantify soil loss and to better understand and manage soil erosion at a hillslope scale. The RUSLE and USLE are designed to predict the long-term average annual soil loss from specified field slopes under particular land use and management systems (Renard and Freimund, 1994; Wang *et al.*, 2002). Modeling soil erosion is complex because soil loss varies spatially and temporally depending on many factors and their interactions but the RUSLE takes into account soil erodability, slope length and steepness, conservation practices, crop type and rainfall erosivity. Elements of the RUSLE are dealt with in more detail in the chapter that follows.

## 1.2 Rainfall erosivity

Climate and land use are the major external agents of water erosion (Yang *et al.*, 2003). Although land use plays an important role in runoff and erosive processes, a number of other factors also have to be considered. Among these, rainfall is one of the key factors to consider (Nearing, 2001; Wei, 2007). Within the USLE/RUSLE formulae, the 'R-factor' or run-off erosivity factor represents the runoff and erosion that results from rainfall. A number of similar definitions are available for rainfall erosivity (RE) but it can be summed up as "a measure of erosive force of rainfall to cause soil erosion" (Zhang *et al.* 2010: 102). It is the sum of the erosivity index (EI) values for all rainfall events in one year (Wang *et al.*, 2002). Soil loss due to rainfall is of particular value as Angulo-Martínez & Beguería (2009: 111) state: "Rainfall erosivity is of

paramount importance among natural factors affecting soil erosion and, unlike some other natural factors, such as relief or soil characteristics, is not amenable to human modification.” With rainfall erosivity so dependent on climate and weather patterns, climate change presents a challenge in understanding, modeling and managing soil loss.

It has been found that several very intense rainfall events are responsible for the largest proportion of soil erosion (Angulo-Martínez & Beguería, 2009). Just as important as the climate and weather patterns of an area or region are the environmental conditions including topography and slope which also play a key role in the extent of damage or influence that rainfall erosivity has in contributing to soil loss. Whereas some factors that control the type and extent of erosion, erosion that results from intense rainfall is one of the significant factors to consider and estimating rainfall erosivity is vital to the assessment of soil erosion risk (Angulo-Martínez & Beguería, 2009). When other factors are kept constant, it is found that the larger the  $R$  factor, the higher the potential annual soil loss (Wang *et al.*, 2002).

Rainfall erosivity (RE) deals with the kinetic energy associated with rainfall and takes into consideration the peak intensity and duration of the rainfall event (Salles *et al.*, 2002). Most commonly used in calculating RE is the 30 minute erosivity index ( $EI_{30}$ ) which is calculated by multiplying the total kinetic energy ( $E$ ) with the maximum 30 minute rainfall intensity of an event ( $I_{30}$ ) (Yin *et al.*, 2007). With respect to soil loss, understanding the amount of kinetic energy in a rainfall event is vital as this is the energy that detaches and dislodges soil particles allowing it to be transported. Kinetic energy in the raindrops also contributes to other processes such as soil splash (van Dijk *et al.*, 2002).

The relationship between rainfall and runoff is well studied. When other input factors are held constant, soil losses are directly proportional to the rainfall–runoff erosivity factor  $R$  (Wang *et al.*, 2002). The importance of rainfall erosivity is found as follows: Van Dijk *et al.* (2002) mention that the soil that is detached by a particular depth of rain is related to the intensity of the rainfall that is received. One of the main factors affecting the erosion intensity or potential erosion on slopes is related to the frequency and different magnitudes of rainfall events in combination with geomorphic thresholds (Baker, 1977). Capolongo *et al.* (2008) show that rainfall erosivity constitutes an important factor for understanding the many hydrological and geomorphologic processes taking place in a landscape, such as soil erosion, mudflows, flash floods and leaching.

### 1.3 Elevation and rainfall erosivity

When dealing with rainfall erosivity, the formation of rainfall, its associated erosivity and a regions rainfall related topographic features (such as mountains, hills or escarpment) must be considered. The forcing of air due to topographic obstacles is responsible for the rainfall that many areas receive as well as creating a rain shadow effect (Hewitt, 2004; Lockwood, 2005).

Within the context of an island environment, the rain shadow effect plays a key role in its hydrological processes (Terry & Wotling, 2011). Relief, topography and large topographic features (hills, valleys) can greatly promote high rainfall depths and spatial variations on islands. Terry & Wotling (2011) note that on mountainous islands, adiabatic cooling takes place when moist oceanic winds (with a predominant direction, such as Trade winds) encounter high-elevation topography, creating uplift, or the forcing of air over a topographic obstacle. Favourable conditions are thus created for the development of cloud and rainfall, as well as affecting humidity and rates of evapotranspiration (Custodio *et al.*, 1991; Terry & Wotling, 2011). This has implications for the erosivity on an island as the distribution of rainfall and possibly its intensity are not uniform.

### 1.4 The case of Mauritius

A number of studies have been performed on Mauritius to investigate erosion on the island. Nigel and Rughooputh (2010a; b) mapped erosion risks on mainland Mauritius and showed that 29% of the island was experiencing high erosion, with 58% of its land experiencing moderate or greater extent of erosion. Le Roux *et al.* (2005) predicted soil loss at a catchment scale under changing land use conditions using SLEMSA and RUSLE and showed that changes in land use will influence soil loss with changes to that of pineapples or vegetable crops posing the greatest threats to soil loss. Until now, much of the erosivity and soil loss studies have been limited by the availability of detailed rainfall data. The chapter that follows addresses research concerning Mauritius in more depth.

With rainfall being the key factor in determining the Erosivity Index, it is important to understand the responsible weather systems and climate of the region (Sauerborn *et al.*, 1999; Angulo-Martínez & Beguería, 2009). Investigating trends in rainfall erosivity as well as other aspects such as magnitude and frequency are important in understanding current and future states of soil environments. With regards to rainfall erosivity, limited work concerning its effect on soil loss has been undertaken. Mauritius makes an interesting case study with respect to

rainfall erosivity as the central regions of Mauritius experience an average annual rainfall of 4000mm, while the western coastal regions of the island experience just 600mm and approximately 1200mm falling on the eastern side of the island (Nigel & Rughooputh, 2010a). These differences are significant as Mauritius measures only around 45km from east to west. Orographic lifting resulting from the island's topography contributes to much of the rainfall the island receives (Fowdur *et al.*, 2006). A gradient in rainfall such as this therefore presents an opportunity to investigate rainfall erosivity associated with different rainfall regimes and the accuracy of RE at differing time intervals.

## 1.5 Rationale

A number of studies using the Universal Soil Loss Equation's 'R-factor' have taken place across the globe in a variety of environments. Each study focused on varying aspects of rainfall erosivity and much work has been put into exploring this subject. Studies have taken place in highland environments (Nyssen *et al.*, 2005), Mediterranean regions (Capolongo *et al.*, 2008) as well as inland continental areas (Zhang *et al.*, 2010). However, limited work has been performed on rainfall erosivity within isolated tropical island environments. Also, the role of topography on rainfall erosivity has been considered by a limited number of researchers. Topography has been found to influence erosivity in the Ethiopian Highlands (Nyssen *et al.*, 2005), the Himalayas (Bookhagen and Burbank, 2006), as well as the Drakensberg (Nel & Sumner, 2007). Limited work has been performed on how the topography of an island affects the rainfall erosivity it experiences. This project aims to address this.

As noted, most studies make use of a 30 minute rainfall intensity period when calculating the Erosivity Index of RE. The use of smaller temporal resolutions in calculating the Erosivity Index is investigated. Furthermore, this project aims to investigate the value of short term rainfall erosivity values compared to using the Modified Fournier Index, which uses monthly and annual rainfall data to calculate erosivity. Better accuracy and prediction of rainfall erosivity will help create a more accurate estimation of soil loss on the island (Yin *et al.*, 2007). The project determines whether a finer temporal scale in determining rainfall erosivity would be beneficial.

An opportunity exists to investigate the attributes of rainfall erosivity in areas experiencing low and high rainfall totals within a small tropical maritime island environment resulting from orographic lifting. Using the western edge and central interior of the island of Mauritius (where the lowest and highest totals of rainfall are experienced within a short



horizontal distance) as a case study, with its elevated topography and high rainfall gradient, various attributes of rainfall erosivity can be compared.

The project also investigates the effect that two different climate change scenarios can have on the rainfall erosivity that the island experiences. This can have implications on the land use and productivity of Mauritius. When investigating literature it is clear that land use, climate change and soil loss are interlinked (Boardman & Flavis-Mortlock, 1993; Dale, 1997; Mosier, 1998; Cotler & Ortega-Larrocea, 2006). The importance in modeling future rainfall and erosivity is best summarized in the comment made by Zhang *et al.* (2010: 106): “As we look forward to a changing future for rainfall erosivity, there is a need for more careful monitoring and updates related to erosivity, which is a critical component for conservation planning and for implementing conservation programs.”

## 1.6 Aim and objectives

The aim of the project is to use Mauritius as a case study to investigate the role that an elevated topography has on the attributes of rainfall erosivity on an isolated tropical island environment. To achieve the above, the following objectives have been set out:

- **Objective One:**  
Perform a comparative study of rainfall erosivity ( $EI_{30}$ ), erosive rainfall and events experienced by areas receiving low and high rainfall resulting from the elevated topography in Mauritius
- **Objective Two:**  
Analysis of rainfall erosivity in western Mauritius using periods of 5 consecutive 6 minute intervals, and set 30 and 60 minute intervals
- **Objective Three:**  
Compare the use of the Modified Fournier Index to the standard  $EI_{30}$  method in calculating rainfall erosivity in Mauritius
- **Objective Four:**  
Investigate the effect of two different climate change scenarios on rainfall erosivity in Mauritius

## **1.7 Outline of the project**

The project has been separated into seven chapters. First, the above Chapter presents an introduction to the project with a brief overview of soil loss, rainfall erosivity and climate change as well as the context of the project. The second chapter presents a review of literature on the RUSLE formula, rainfall erosivity and soil loss with respect to islands, the tropical environment and climate change. Chapter Three provides information regarding the study area and background of the island including information on its topography, geology, climate and land use. Chapter Four outlines the methodology followed and used in analyzing and mapping the data used in the project. Following the methodology, Chapter Five presents the results produced from the investigation after which Chapter Six provides a detailed discussion of these results. Finally, Chapter Seven concludes with a summary and the conclusions of the project along with recommendations for future studies.

## Chapter Two: Literature Review

This chapter discusses the literature available on rainfall erosivity and soil loss within the context of a tropical island environment.

### 2.1 Introduction

Soil is present in most regions and landscapes of the planet and plays a crucial role in supporting natural ecosystems (Singer & Warkentin, 1996). Soil provides a medium for plant growth (providing nutrients, water and air), acts as a reservoir for water, influences water quality, aids in the recycling of dead plants and animals and provides a habitat for numerous organisms (Chapman, 2005). The erosion of soil is thus a major problem that many countries face (Lal, 2001) particularly in agriculture and developing countries across the world (Morgan *et al.*, 1998). Erosion of soil is often the cause of economic, socio-economic and environmental problems that are experienced in the world (Lal, 1998). Some of the numerous problems associated with soil loss and erosion are a decrease in the quality and productivity of the soil, pollution, loss of top soil, sedimentation, as well as off-site problems which include siltation and pollution of water bodies (Martin-Moreno *et al.*, 2008) and an overall increase in land degradation. Yang *et al.* (2003) state that soil erosion is a principal degradative process resulting in a decrease in effective root depth, nutrient and water imbalance in the root zone, and reduction in productivity. It is a major environmental threat to the sustainability and productive capacity of agriculture. The increase in human and animal populations has compounded this problem (Lal, 2001).

Soil erosion is a three stage process which is accomplished through 'work' from energy provided from physical sources (wind, water and ice), gravity, chemical reactions and anthropogenic influences. The three stages of erosion are: (1) detachment of soil, (2) transportation and (3) deposition of soil. The severity of erosion processes is determined by the rate and magnitude of energy providing such forces. Soil erosion is affected by the interaction of a number of factors including soil properties, climatic variables, ground cover and topography (Lal, 2001).

Soil erosion by water is considered to be the major form of erosion and includes processes such as runoff, rainsplash, rill and gully development (Chapman, 2005). Although it is sometimes considered to be a purely natural process caused by rainfall and water flow, human activities greatly aggravate erosion through alteration of land cover and disturbance of soil structure through cultivation (Yang *et al.*, 2003). Erosion due to water and rainfall is a complex process resulting from the interaction between the soil, climate relief, surface cover and land

use (Hoyos *et al.*, 2005). Countries such as Kenya have instituted management programs to minimize the problems associated with erosion. To be effective at implementing these preservation programs, knowledge is needed; management practices to minimize such problems can only be effectively carried out if the magnitude and spatial distribution of soil erosion are known (Oyando *et al.*, 2005). Yang *et al.* (2003) note that for a better understanding of environmental issues on the planet, it is desirable to have a global view of past and present soil erosion, as well as a projection of future soil erosion.

## 2.2 The USLE and RUSLE

Quantifying soil loss has been the subject of study for a number of decades, with research being conducted as far back as the 1940's (Wischmeier & Smith, 1978). A number of models have been developed and put into practice in an attempt to quantify soil loss. These include the Water Erosion Prediction Project (WEPP) (Flanagan & Nearing, 1995), the European Soil Erosion Model (EUROSEM) (Morgan *et al.*, 1998), Mediterranean Rainfall Erosivity Model (MEDrem) (Diodato & Bellocchi, 2010) and, more locally, the Soil Loss Estimation Model for Southern Africa (SLEMSA) (Elwell, 1976). These models consider a variety of factors and each one has its own limitations and advantages.

One of the most extensively used models in quantifying soil loss is the Universal Soil Loss Equation and, in its updated format, the Revised Universal Soil Loss Equation (Renard *et al.*, 1997). The RUSLE is calculated by using the following formula (Renard *et al.*, 1994):

$$A = R \cdot K \cdot LS \cdot C \cdot P$$

The factors in the formula are as follows:

- A - Predicted soil loss (tons<sup>-1</sup> acre<sup>-1</sup> year).
- K - Soil erodibility or the susceptibility of a particular soil to erosion and rate or runoff measured on a standard plot.
- L - Slope length represents the ratio of soil loss from the field slope to that from a 22.1m length on the same soil type and gradient. Slope steepness and length are generally used together when calculating the RUSLE.

- S - Slope steepness represents the role of slope steepness on erosion and, similarly to slope length, it is the ratio of soil loss from the field gradient to that of a 9% slope under identical conditions.
- R - Rainfall runoff erosivity factor, which is discussed in detail later.
- C - Crop type and management calculated by using the ratio of soil loss from an area with specified cover and management to that of an area tilled in continuous fallow.
- P - Supporting conservation practices factor which is the ratio of soil loss with a supportive practice (such as strip-cropping and contouring) to that with straight row farming.

The Universal Soil Loss Equation was initially developed between 1940 and 1956 from a need to quantify field soil loss in the 'Corn Belt,' the Midwestern region of the United States where corn is predominantly cultivated. Working with slope length and steepness, a number of factors were added and/or developed until the formula was published in its current form by the National Runoff and Soil Loss Data Center (Wischmeier & Smith, 1978). The formula has since been developed to create the Revised Universal Soil Loss Equation in which all the factors of the formula were re-examined, modified and improved. The resulting formula is accepted to provide a more accurate and 'scientific' estimate of actual field conditions (Renard *et al.*, 1994; Toy & Foster, 1998).

The advantage of using the USLE or RUSLE model is that it has been widely applied and tested over many years and the validity and limitations of this model are well known (Renard *et al.*, 1997). The disadvantage of this model is that it was developed using data from the Midwest of the USA, and therefore significant adjustments are required to the algorithms used to derive the key factors before the model can be applied to other areas (Shamshad *et al.*, 2008). Also, one of the limitations of RUSLE is that sedimentation processes are neglected in the equation (Siakeu and Oguchi, 2000). Users of the USLE and RUSLE formulae should be reminded that they are empirical relationships and should be considered valid only within the range of experimental conditions from which they are derived. Only the rainfall erosivity and soil erodability factors in the formula have units (Renard & Freimund, 1994).

### 2.3 Rainfall erosivity

Arguably, one of the most important elements of the USLE and the RUSLE is the  $R$ -factor (Wischmeier & Smith, 1978; Shamshad *et al.*, 2008). If all other parameters of the formula are held constant, soil loss is directly proportional to the rainfall erosivity (Wang *et al.*, 2002). The  $R$ -factor in the RUSLE is the sum of individual erosive event EI-values for a year averaged over long time periods to accommodate cyclic rainfall patterns. Of the six factors considered in the USLE/RUSLE, the  $R$ -factor is the most precisely defined (Yu *et al.*, 1998). Rainfall erosivity is the ability of rainfall to cause soil loss on hillslopes (Yin *et al.*, 2007) and it is an indicator of the aggressiveness of precipitation (Angulo-Martínez & Beguería, 2009). Van Dijk *et al.* (2002) state that it is well established that the amount of soil that is detached by a particular depth of rain is related to the intensity at which this rain falls. Zhang *et al.* (2010) found that in China a 1% increase in rainfall erosivity is associated with a 1% increase in soil loss. Rainfall erosivity (RE) is a major control on splash detachment and is dependent on the kinetic energy (KE) of the rainfall which varies with drop mass and rainfall intensity (Brooks & Spencer, 1995).

In rainfall erosivity studies, the  $R$ -factor is derived by calculating the mean annual sum of individual erosive event erosion index values ( $EI_{30}$ ), which depends on the value of the KE, the total kinetic energy ( $E$ ) of the erosive event and the  $I_{30}$  value, or the maximum 30 minute rainfall intensity (Shamshad *et al.*, 2008). The EI term is an abbreviation for energy multiplied by the maximum intensity in 30 minutes (Renard & Freimund, 1994). In the development of the RUSLE formula, Wischmeier & Smith (1958) found that the maximum 30 minute intensity (as compared to other time periods) when multiplied by the kinetic energy of the erosive event provided the best correlation with soil loss. This interval is used when breakpoint data are read manually from graphical charts produced by continuously recording rain gauges, where time intervals indicate same or similar intensities (Yin *et al.*, 2007). Rainfall gauges that produce such breakpoint data are often not available, and recent research has made use of fixed time interval rainfall data in erosivity data (Yin *et al.*, 2007).

A key element in the energy portion of  $EI_{30}$  is that of kinetic energy and raindrop size. The KE of a unit rainfall amount depends on the size and terminal velocity of raindrops. These are both related to rainfall intensity. The total erosive event energy depends on the intensities at which the rainfall occurs and the amount of rainfall that occurs at each intensity (Wischmeier & Smith, 1978; Renard & Freimund, 1994). This can be calculated from recorded rainfall data and the depth of the rainfall during a time increment. Erosive event characteristics can also be highly variable, with some erosive events having multiple peak intensities in a single event which can aggravate rainfall erosivity (Salako *et al.*, 1995).

The size of the raindrop has importance for rainfall erosivity as drop size is related to the terminal velocity of the raindrop as it falls. The larger the raindrop size, the greater its terminal velocity and the greater the energy the raindrop carries to dislodge soil particles. Another aspect of rainfall erosivity is that the kinetic energy of the raindrop as it hits the ground is expressed as  $E_k=mv^2$  or the product of the mass of the drop and the square of its terminal velocity. Side winds, altitude, canopy, and ground cover can alter the energy the drop carries by the time it reaches the ground (van Dijk *et al.*, 2002). Raindrops that have a diameter of larger than 3mm are considered to be erosive (Salako *et al.*, 1995). However, determining energy from raindrop size is difficult, and since such data are often difficult to attain, estimations for the intensities of erosive events have been developed (see Kinnell, 1981; Renard & Freimund, 1994).

Researchers frequently make use of rainfall data, such as breakpoint data (Yin *et al.*, 2007) and pluviographs (Angulo-Martínez & Beguería, 2009) gathered from weather stations, as a valuable component in calculating erosivity and soil loss. In calculating rainfall erosivity, the erosivity index is a vital element in its calculation. This index depends on a high temporal scale of data (at least 15 minute intervals of rainfall) when time intervals are used, but many studies have developed methods to determine the *R*-factor using various interpolation and statistical methods. In order for results to be accurate, consistent and usable, long rainfall series of rainfall data are needed that adequately represent the circulation and synoptic weather patterns of the area (Yin *et al.*, 2007; Shamshad *et al.*, 2008; Angulo-Martínez & Beguería, 2009). It is accepted that the 30 minute interval is used when calculating the Erosivity index as it follows the method developed by Wischmeier & Smith (1958). It was found that finer resolution intervals do provide a greater accuracy (Yin *et al.*, 2007). Rainfall erosivity or Factor 'R' in the USLE/RUSLE formulae is the product of the kinetic energy of the rain and the maximal thirty-minute intensity. The product is named index  $EI_{30}$ , erosion index, or index of rainfall erosivity (Yin *et al.*, 2007). When such data are not available, indirect methods and models have been developed in an attempt to calculate rainfall erosivity over time (Renard & Freimund, 1994). Rainfall erosivity is variable over a temporal scale but is also variable over a spatial area. This means that RE should ideally be studied over a geographic area and over long time periods.

It is accepted that a fine temporal scale of rainfall data is needed to accurately represent or calculate the rainfall erosivity through the use of the Erosivity Index. Angulo-Martínez & Beguería (2009) suggest that use of at least 15 minutes of relatively continuous rainfall data series be used for the accurate assessment of the *R*-factor. Therefore, for accurate calculations to be made, it is preferable to have a series of short high resolution data coexisting with a long series at a day resolution (Angulo-Martínez & Beguería, 2009). Although using rainfall at an

hourly scale has provided usable results (Bhattarai & Dutta, 2007; Yin *et al.*, 2007), the  $EI_{30}$  calculated at a 30 minute interval, is the most commonly used and accepted interval of time for calculating the erosivity index (Yin *et al.*, 2007).

Salako *et al.* (1995) show that data collected for the description of rainfall erosivity should be representative of a geographical area before conservation plans are made. This implies that the area and time covered must be substantial. The temporal scale and use of time increments when calculating the erosivity index is a vital aspect to consider when dealing with the erosivity index. Different approaches have been made when calculating erosivity, and appear to be mostly dependent on the type and duration of rainfall data that are provided. Models based on annual totals (Renard & Freimund, 1994; Renard *et al.*, 1997; Capolongo *et al.*, 2008), and monthly totals (Diodato & Bellocchi, 2007; Dabral *et al.*, 2008) in determining RE have been used. However, Diodato (2005) points out that, with reference to RE, that in many cases monthly or annual rainfall totals cannot be assumed as a good representation of the erosivity index. The long time intervals used in these models require the use of regression models and values tend to be underestimated (Diodato, 2005).

Frequently, not enough data are available in reality to compute the R values accurately. Alternate procedures to compute the R factor could make the RUSLE less effective, if proper procedures are not adopted to calculate the R factor (Shamshad *et al.*, 2008). In situations where daily rainfall data have been limited, rainfall kinetic energy and rainfall momentum (Mihara, 1951; Free, 1960) have been used in the past as an indicator of rainfall erosivity (Rose, 1960). In the absence of daily rainfall data, other ways to estimate the R factor are based on regression of intensity precipitation indices on monthly or annual scales. (Angulo-Martínez & Beguería, 2009).

Inherent limitations when calculating rainfall erosivity should also be considered. Hoyos *et al.* (2005) caution against the use of annual averages as 'significant' differences are found between the erosivity produced during wet and dry seasons. Unusually low or high values that are sometimes associated with climatic events are also not taken into account with regression models. Mannaerts & Gabriels (2000a) warn that the use of statistical mean or average values of rainfall and runoff, for calculating soil losses can introduce a serious bias in the evaluation of erosion rates in tropical semiarid regions like the Cape Verde Islands. Mannaerts & Gabriels (2000a) found that a high variability of rainfall that occurs in such regions can cause large overestimations of erosion which arise during dry years. Additionally, underestimations as much as 200% to 500% in wet years are calculated because of extremely large events usually in the wet season causing major impacts on the soil environment and landscape in general.



Some research has been undertaken with success using smaller time intervals in calculating rainfall erosivity, but none has been done on an island environment. Limited work has been done in investigating the accuracy of results that may occur when using time intervals of various lengths, which may be as small as 5 minutes to intervals that are longer than an hour. Yin *et al.* (2007) investigated the use of 5 minute to 60 minute breakpoint rainfall data in erosivity calculation for their work in China. The researchers found that greater temporal resolutions provided better accuracy when estimating rainfall erosivity. As an example: 30 minute intervals provided more accurate results than 60 minute data. However, they also mention that it was not necessary to use less than 30 minute intervals to attain a significantly better result. The research theme is fairly understudied and this project seeks to better understand the effectiveness of smaller intervals when calculating the erosivity index with differing annual totals. The question also remains if the use of such staged time intervals miss the peak intensities when recording rainfall. This project aims to investigate the accuracy of estimated rainfall erosivity from the use of these types of data as compared to estimation from daily, monthly and yearly rainfall totals.

#### **2.4 Elevated topography and rainfall erosivity**

It is well established that topography plays a role in the development of cloud and rainfall through orographic lifting (Hewitt, 2004; Lockwood, 2005; Tobin *et al.*, 2011). Orographic lifting may result in the formation of cloud when air is forced to rise over mountains or other topographic obstacles. As the air is forced up, it cools due to the decrease in pressure and increase in volume as the air mass rises in the atmosphere at the dry adiabatic lapse rate (9.8°C/Km) until its saturation point is reached and cloud is formed due to the condensation of the water vapour within this air mass. The air then continues to rise and cool at the saturated adiabatic lapse rate until this parcel of air is at the same pressure as the external pressure of the surrounding atmosphere (Lockwood, 2005). If air is forced to rise due to topography in a convectively unstable atmosphere, then convective cloud and rainfall can occur. This can create often intense extreme events resulting in severe erosion (Bookhagen & Burbank, 2006). Associated with this is the 'rain shadow' effect: a reduction of rainfall on the lee side of the mountain or influencing topography resulting from the adiabatic warming of air as it descends down the lee side of the mountain, creating drier conditions (Lockwood, 2005).

Bookhagen & Burbank (2006) investigated the large scale relationship between topography relief and rainfall in the Himalayas. They determined that topography and relief not

only cause the high rainfall bands within the Himalayan Mountains but also affect their characteristics. Bookhagen & Burbank (2006) mention that clear relationships emerge between topographic characteristics and the areas where maximums in rainfall occur noting that high rainfall zones are likely to modulate erosion.

The creation of high intensity rain events as a result of topography plays a key role in the depth and type of rainfall and rainfall erosivity within a region. Nyssen *et al.* (2005: 173) state “Next to factors related to the land and its cover, differences of more than 200mm yearly rain can have important repercussions on erosion processes, agricultural productivity, and sometimes on waterlogging.” They also found that steep over-all gradient and not elevation control the spatial distribution of rainfall depth in the Ethiopian highlands. Their work in the highlands found that rain depth was highest where air masses flowing through preferred flow paths (such as large valleys) are lifted over important differences in elevation. The topography of Mauritius is dissected, and on the western portion of the island the topography rises from a sea level to over 600m a.s.l. in less than a 20km longitudinal line creating a high rainfall gradient over the island.

## **2.5 Soil Loss and the island environment**

Although soil erosion takes place in regions across the world in a variety of climatic conditions and biomes, island environments are particularly susceptible to soil erosion as they are vulnerable to climate change. A number of studies have been performed to investigate island environments and the rainfall erosivity that affects them. Like Mauritius, The Cape Verde Islands (located off the coast of West Africa) are influenced by a tropical climate, the Inter Tropical Convergence Zone, anti-cyclones and a number of high and low pressure zones. The region also has extremely variable rainfall regimes, with rainfall amounts generally dependent on elevation. Mannaerts & Gabriels (2000b) used daily rainfall data to determine rainfall erosivity in these islands, but they warn that daily rainfall amounts will always remain an approximate predictor of erosivity. Large under or overestimations are possible with the low and high extreme rainfall depths of an event (Mannaerts & Gabriels, 2000b) which are attributed to the inherent natural variations in erosive event properties. These include durations, high and low intensity periods and an events maximum intensity. Erosive inter-annual variability with some low values and some significantly high values for other years were experienced by the islands. Findings indicated that most of the recorded rainfall erosivity can be attributed to several erosive events that took place during the studied periods (Mannaerts & Gabriels, 2000a; b).

From an historical perspective, Kirtch (1996) performed an examination of a core taken from a central Polynesian island and found that erosion rates on this island over the past 5000 years was influenced mainly by the El Niño -Southern Oscillation events. Only since human settlement has the rate of erosion significantly increased, confirming that human influence on an Island environment can exacerbate erosion problems (Kirch, 1996). Rainfall erosivity was also mentioned in work done by El-Swaify (2002) on the island of Hawaii. The watershed that was investigated underwent a low mean annual soil loss which correlated to a low annual and total rainfall erosivity that the region experienced. Findings from the island were similar to Mannaerts & Gabriels (2000b) in that only a few erosive events were responsible for the majority of the soil loss. El-Swaify (2002) also confirmed that soil cover plays a role in reducing the vulnerability of the soil that could otherwise be washed away.

More recently, Naxos Island (Greece), which has a Mediterranean Environment, was studied in relation to climate change as a driver of soil erosion. In the study, daily rainfall data were analyzed for 52 years and Nastos *et al.* (2010) determined that recent changes in climate over the past decades have produced heavy rains over the island which has resulted in intense runoff. This confirms projections from the IPCC (2007) which indicate that erosion will intensify with more erosive events taking place in the future.

Changes in land use should also be considered. On the island of Borneo, Brooks & Spencer (1995) investigated the extent of rainfall erosivity under a canopy of tropical rainforest and the rainfall erosivity experienced after logging had taken place. The study indicated that changes in rainfall energy can be significant to erosion and need to be included in physically-based models to assess the impact of rain forest disturbance on accelerated soil erosion. Where such vegetation is present, rainfall has similar energy regardless of the intensity at which it is falling. However, little work has been done in investigating rainfall on an island with respect to using smaller time intervals.

Soil erosion from rainfall is an issue that affects tropical regions and island environments around the world due the intense rainfall that is experienced within tropical environments. Hoyos *et al.* (2005) state that rainfall erosivity seems to be higher in tropical regions than in temperate regions of the world. They note that average  $EI_{30}$  values fall within the range observed in other tropical regions of the world, while they are higher than the ones generally found in temperate regions which confirms that in general, higher amounts of rainfall and frequency of intense erosive events occur in the tropics (Hoyos *et al.*, 2005). Rainfall erosivity has also been found to be higher in tropical regions than northern latitudes (Salako *et al.*, 1995) as tropical rains are

more intense and are more concentrated in time than other climates (Alfsen *et al.*, 1996; Lal, 1998; Nyssen *et al.*, 2005).

## 2.6 The uncertainty of climate change

With regards to climate change, much uncertainty exists about if, how and to what extent climate is changing. Because Mauritius is an isolated island, it is susceptible to changes in climate, particularly with reference to the El Niño/Southern Oscillation (ENSO) phenomenon (Lal *et al.*, 2002; Senepathi *et al.*, 2010). Climate change can potentially affect the seasonality of ENSO, which will also directly affect sea surface temperatures, rainfall and air temperatures. Important to consider, especially within the context of this project are changes in rainfall intensity. Global circulation models indicate that, in the Indian Ocean region, there will be slightly less (in the region of 3%) days of rainfall. This is predicted to be coupled to an increase in the intensity of daily precipitation (Lal *et al.*, 2002; IPCC, 2007).

ENSO affects circulation over the Indian Ocean such that Mauritius experiences significantly less rain during La Niña than El Niño years (Senepathi *et al.* 2010.) However, with particular reference to ENSO, much uncertainty remains on whether there will be any change in the amplitude or frequency of El Niño events in the future (Lal *et al.*, 2002). This is confirmed by McSweeney *et al.* (2008) who state “Model simulations show wide disagreements in projected changes in the amplitude of future El Niño events. The climate of Mauritius can be strongly influenced by ENSO, thus contributing to uncertainty in climate projections for this region.” The researchers also mention that the great inter-annual and inter-decadal variations in rainfall over the Indian Ocean region make it difficult to identify long term trends (McSweeney *et al.*, 2008).

Additionally, Mauritius lies in the south western part of the Tropical cyclone belt of the Indian Ocean (Cheeroo-Nayamuth *et al.*, 2000). Cyclones are expected to become more intense and possibly more frequent in the future (although some debate does exist on this matter) as a result of climate change (Walsh & Ryan, 2000; Lal *et al.*, 2002; Knutson & Tuleya, 2004; Webster *et al.*, 2005, Oouchi *et al.*, 2006). Such changes will affect current soil loss rates on the island. Therefore, this project will investigate the following two climate change scenarios given the uncertainty that already exists concerning the projected climate change over small tropical islands (Christensen *et al.*, 2007): first, a change in climatic conditions such that the intensity of rainfall generally decreases over Mauritius and second, a change in climate such that the intensity over the island increases. The value of this current study seeks to assess how

changes in rainfall intensity will affect erosivity on Mauritius considering the uncertainty that currently exists.

## 2.7 Climate change and soil erosion

As mentioned, research has shown that climate change has the capacity to affect erosion rates, particularly erosion resulting from rainfall. Rising atmospheric temperatures and subsequently more intensive hydrologic cycles may also lead to a change in rainfall characteristics and particularly a higher variability of rainfall. This will have an effect on soil erosion (Flanagan & Nearing, 1995; Sauerborn *et al.*, 1999). If extreme climatic events increase in intensity and frequency as a result of climate change then this could affect extreme rainfall events, tropical cyclones, fires and droughts (IPCC, 2007, McClanahan *et al.*, 2008; Nowbuth, 2010). Zhang *et al.* (2010: 97) state “Global changes in temperature and precipitation patterns will impact soil erosion through multiple pathways, including precipitation and rainfall erosivity changes.” Several of these are mentioned: precipitation amounts and intensities, temperature impacts on soil moisture and plant growth, and direct fertilization effects on plants due to greater CO<sub>2</sub> concentrations. When considering the island environment, Mauritius is also subject to a number of tropical cyclones which also have the capacity to influence rainfall erosivity, but the most direct impact will come from the change in the erosive power of rainfall (Nearing, 2001).

Lavee *et al.* (1998) used the term ‘ecogeomorphologic’ and ‘climo-ecogeomorphological’ systems when reporting on their investigations on how soil erosion might change under a changing climate. Soil, water, vegetation and erosion are interlinked, and responses in one of these elements to climate change will affect the other elements. Yang *et al.* (2003) estimate nearly 60% of present soil erosion on the planet was induced by human activity and with the development of cropland in the last century. Potential soil erosion is estimated to have increased by about 17%. Their projections show that soil erosion increases in the most dense population areas due to land use changes, but climate change induces a different type of erosion change.

Climate change and its impact on the extremes in climate and weather can affect patterns in rainfall and its associated rainfall intensities (Sauerborn *et al.*, 1999; Capolongo *et al.*, 2008). These impacts can affect the amount of ‘geomorphic work’ or the energy that the rain provides for the movement of topsoil and surface materials and the associated modification of the landscape. Rainfall frequency and magnitude are therefore essential factors in the role that climate and climate change has on influencing the morphology of the landscape (Baker, 1977).

Understanding how soil erosion will change in the future is not an easy task. Boardman & Flavis-Mortlock (1993) mention that prediction of erosion in the future has to be based on a thorough understanding of land use as well as climate and the physical processes involved with water and wind erosion. The prospect of higher rainfall amounts and intensities threatens to increase soil erosion more than higher temperatures. Nearing (2001) confirms this by stating the most consequential effect of climate change on water erosion will be in changes of erosive power of rainfall. Research shows that the response of erosion to climate change is far more sensitive to changes in rainfall intensity and amount than other erosive factors (Nearing *et al.* 1989). It should be noted that changes in soil erosion will not be uniform, but will vary from region to region as some areas will become drier and other areas wetter (Nearing, 2001).

A core concept in the discussions around climate change is that of 'adaptive capacity' or the potential of a society to adapt with the changes (if any) that might occur in the social-ecological system from climate change (IPCC, 2007; McClanahan *et al.*, 2008). Changes in climate have the potential to affect the agricultural industry which in turn can affect economic investment and population movements in countries. The livelihoods of many people, notably the poor and vulnerable, could be threatened if government and resource managers are not prepared for even the modest changes associated with climate change (Downing *et al.*, 1997).

Zhang *et al.* (2010) and Sauerborn *et al.* (1999), among others, have used Global Circulation Models (GCM's) to project future rainfall erosivity. Challenges that they faced include a need to downscale some of the data and to apply it in particular regions. Both studies used monthly rainfall data. A question remains on the value of daily and hourly data when using various datasets and how this might affect future predictions. Statistical relationships between monthly and annual precipitation and rainfall erosivity have been used to study the *R*-factor changes with GCM outputs (Renard & Freidmund, 1994; Nearing, 2001). Generally, monthly and annual precipitation values are used to calculate rainfall erosivity values. The study by Zhang *et al.* (2010) showed that a 1% increase in rainfall erosivity in China will negatively affect the soil resources and 'significantly' impact on agricultural production. The increase in erosive power of rainfall is not the only concern of climate change. A rise in temperatures and increase in droughts may also affect the magnitude of the erosion that takes place. It has been suggested that 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 the break-down of its structure (Potratz, 1993; Sauerborn *et al.*, 1999).

Nearing *et al.* (2005) point out that soil erosion responds both to the total amount of rainfall as well as differences in rainfall intensity with the dominant variable appearing to be

rainfall intensity and energy rather than just rainfall amount. They list four points regarding climate change and its impact on rainfall erosivity:

- Erosion is likely to be more affected by changes in rainfall and cover than runoff, though both are likely impacted in similar ways.
- On a purely percentage basis, erosion and runoff will change more for each percent change in rainfall amount and intensity of an extreme event than to each percent change in either canopy or ground cover.
- Changes in rainfall amount associated with changes in extreme event rainfall intensity will likely have a much greater impact on runoff and erosion than changes in rainfall amount alone.
- Changes in ground cover (cover in contact with the soil surface) have a greater impact on both runoff and erosion than changes in canopy cover alone.

## **2.8 Soil erosion, Mauritius and rainfall erosivity**

Soil erosion is a problem on Mauritius. Nigel and Rughooputh (2010a; b) used the Mauritius Soil Erosion Risk Mapping (MauSERM) model to investigate soil erosion risk on the island and findings show that as much as 50% of arable land has undergone some form of erosion. Moderate to severe soil loss was found in land under banana, pineapple and mixed cropping systems. In addition moderate sheet erosion was found to have occurred in sugercane fields and grazing land (Anon., 1992, see also Atawoo & Heerasing, 1997). Nigel and Rughooputh (2010a) cite rugged topography, its sugercane cultivation, and tropical climate as the main factors that make Mauritius vulnerable to soil erosion. Mean monthly data were used by Nigel and Rughooputh (2010a; b) to determine the erosivity of the Island using the Modified Fournier Index. Results show that the western portion of the island experienced low erosivity, which agrees with the low annual rainfall that the region experiences. During January and February, however, the entire island experiences very high erosivity due to torrential rains. The central and eastern parts of the island experience the highest erosivity on an annual basis, with most of the erosivity experienced during the wet season. Sugercane does offer some protection to soil erosion from rainfall (about 80%, and as much as 99% on certain soil types) (Ramjeawon, 2004; Seeruttun *et al.*, 2007). The sugercane industry uses a large amount of fertilizers which also carries implications for soil erosion (Drechsel *et al.*, 2001; Ramjeawon,

2004). An increase in fertilizers usage may mitigate the loss of soil but does carry concerns for health and the destruction of natural habitats (Pimentel *et al.*, 1995).

Le Roux (2005) investigated soil loss at a catchment scale using the RUSLE and SLEMSA models. Within the context of changing land use, the study confirms that soil erosion within sugercane is less than under other vegetables. The most vulnerable time for erosion is in the early part of the wet season when there is high rainfall but vegetation has not fully developed. The use of the RUSLE model also provided much lower values of soil loss than the SLEMSA model. This was attributed to the high sensitivity that SLEMSA had to rainfall energy.

The studies mentioned above used the Modified Fournier Index (MFI) when calculating rainfall erosivity used in the soil erosion calculations, which is dependent on monthly and annual totals. Atawoo & Heerasing (1997) investigated two methods to assess rainfall erosivity on Mauritius, one method (following Arnoldus, 1977), which also used the MFI, used both monthly and annual totals and the second method used purely annual rainfall totals (see Lo *et al.*, 1985). Findings show that using only annual totals produced values that were too high. The Arnoldus (1977) method produced results that were more acceptable, but as yet, no studies have used rainfall time intervals of less than 30 minutes in Mauritius.

This chapter has presented an introduction to rainfall erosivity with past and recent literature on the subject. The Revised Universal Loss Equation and soil erosion was briefly discussed to provide some context and background to this study. The effect of climate change, its uncertainty with regards to rainfall and ENSO, and effect on soil loss was also introduced. Furthermore, relevant research that has taken place concerning soil erosion on Mauritius was provided.



## Chapter 3: Study Area

This chapter provides a background to the locality, geology, topography, pedology, climate and land cover of Mauritius.

### 3.1 Location

Mauritius forms part of the Mascarene Islands with Reunion, Agalega, Saint Brandon and Rodrigues. It is approximately 40km across (East - West) and 60km in length (North - South). Its geographical location is in the southwest Indian Ocean at latitude 20°10' S and 57° 30' E, 900 km east of Madagascar, has an area of 2 040 km<sup>2</sup> and a maximum elevation of 828m a.s.l. The nearest island is Reunion which is located 200km southwest of Mauritius. The capital of the Island is Port Louis, with a major population center at Curepipe. The main airport is Sir Seewoosagur Ramgoolam International Airport (SSR Airport) located on in the south eastern region of the island (Figure 3.1).

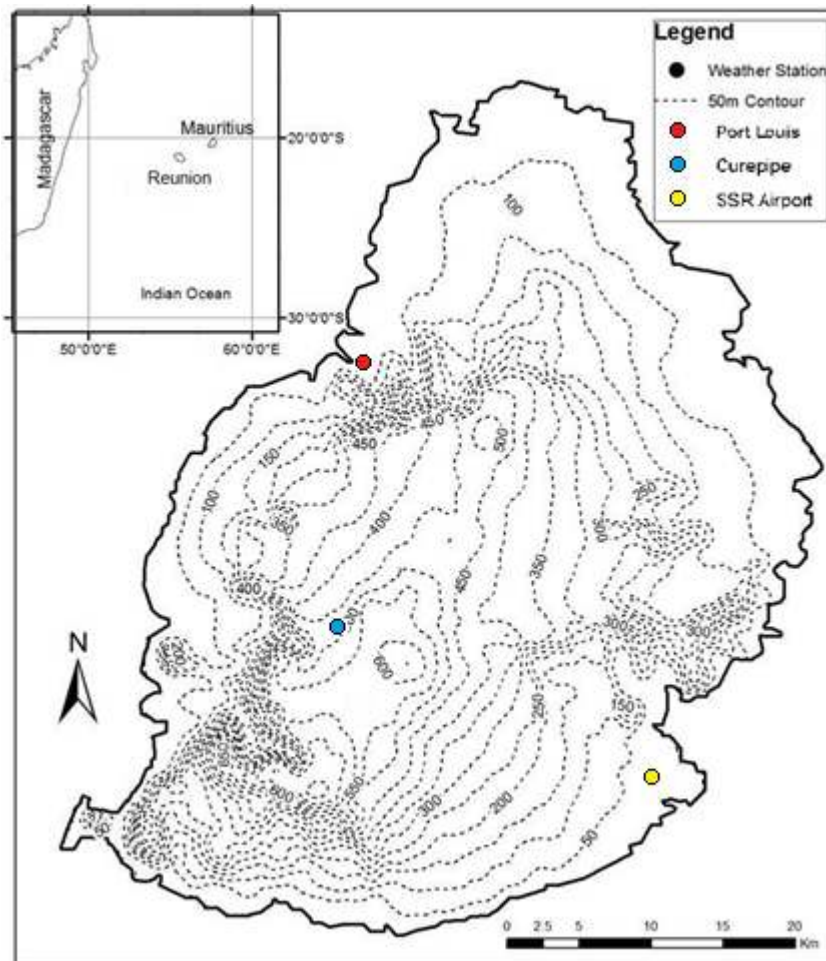


Figure 3.1: Locality and elevation map with the location of the capital Port Louis, SSR Internation Airport, and Curepipe, a major population center.

## 3.2 Geology

Mauritius is almost entirely a volcanic island comprising basalt of differing densities due to the complex nature of its formation (Proag, 2006). Exceptions to this are beaches, coral reefs and alluvium that occur along the coast. According to Simpson (1951), the island was formed as a result of two major periods of volcanic activity, namely:

- Emergence and Older Series (10 – 5 million years ago)
- Intermediate and Younger Series ( 3.5 million years to 25 000 years ago)

These periods of activity can be separated by their relative chronological development to show four major phases in the formation of the island; the Emergence of the island, Older Volcanic Series, Intermediate or early volcanic series, and the Younger Volcanic or Late volcanic series. Mauritius is the second youngest island in the Reunion mantle plume track stretching northward from Mauritius to the Mascarene Plateau, the Chagos–Laccadive Ridge, and the Deccan Traps of western India, respectively (Morgan, 1981; Duncan & Richards, 1991).

Briefly, the geologic history of the island can be described as follows:

The emergence period of the island (10-6.7 million years ago) started as a rift in the ocean floor acted as an eruptive fissure emitting volcanic product. The original island foundation was made up of pillow lava and was characterized by a bulge in its structure. A 500 000 year period of calm followed which caused subsidence to take place in the center of the island as the underlying magma decreased in pressure (Proag, 1995).

The second phase (6.2 – 5 million years ago) is one where the island was characterized by a single volcano with a circular, shielded shape. A vast 40km diameter, 900m high portion of the volcano emerged from the ocean. The period was marked by occasional lava flows (50-100m thick) and a crumbling on the shield summit creating a caldera 24km in diameter (Proag, 1995). This period gave rise to transitional basalts now found in the island (Paul *et al.*, 2007).

After about 1.5 million years of calm geologic activity coupled with intense erosion, the intermediate series or “Early Lavas” were produced by volcanic activity from smaller vents and at a smaller scale than had previously been experienced. This lasted from 3.5 – 2 million years ago (Proag, 1995).

The younger series (1.9 million – 25 000 years ago) also takes place after a period of calm geologic activity and weathering when renewed eruptions took place 700 000 – 25 000 years ago from 26 craters (linked to a reactivation of a separate rift). In addition, sea level

fluctuations, intense cutting of valleys and gorges took place during this period, affecting much of the topography of the island (Proag, 1995).

The raised central region which lies higher than 550m (Figure 3.1) affects the island's climate and can be attributed to the geological processes that formed the island as well as some of the more recent erosive processes. From a geologic perspective, except for the sandy beaches, the island is predominantly made up of basalts, trachytes, and pyroclastic "old, intermediate, and new lavas" (Figure 3.2).

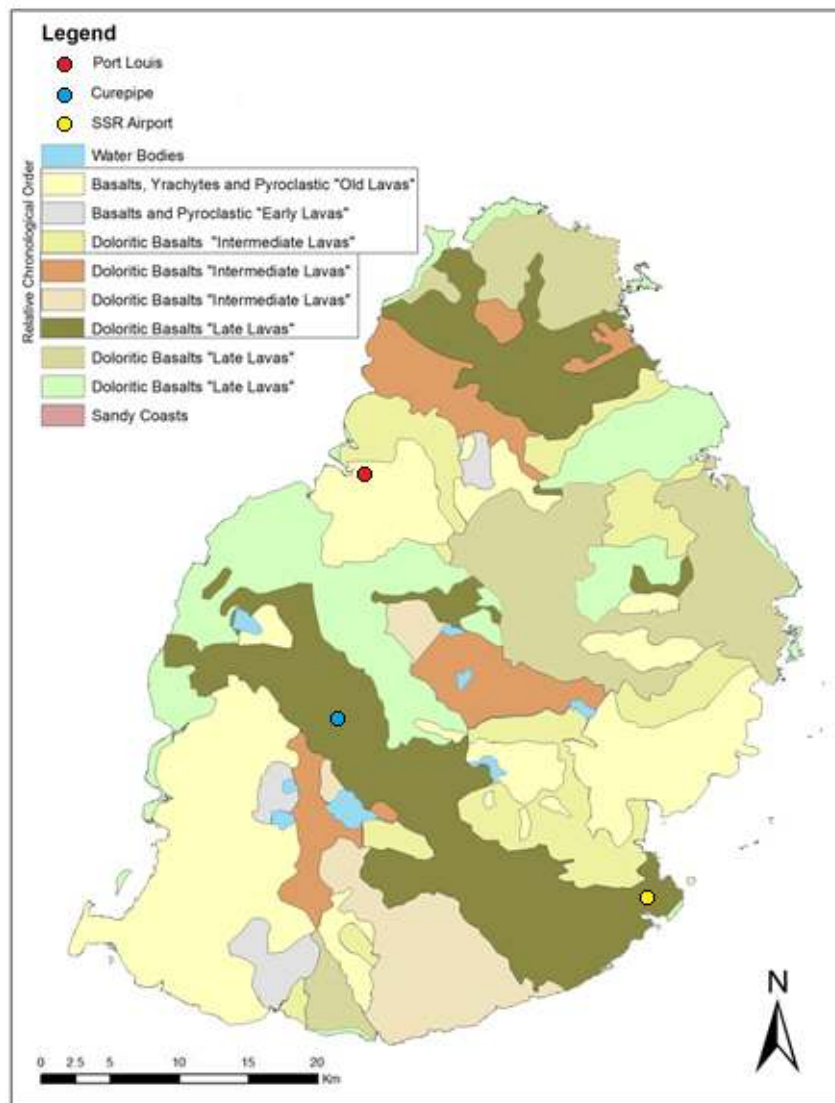


Figure 3.2: Summary of the geological development of Mauritius (after Proag, 1995).

### 3.3 Climate

Mauritius experiences a tropical climate that is influenced by the surrounding ocean and two main weather regimes: the seasonal tropical cyclones and the South-easterly Trade Winds. Orographic lifting takes place over the island as a result of its raised topography and has contributed to the creation several micro-climates (discussed below) (Nigel & Rughooputh, 2010a).

Rainfall is the only source of water for rivers, agriculture and human needs. No snow occurs and no water from the ocean is exploited for the population. On an annual basis, February and March are the wettest months (Proag, 1995). The wet season takes place from November to the end of April and the dry season from May to October, with 70% of the rainfall occurring during the wet season (Nigel & Rughooputh, 2010a). The rainfall that the island generally experiences comes from the orographic lifting of the moisture found around the circulation of weather systems that move over the island and occasional cyclones and depressions. In the summer months, rainfall is attributed to a series of low pressure troughs. Records show that the island does experience drought conditions if the island lies outside of the path of these tropical depressions (Proag, 1995). Of the annual rainfall that Mauritius receives, 30% is lost to evaporation and transpiration, 10% is absorbed for groundwater recharge and 60% is surface runoff (WRU, 2007).

Long term mean annual rainfall reveals that the eastern portion of the island receives approximately 1200mm rainfall, up to 4000mm in the elevated central region, and as little as 600mm on the western coast (WRU, 2007; Figure 3.3). Due to orographic lifting, the following microclimate zones have been identified: the central uplands are super humid (46% of the total area), east and south are humid regions (19%), and a small area in the west is defined as semi-arid (Halais & Davey, 1969; Fowdur *et al.*, 2006; Nigel & Rughooputh 2010a). Humidity has an average value of 80% across the island and this remains constant throughout most of the year. Spatially, throughout the year, humidity is higher in the southern central region (central plateau and highlands) of Mauritius and lowest near the coast. The annual average humidity has a similar spatial distribution as the isohytes in Figure 3.3 which affects the evaporation rates of water on Mauritius and can be partially attributed to the orographic lifting (Proag, 1995; Nigel & Rughooputh, 2010a).

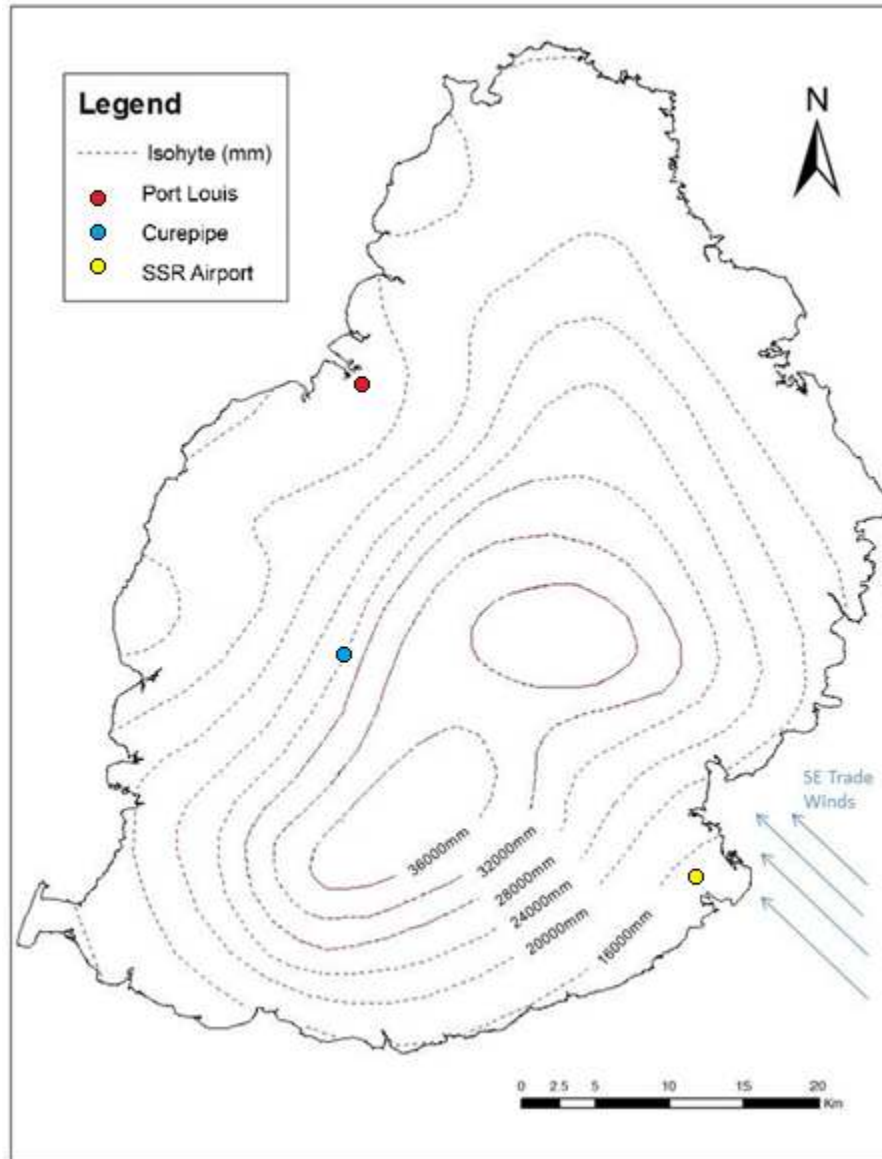


Fig. 3.3: Annual rainfall isohytes on Mauritius (Paturau, 1988).

There are over 250 weather stations scattered around Mauritius that record rainfall. These are maintained by Government Departments, volunteers, sugar estates and other authorities (MMS, 2010a). Of these, 20 are automatic weather stations. Records for automatic weather stations are historically short as most have been installed within the last two decades. The highest rainfall totals on the island occur on the central plateau and southern upland regions due to orographic lifting (MMS, 2010b; Nigel 2011). The rainfall over Mauritius can be highly variable with droughts occurring often, but with some sporadic cyclones and heavy rainfall. This has created the potential for many flooding problems and associated agricultural and economic concerns (Yahya *et al.*, 2010). Droughts periods have taken place on Mauritius. Dry conditions are associated with cyclone free summers with drought conditions prevailing in

the sub humid zones in the island. The worst drought on record occurred during the summer of 1998/99 (MMS, 2010c) although no further data were available to provide details on this event.

According to WRU (2007), annual evaporation is estimated to be 30%, surface runoff as 60% and groundwater recharge at 10%. As much as 60 – 70% of annual rainfall takes place during the summer months, but rainfall can be associated with periods of drought of variable durations (Padya, 1984; Soopramanien *et al.*, 1990). The summer period from November through April is mainly influenced by tropical cyclones and atmospheric depressions, however most of these cyclones do not make a landfall (tropical cyclones have greater wind speeds than tropical depressions). During the drier April to October months, the climate is dominated by the South East Trade winds (Padya, 1984).

Mauritius, due to its position in the Indian Ocean is subject to a number of tropical cyclones (Figure 3.4), atmospheric depressions and therefore erosive events. The island is located in the south western part of the tropical cyclone belt in the Indian Ocean and an average of 10 atmospheric depressions (of which 3 develop into cyclones) occur each year during November through April (Padya, 1984; Cheeroo-Nayamuth *et al.*, 2000). January 2002 was the most recent intense cyclone that directly affected Mauritius with 488 mm of rain recorded at Vacoas during the event, the highest wind gust reached 209 km/h. During Tropical Cyclone Hyacinthe in January, 1980, 1011mm of rain was recorded. Mauritius has had close to 70 tropical cyclones that have affected it in the last century. The types and strength of tropical storms and cyclones are provided in Table 3.1:

Type	Wind Guts (km/h)
Tropical depression	<89
Moderate tropical storm	89 - 124
Severe tropical storm	125 - 165
Tropical cyclone	166 - 233
Intense tropical cyclone	234 - 299
Very intense tropical cyclone	>300

Table 3.1: Types of tropical storms and cyclones with each respective strength (after MMS, 2010b)

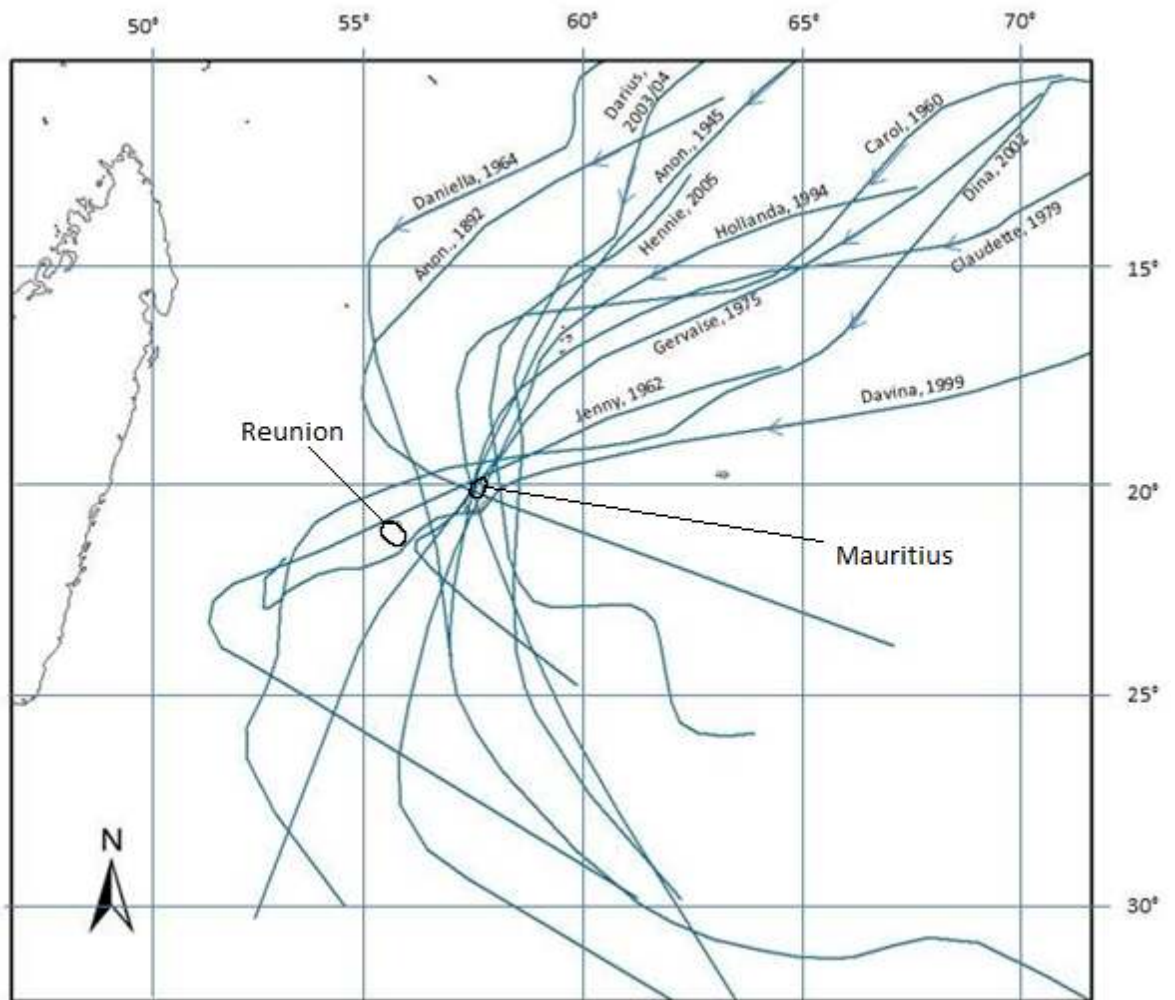


Figure 3.4: Paths of the major cyclones that have affected Mauritius since 1945 (MMS, 2010d).

During the study period, three tropical cyclones passed near Mauritius. In March 2005 (22 - 25th) saw tropical cyclone Hennie (classified as a Class I cyclone – having minimal cyclone strength) passed as close as 60km to the south east of the island with winds as high as 112km/h. During March 2006 (3 – 4th) tropical cyclone Diwa (Classified Class II) passed 220km North West of the island with winds as high as 126 km/h. During February 2007, (22 - 25th) Tropical Cyclone Gamede passed 230km North West of Mauritius. Winds peaked at over 158 km/h and it has been recorded as one on the wettest cyclones (3929mm was recorded over 72 hours at Cratère Commerson on Reunion) having been classified as Cyclone Warning Class IV (MMS, 2010d; Queterlard *et al.*, 2009). Unfortunately, the automatic stations were offline during the Cyclone Gamede event. A list of historical cyclones that has influenced Mauritius since 1989 is provided in Table 3.2.

<b>Name</b>	<b>Year</b>	<b>Date</b>	<b>Classification</b>
Krissy	1989	4-6 Apr	Severe Depression
Hollanda	1994	9-11 Feb	Intense Cyclone
Christelle	1995	7-8 Jan	Moderate Depression
Ingrid	1995	24-27 Feb	Cyclone
Kylie	1995	8-13 Mar	Severe Depression
Edwige	1996	24-25 Feb	Moderate Depression
Itelle	1996	14-16 Apr	Intense Cyclone
Daniella	1996	6-8 Dec	Intense Cyclone
Anacelle	1998	10-11 Feb	Cyclone
Davina	1999	8-10 Mar	Intense Cyclone
Connie	2000	27-29 Jan	Intense Cyclone
Eline	2000	13-15 Feb	Severe Depression
Dina	2002	20-22 Jan	Very Intense T.C
Gerry	2003	12-13 Feb	Tropical Cyclone
Darius	2003/04	31 Dec '03 - 03 Jan '04	Severe Tropical Storm
Hennie	2005	22-24 Mar	Severe Tropical Storm
Diwa	2006	03-04 Mar	Severe Tropical Storm
Gamede	2007	22-25 Feb	Tropical Cyclone

Table 3.2: List of major cyclones and tropical storms that have affected Mauritius since 1989 (after MMS, 2010d).



Mauritius, like other islands, is vulnerable to climate change and its effect on systems such as the ENSO (El Niño/ Southern Oscillation) phenomenon and cyclones. The intensity of tropical cyclones as well as general rainfall intensity is expected to increase under enhanced carbon dioxide conditions. It is also expected that the variability of inter-annual rainfall associated with the El Niño effect will change, raising concerns of the increased frequency of flooding and drought (Lal *et al.*, 2002). Additional climatic information is as follows (Proag, 1995):

- Weather patterns are influenced by the sea surface temperatures (SST's) in the western part of the tropical and sub-tropical parts of the Indian Ocean. SST's near Mauritius are around 22°C in March and 27°C in September.
- South-East Trade Winds blow over Mauritius almost permanently at speeds ranging from 1-45 km/h. The major gusts that are experienced are usually associated with tropical cyclone events. The highest wind speeds associated with the SE Trade Winds are usually felt from June – November.
- Average air temperatures is between 20 - 22°C. The temperature can drop to below 10°C during winter evenings and can peak higher than 35°C in summer afternoons. The season, position relative to prevailing winds and elevation are the main controlling factors affecting the temperature experienced on Mauritius.

This project has made use of rainfall data provided by the Mauritius Meteorological Service. The data was recorded from 01/01/2003 – 31/12/2008, a period that spans 7 years. Detailed information concerning this data is provided in Chapter Four.

### **3.4 Topography**

The topography of Mauritius can be separated into three patterns as defined by Saddul (1995): Old Lavas give rise to mountain ranges, the intermediate Lavas give rise to a gently rolling topography with deeply incised rivers with terraces and stabilized gullies, and Late Lavas give rise to flat rocky areas (Nigel & Rughooputh, 2010b; Figure 3.5).

Saddul (1995) identified five geomorphologic domains:

- 1) A discontinuous ring of three mountain ranges
- 2) A central plateau encircled by the mountain ranges (400 – 650m a.s.l.).

- 3) The southern highlands being the domain of early lavas and with undulating slopes (600 -750m a.s.l)
- 4) The recent lava plains lying mostly below the 200m contour (but can extend up to more than 400m a.s.l.)
- 5) Coastal environments composed of sandy beaches, rocky coastline and coral reefs.

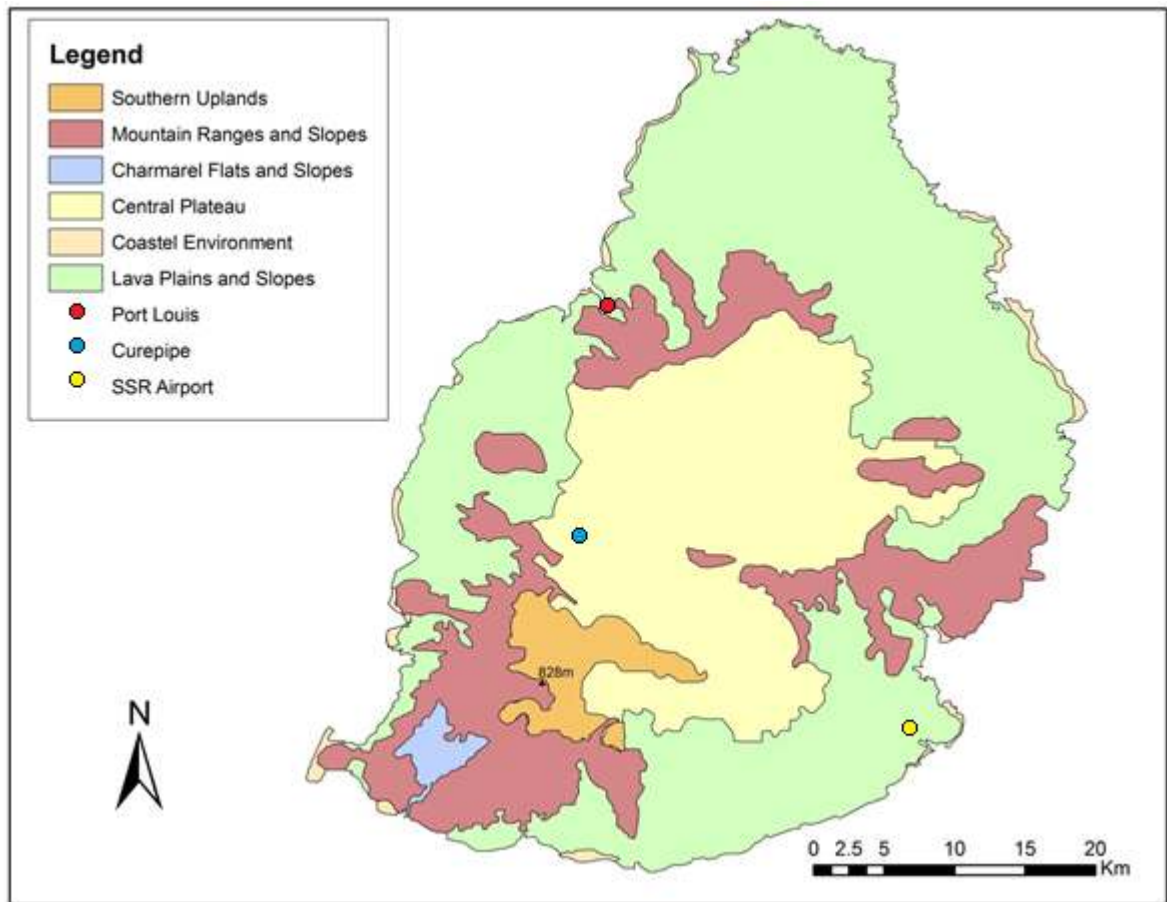


Figure 3.5: Main geomorphological domains on Mauritius (after Saddul, 1995).

In addition to the incised nature of the rivers, a number of cascades and waterfalls also occur within the island and torrential flows have played a role in erosion and shaping the landscape (Nigel & Rughooputh, 2010a). For this project, the central plateau is referred to as the central interior.

According to Proag (1995), the mountain ranges that surround the plateau have an asymmetric profile, or no real balance or symmetry in their structure, due to the geologic processes that formed the island. Topographic profiles for the island are displayed on the

following page (Figure 3.6). The Ranges generally surround the central plateau and they can be separated into the following four zones

1. The northwestern Nicoliere Range
2. The eastern Montagne Blanche – Montagne Fayence Range
3. The southern Bambou Mountain Range
4. The south Western Riviere Noire-Savanne range

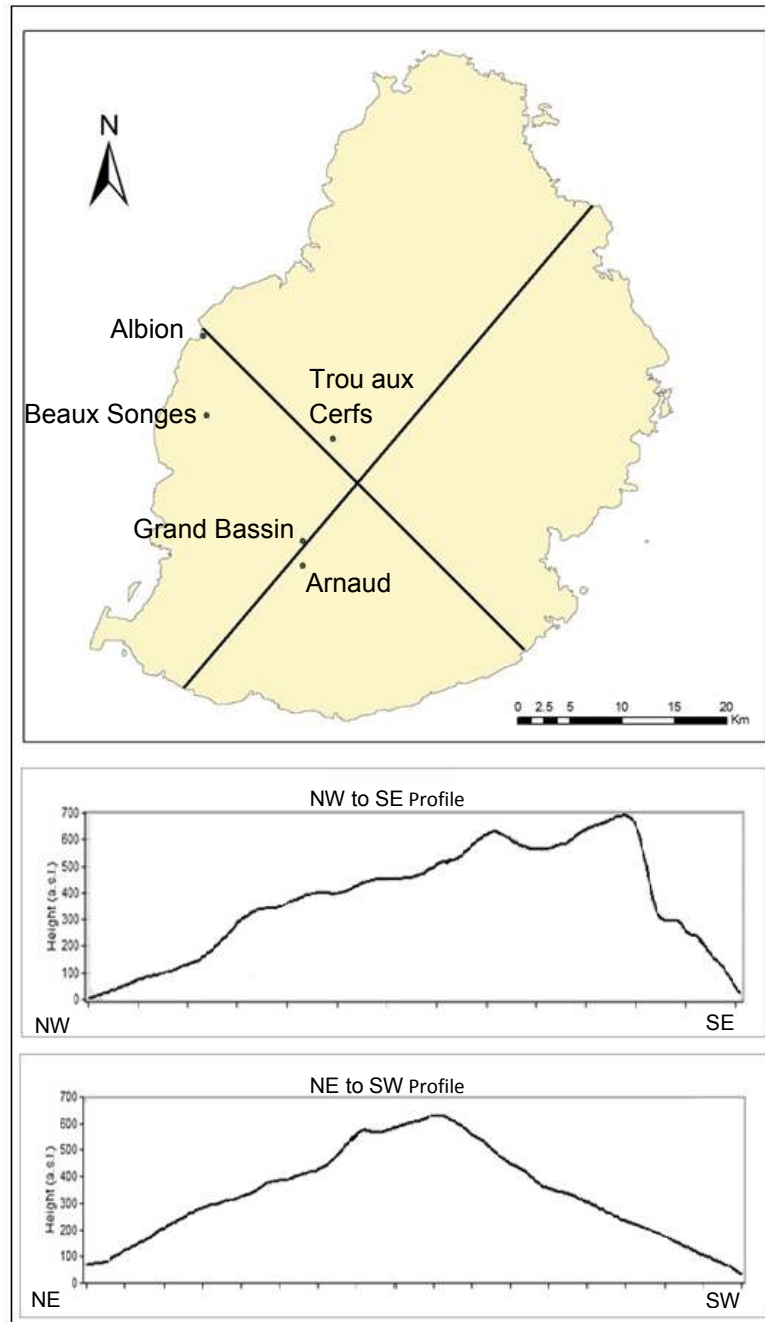


Figure 3.6: Topographic profiles of the island. The NW-SE profile is 40km long. The NE-SW profile is 30 km long

The highest point in Mauritius is found in the Riviere Noire-Savanne range (in the Southern Uplands) with a maximum altitude of 828m. Several isolated separate peaks and hills are also found, away from these ranges on the island.

Mainland Mauritius is surrounded by a number of coastal plains, variable in expanse, with the largest occurring at the north of the island. This northern plain has the lowest gradient (8.5%) while the other plains are generally steeper (in the region of 20-30%). Not all parts of the island have coastal plains (Proag, 1995).

### **3.5 Pedology**

Mauritius and parts of the Hawaiian Islands are remarkably similar with regards to geology, climate, soils and cropping. The classification system used for the soil survey of the territory of Hawaii was thus adopted for the island of Mauritius (Proag, 1995). Mauritian soils can be placed in two categories. Mature ferralitic soils (latosols) which result from the decomposition basaltic lava rock are the first group. It can be further sub-divided into Low Humic, Humic, Hydrol Humic and Humic Ferruginous that represent areas of similar climate and topography, and thus similar soils. Virtually no undecomposed minerals are found in this soil complex. Immature soils (Latosolic) form the second group, which, unlike the mature soils, still has minerals present and is still undergoing the process of weathering. They are characterized by the presence of angular stones and gravel of vesicular lava (Proag, 1995).

As Proag (1995:20) states: “Mauritius provides a very fine example of the zonality of soils, that is, the progressive intensity of weathering and soil development with increase in the soil forming factors, most notable rainfall.” Due to the low fertility of soils on the island, nitrogen, phosphate and potash have to be grown artificially for agriculture. When these nutrients are supplied, fertility becomes a function of rainfall. With rainfall being a function of the island’s topography and the strong relationship between rainfall and elevation, a vertical zonality of soils is thus created (Figure 3.7).

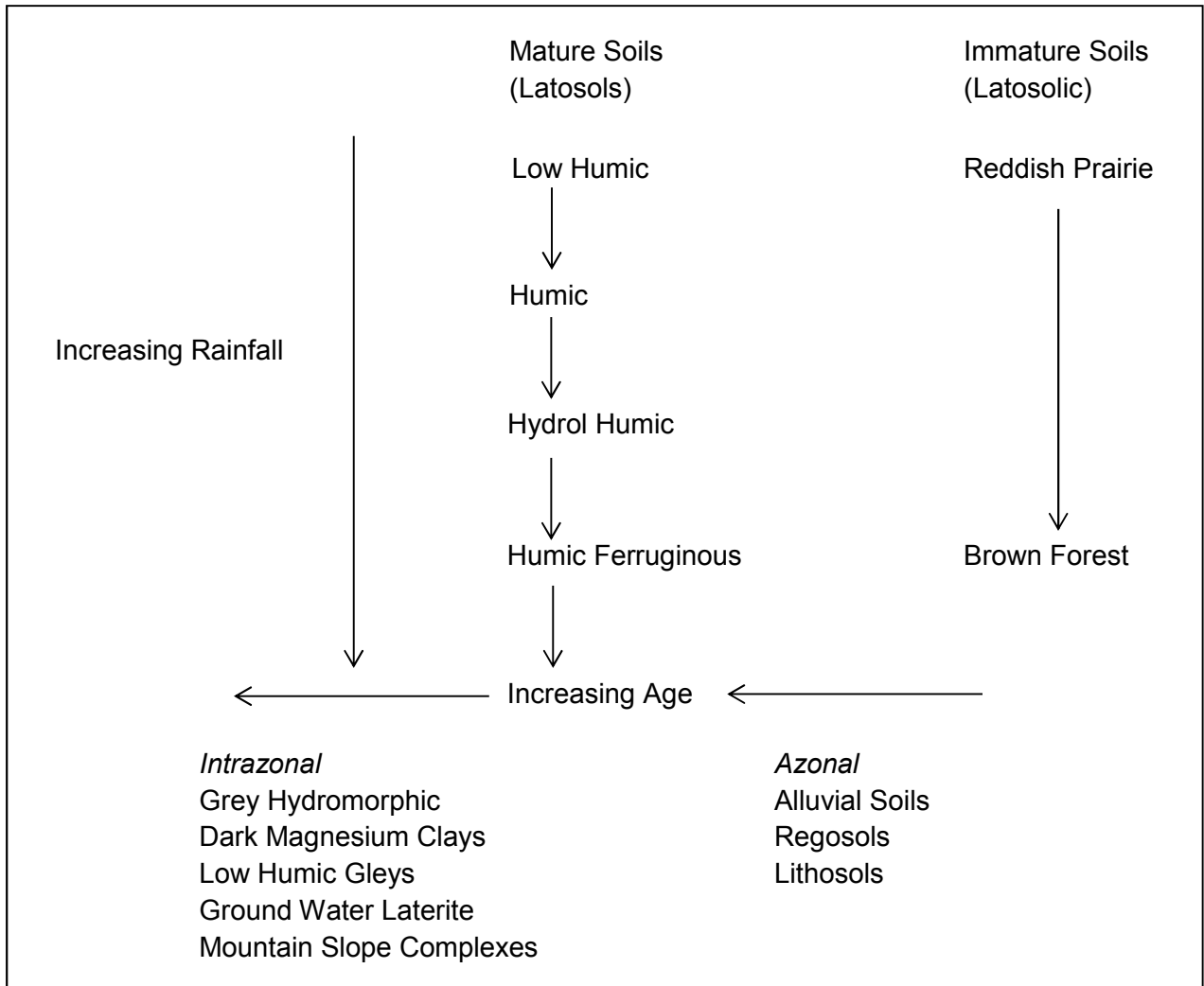


Figure 3.7: Classification on Soils in Mauritius (after Pears, 1985). Note the change in classification with increasing rain and age.

Latosolic soils can be divided into three categories based on this zonality of soil: Zonal, Interzonal and Azonal. The Zonal soils make up approximately 33% of the island surface area, interzonal makes up 36% and 18% Azonal soils respectively, with the remainder of the island covered in various water bodies (Nigel, 2011). They are described as follows (World Water, 1987; Proag, 1995):

- Zonal soils developed principally from the Intermediate Lavas under mean annual rainfall of 1000 – 5000mm of rain. They include the Low Humic Latosols, Humic Latosols and the Humic Ferruginous Latosols.
- Interzonal soils developed under conditions of climate and vegetation but are masked by local environmental factors such as relief, drainage and composition of

parent material. Created from the Late Lavas, these soils include the Latosolic Reddish Prairie (in dry areas) and the Latosolic Brown forest soils (in wet areas).

- Azonal Soils have little or no profile development and include alluvial soils (deposits from recent alluvium), regosols (coral deposits and soils of deposits other than alluvium), and lithosols (eroded rough broken land of mountains and gorges).

A general map of Mauritian soil is presented in Figure 3.8.

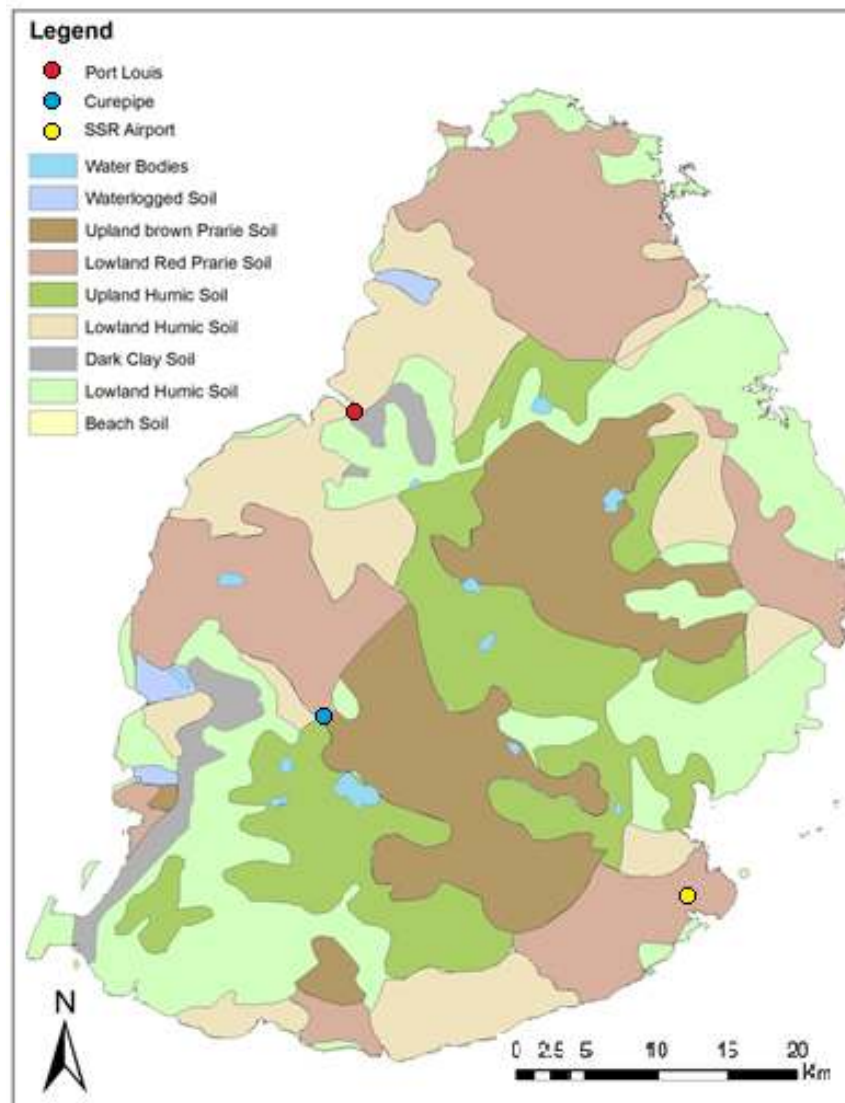


Figure 3.8: Summary of the pedology of Mauritius (World Water, 1987; Proag, 1995).

### 3.6 Hydrological resources

Many streams and rivers occur in the island, but Proag (1995) points out that their distribution is highly irregular. There are 59 main rivers and over 180 feeders have been identified. Due to their low gradients, the coastal plains in the north, portions of the eastern and south western plains as well as portions of the uplands have no surface drainage and no rivers.

The majority of the rivers originates from the Central Plateau and flow radially toward the ocean. There are two natural Lakes on the island: Grand Bassin and Bassin Blanc along with eleven reservoirs, the largest being Mare aux Vacous. Five main aquifers are found on Mauritius making up the island's groundwater resources. Groundwater plays a major role in sustaining flows in the rivers (Proag, 2006). Mauritius has been divided into 25 main, and 22 minor catchment areas which vary in size from 3 – 64km<sup>2</sup> (Figure 3.9). Each catchment is characterized by its own main river and coastal zone which is drained by small streams or rivulets. Many springs and streams also occur (usually near the coast) that have substantial flows and are sometimes used for irrigation.

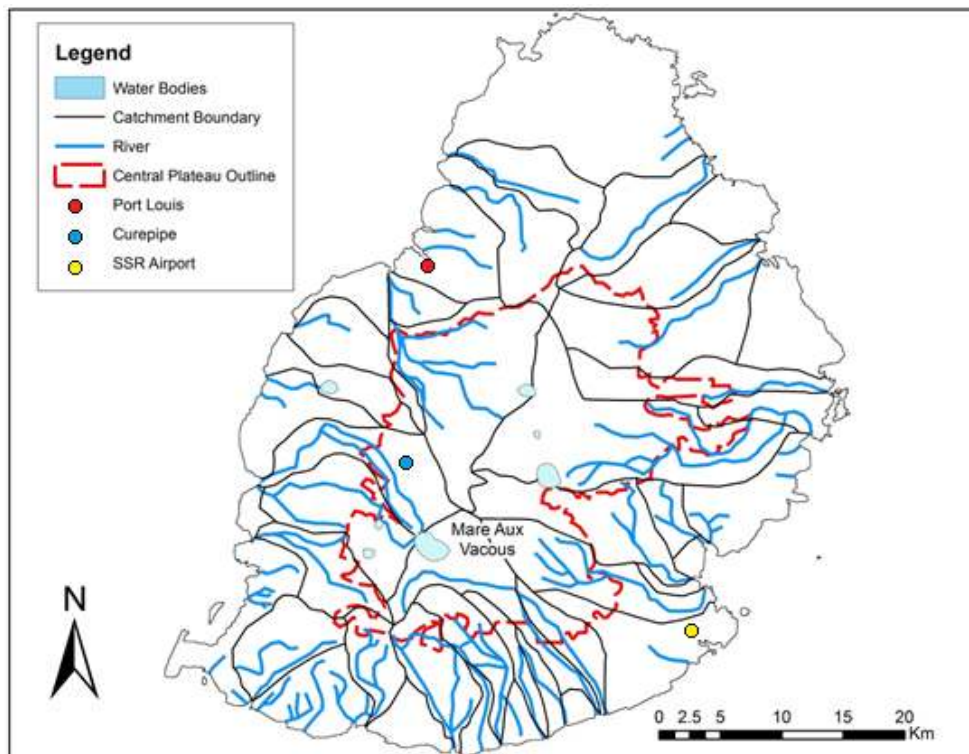


Fig. 3.9: Catchment boundaries, major river and water bodies on Mauritius (WRU, 2007).

### 3.7 Land use and vegetation

Before colonization, Mauritius was almost completely covered by wet or dry evergreen forest. Since colonization in 1638 up to 95% of its native vegetation area has been reduced (Safford, 1997) but six forest-living native passerines protected by legislation still occur on Mauritius and these are. The main vegetation that remains in the uplands is the moist montane tropical evergreen forest. Some cloud forest with scrub and marsh vegetation occurs in small areas with dry forest dominating the rain shadow regions (Vaughan & Wiehe, 1937; Safford, 1997). Invasion of exotic plants, poor regeneration of native plants, and urbanization are some of the issues currently facing the indigenous vegetation on Mauritius.

In 2002, 55% of the island's land was classified as cultivated, 27% was covered by forest, 11% was scrub, and 6% of it was urbanized with the remaining 1% comprised miscellaneous land uses (Saddul, 2002). Much of the island has been cultivated and is now used for the production of sugarcane (Figure 3.10 and 3.11). Currently, 69 000 ha (85% of arable land) is used for sugarcane cultivation, an export product that the Mauritian economy is heavily dependent upon (Cheeroo-Nayamuth *et al.*, 2000; Soobadar & Kwong, 2012).

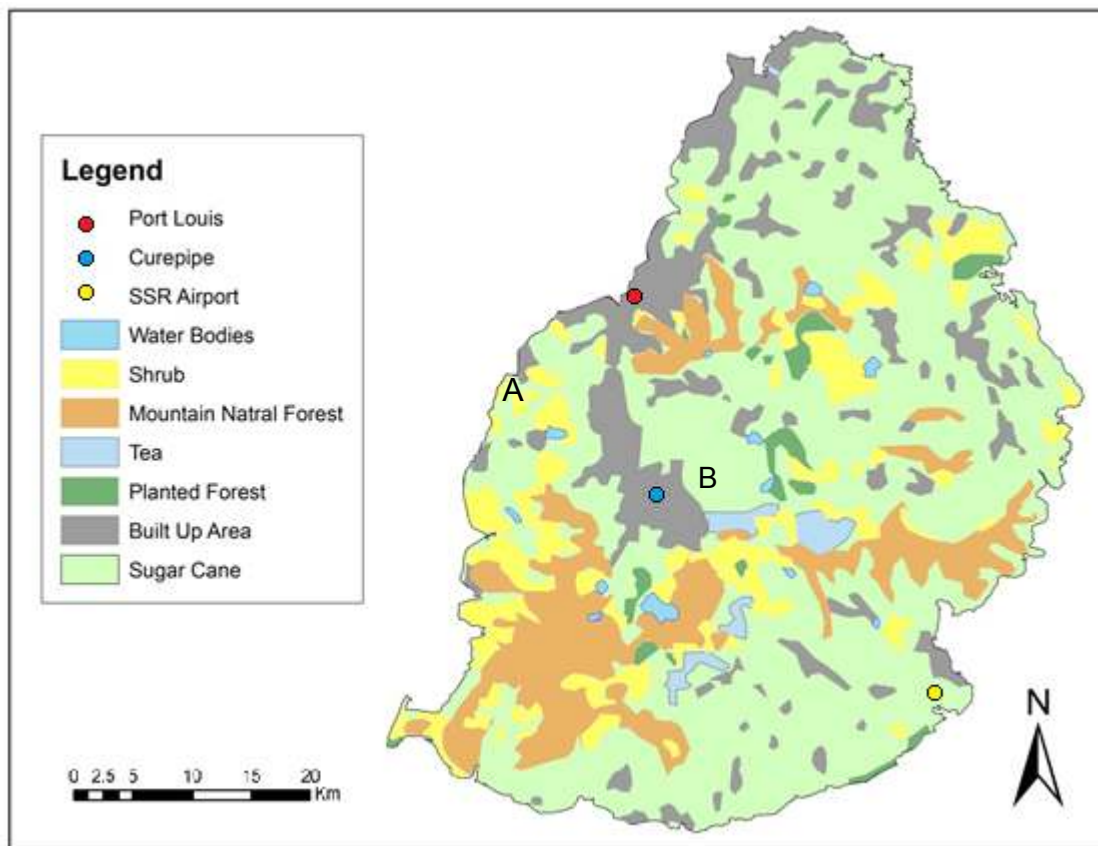


Figure 3.10: Land uses on Mauritius (after Saddul, 2002).





Figure 3.11: Various land uses that often occur within small areas. Sugar cane, banana cultivation and natural vegetation occur in this single image.

The two regions that are under investigation in this project have differing types and extent of vegetation due to the different rainfall regimes that they are subject to. On the western region (which receives 600mm annually), the vegetation is shrub-like, grassy and sparse and the central interior (which receives 4000mm annually) is marked by far denser and lush vegetation. Figure 3.12 and 3.13 were taken on the same day on 28 June 2010 and the difference in vegetation cover and density is apparent. The locations where these pictures were taken have been indicated on Figure 3.10 as “A” and “B” respectively.



Figure 3.12: Landscape near the station at Albion (Photo taken 28 June 2010).



Figure 3.13: Landscape near Trou aux Cerfs (Photo taken 28 June 2010).

This chapter has provided relevant background information for this study. This includes information about the geological development of the island, the vegetation and land use that is currently occurring on the island. A detailed description of the climate that affects the island has been included with particular reference to rainfall, with mention of tropical cyclones. Topography, pedology and hydrology of the island has also been briefly discussed to provide the context in which the next chapter will continue. In summary, Mauritius is diverse and its topography, climate, and location have created several microclimates unique to the island which is reflected in the type and density of vegetation across the island. The study methodology is discussed in greater depth in Chapter 4.

## Chapter 4: Methodology

This chapter deals with the method and materials used in the completion of this project. It describes the research design followed in analyzing the data, some limitations of the methodology, as well as presenting the equipment that was used, the data, and the analyses that were undertaken. As presented in chapter one, the objectives that were set out are as follows:

- Perform a comparative study of rainfall erosivity ( $EI_{30}$ ), erosive rainfall and events experienced by areas receiving low and high rainfall resulting from the elevated topography in Mauritius
- Analysis of rainfall erosivity in western Mauritius using periods of 5 consecutive 6 minute intervals, and set 30, and 60 minute intervals
- Compare the use of the Modified Fournier Index to the standard  $EI_{30}$  method in calculating rainfall erosivity
- Investigate the effect of two different climate change scenarios on rainfall erosivity in Mauritius

### 4.1 The data

Data were obtained from the Mauritius Meteorological Service from five weather stations in the area of interest for the period 01/01/2003 – 31/12/2008 (Figure 4.1). The area of interest for this project includes the central wet interior and the dry western lava plains. The weather stations are located at different altitudes to capture the differences in rainfall and its associated rainfall erosivity due to orographic lifting. Two stations, Albion and Beaux Songes, are located on the coastal plain and fall within the rain shadow area. The remaining three stations, Aranud, Grand Bassin and Trou aux Cerfs are located in the central interior which is also the region receiving the highest rainfall. Unfortunately, no data were available for comparison with other sites on the island. Thus, rainfall erosivity at the two climatological extremes in Mauritius is investigated, in the driest and wettest part of the island.

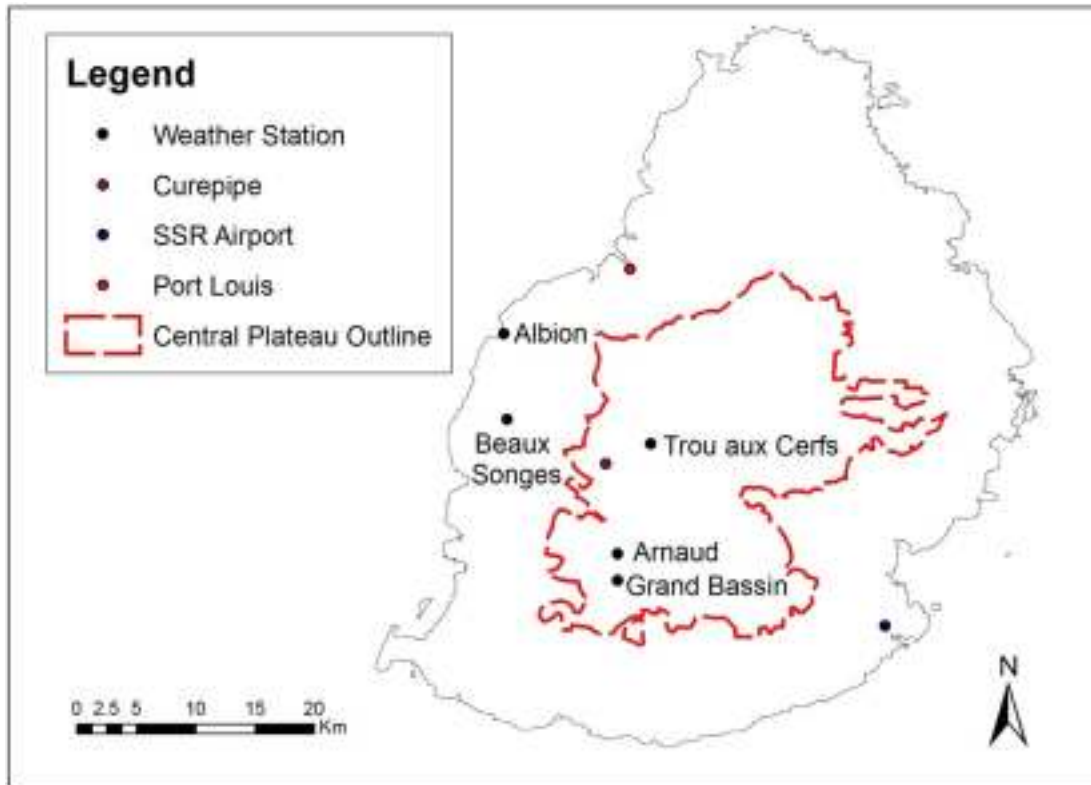


Figure 4.1: Location of stations used to the collect data used in this project.

These stations were used for the following reasons: First, they were the only automatic stations that were made available which had the type and extent of data that were necessary for the project. On Mauritius, 22 of the stations used by the Mauritius Meteorological Service are automatic and offer the resolution of data desirable for the project. The automatic nature of the stations also reduces human error in the readings (MMS, 2010a). Consistent rainfall data from five of these automatic stations were provided by the Mauritius Meteorological Service for the period 2003 - 2008.

Second, two of the stations are located in the driest part of the island and the remaining three are located in the wettest portion. This provides an opportunity to investigate rainfall erosivity in the two extremes of rainfall experienced on Mauritius. No data from the eastern portion of the island were available.

Third, the stations are located in four of the five geomorphic domains as described by Saddul (1995) (Figure 4.3). They are the coastal environments, recent lava plains, mountain ranges, central plateau, and southern uplands. No stations in any of the mountain ranges were available to be used for this project. Stations covered each of the geomorphic domains and

located in the central and western portion of the island, providing the best coverage of the area of interest given the available data.

The station at Albion is located within 50m of the coastline on property owned by the Department of Agriculture. Beaux Songes is located 6km inland on the lava plains, Trou aux Cerfs is located deep in the central plateau and Arnaud is located around 200m from the Mare aux Vacous Reservoir. The station at Grand Bassin is located at the Grand Bassin Temple, also several hundred meters from a Lake Grand Bassin. Elevation and location information are presented in Table 4.1.

<b>Station</b>	<b>Latitude</b>	<b>Longitude</b>	<b>Altitude (above sea level)</b>	<b>Geomorphic Domain</b>	<b>Rainfall Region</b>
Albion	-20.212	57.400	12m	Coastal Environment	Semi-arid
Beaux Songes	-20.278	57.408	225m	Recent lava plains	Semi-arid
Trou aux Cerfs	-20.297	57.517	614m	Central Plateau	Super- Humid
Grand Bassin	-20.400	57.492	605m	Southern Uplands	Super- Humid
Arnaud	-20.380	57.492	576m	Southern Uplands	Super- Humid

Table 4.1: Location, altitude, geomorphic and climatic information of stations.

Arnaud and Grand Bassin share similar altitudes and surrounding vegetation, are within 5km of each other and are located near water bodies (Trou Aux Cerfs reservoir and Lake Grand Bassin respectively). They are found in the southern uplands geomorphic domain. These two stations are found in the wettest region of the island, and provide an opportunity to investigate differences in erosivity experienced by two points that are in close proximity to each other. Images of the stations are presented in Figures 4.2 – 4.6.



Figure 4.2: Station at Albion (12 m a.s.l.).



Figure 4.3: Station at Beaux Songes (225m a.s.l.).



Figure 4.4: Station at Trou Aux Cerfs (614m a.s.l.).



Figure 4.5: Station at Arnaud (580m a.s.l.).



Figure 4.6: Station at Grand Bassin (605m a.s.l.).  
This particular bucket had an outer covering around the pole but the system is the same.

## 4.2 Research instruments

Rainfall data with a high temporal resolution are necessary for accurate calculations in rainfall erosivity (Yin *et al.*, 2007). Rainfall data sourced for this project were recorded by the Mauritius Meteorological Service at 6 minute intervals using the Precis Mecanique R01- 3030 Pluviometer with tipping bucket (Figure 4.8 and 4.7). Rainfall is measured in increments of 0.2mm. Stations are mounted on a 1 meter high pole at sufficient distance from any other surface that may influence readings by adding rain splash from other structures. The system incorporates a tipping bucket which records total rainfall amounts every six minutes which is downloaded into a Microsoft Excel file. The tipping bucket itself contains deflectors which reduce losses of received rainfall during high intensities of rainfall but record continuously in both wet and dry conditions. The bowl has a diameter of 230mm with a collecting area of 1000cm<sup>2</sup> and the rim of the station is thin to minimize rainfall splash. The device is held securely in the ground to avoid vibrations from nearby activities or structures which could also influence readings (Alexandropoulos & Lacombe, 2006).



Figure 4.7: Example of the automatic rainfall bucket used by the Mauritius Meteorological Service to record rainfall data.





Figure 4.8: Collecting bowl of the rainfall bucket.

### 4.3 Missing/Unreliable data

Due to technical issues (maintenance, blockages, and malfunctions), a number of months of missing data were found within the data set, but, for the months where data were missing or incomplete, all stations had data missing at the same or nearly the same periods, thus still allowing the station data to be compared for the study period. The following months were not used in calculation due to incomplete data: June and July 2004; November and December 2006; and January, February and March 2007. During this time, Tropical Cyclone Gamede passed near the island. It is likely that erosive rainfall did occur during this period, thus when looking at the results of the project, the actual *R*-factor values may be higher. The data that was missing for this project is indicated in Table 4.2:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2003	~	~	~	~	~	~	~	~	~	~	~	~
2004	~	~	~	~	~	X	X	~	~	~	~	~
2005	~	~	~	~	~	~	~	~	~	~	~	~
2006	~	~	~	~	~	~	~	~	~	~	X	X
2007	X	X	X	~	~	~	~	~	~	~	~	~
2008	~	~	~	~	~	~	~	~	~	~	~	~

Table 4.2: Table indicating the reliability of the data. The “~” symbol indicates reliable data. The “X” symbol indicates missing/incomplete data.

Due to the highly variable nature of rainfall, its associated intensity and the key role that this intensity plays in calculating rainfall erosivity, the use of statistical extrapolation methods were not used to fill in the gaps of the missing data as these estimations or rainfall can lead to inaccurate results that decrease the value of the results presented in the next chapter. In addition, several apparently extreme events that took place during February 2006 at Grand Bassin were not included in the data as the rainfall recorded during the event was extraordinarily high. These events were deemed anomalous as triple double and triple digit rainfall totals were recorded within a 6 minute period with no other rainfall recorded within several hours before or after the event.

#### **4.4 Analyzing the data**

Each separate weather station recorded information at the site including rainfall totals, rainfall intensity (rainfall that was received within 6 minutes), temperature, wind speed and pressure as a separate Microsoft Excel file on a daily basis. These files were “stitched” together so that all months for a single station were consolidated into a single Excel spreadsheet, and all years for a station were placed in a single Excel file for ease of use. Days with rainfall were then separated from days without rainfall for and these days without rainfall were then removed from the data set. For this project, a rainfall day was set as a day which received >1mm rainfall during the 24 hour period.

#### **4.5 Defining an erosive event**

The rainfall data was separated into the erosive events that were used to calculate the rainfall erosivity index. The definition of an erosive event has been well established within the literature. The following parameters were set for this project to determine an erosive event (Wischmeier & Smith, 1958; Elwell & Stocking 1973):

- > 12.5mm rain within a 30 minute period.
- 2 hour rain-free interval between erosive events.
- 5 minute intensity > 25mm/h.

Due to the fact that 6 minute interval data are used in this project, 6 minute intensity > 30mm/h was used for the last parameter listed above as this is still intense rainfall. An event was also taken if 6.3mm of rain occurred within 15 minutes (Wischmeier & Smith, 1978; Diodato, 2005; Angulo-Martinez & Begueria, 2009).

When the above definition for an erosive event is applied, a total of 377 erosive events were recorded for the five stations over the six year study period.

#### 4.6 The “R” Factor: Calculating “E” and “I”

When using the Erosivity Index, the *R*-factor is calculated as follows (Renard *et al.*, 1997):

$$R = \frac{1}{N} \sum_{j=1}^n \sum_{k=1}^m (E)_k (I_{30})_{30j} \quad (1)$$

where *E* is the total erosive event kinetic energy ( $\text{MJ h}^{-1}$ ),  $I_{30}$  is the maximum 30 minute rainfall intensity ( $\text{mm h}^{-1}$ ), *j* is an index of the number of years used to produce the average, *k* is an index of the number of erosive events in a year, *N* is the number of years used to obtain the average *n*, and *m* is the number of erosive event in each year. Individual erosive event erosivity values are directly additive (Wischmeier & Smith, 1978).

The erosivity index is calculated as the product of the total erosive event kinetic energy (*E*) ( $\text{MJ h}^{-1} \text{mm}^{-1}$ ) and the maximum amount of rainfall ( $I_{30}$ ) in a 30 minute period expressed in millimeters per hour ( $\text{mm h}^{-1}$ ). Mathematically, the formula is as follows (Santosa, 2010):

$$E = \sum_{j=1}^m e_r \Delta V_r \quad (2)$$

Where  $e_r$  is the rainfall energy per unit depth of rainfall per unit area ( $\text{MJ ha}^{-1} \text{mm}^{-1}$ ) and  $\Delta V_r$  is the depth of rainfall (mm) (Brown & Foster, 1987; Santosa *et al.*, 2010). As a general rule, an erosive event with higher intensity is associated with an increase in drop size and terminal velocity. A number of formulae have been created that attempt to calculate the kinetic energy of an erosive event. The formula that was used in this project is the general erosivity formula developed by van Dijk *et al.* (2002):

$$E_K = 28.3[1 - 0.52^{(-0.042R)}]$$

(3)

where  $R$ =rainfall intensity

The above general formula was chosen to remain consistent with global studies. This formula (3) was based on the average parameter values derived from the best data sets from around the globe. The formula aims to best describe the rainfall energy – Kinetic energy ( $R-E_K$ ) relationship. It is based on the continuous exponential relationship suggested by researchers such as Kinnell (1981) and van Dijk *et al.* (2002):

$$e_K = e_{max}[1 - a^{(-bR)}]$$

(4)

$e_{max}$  was set at  $28.3 \text{ Jm}^{-2} \text{ mm}^{-1}$  as this is accepted to be a constant kinetic energy limit that is reached when rainfall intensities exceed this intensity. The values  $a$  and  $b$  are empirical constants. Van Dijk *et al.* (2002) explains that  $e_{max}$  determines the minimum kinetic energy constants (the value attained at low intensities). The constant  $b$  defines the shape of the curve. This formula, as compared to the power or the logarithmic-type formulae, is particularly accurate when calculating energies at higher intensities ( $> 50\text{mm}^{-1}$ ). This is useful as higher rainfall intensities are of greater importance in calculating overall erosive event kinetic energy than lower intensities. However, duration (more than intensity itself) has the potential to contribute more to the total event erosivity when higher intensities are involved. The figure below is a plot of the above equation in Microsoft Excel.

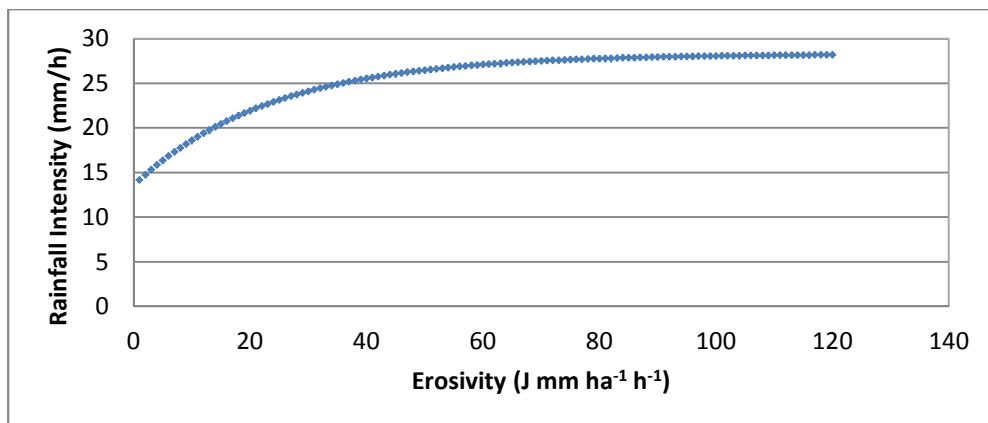


Figure 4.9: Plot of the formula used to calculate erosivity in this project.

$I_{30}$  is taken as twice the maximum intensity recorded during a 30 minute period during an erosive event. This can also be calculated as (Brown & Foster, 1987; Santosa *et al.*, 2010):

$$I_{30} = \frac{(P_{30})}{0.5h}$$

(5)

Where  $P$  (mm) is the maximum 30 minute rainfall depth

Rainfall intensity for a rainfall event ( $i_r$ ) can also be calculated as (Santosa *et al.*, 2010):

$$i_r = \frac{\Delta V_r}{\Delta t_r}$$

(6)

Where  $\Delta t_r$  is the duration of the increment over which rainfall intensity is considered to be constant in an hour (h), with  $\Delta V_r$  representing the depth of rain (mm) that is received within that hour. The method used to calculate rainfall intensity for this project is discussed below.

#### 4.7 Calculating the $EI_{30}$ of an erosive event

Wischmeier & Smith (1978:5) state that “a rainfall factor used to estimate average annual soil loss must include the cumulative effects of the many moderate sized erosive events, as well as the effects of the occasional severe ones.” They also emphasize that the  $R$ -factor must quantify the raindrop impact effect and provide relative information on the quantity and rate of runoff likely to be associated with the rain. Their erosivity index ( $EI_{30}$ ) is therefore described as a statistical interaction term that indicates how total energy and peak intensity are combined for each individual erosive event.

With the above in mind, for each erosive event, the above formula (3) for erosive event kinetic energy ( $E$ ) developed by van Dijk *et al.* (2002) was used to calculate the 6 minute incremental kinetic energy content derived from rainfall intensity. It should be noted at this point that a uniform drop size was assumed when the kinetic energy was analyzed. For each 6 minute, the kinetic energy was totaled and then multiplied by the amount of rain that fell in that 6 minute period to give the kinetic energy for that period. These values were subsequently summed to give the total kinetic energy for the erosive event.

After the kinetic energy ( $E$ ) of the event was calculated, it was multiplied by the maximum 30 intensity ( $I_{30}$ ) calculated during the erosive event (equation (2)) to provide the total erosivity of the erosive event. All the erosivity values calculated for each event for a particular station were then summed over a period of one year to provide an annual erosivity total. The annual totals were then averaged (Equation (1)), which produced the  $R$ -factor, which as discussed earlier, gave an indication of the rainfall erosivity that a station experiences over time.

#### **4.8 Objective One: Comparative study of the stations**

The core aspect of this project is covered in this objective. For general comparisons that are made in this portion of the project, the erosivity totals taken from the 5 consecutive 6 minute intervals are used as they provide a more accurate comparison of the erosive events. The focus of this project is the characteristics of the rainfall erosivity, rainfall and events experienced by the island over the 6 year period. Characteristics, such as the intensities and kinetic energies experienced by individual erosive events, are not considered further.

The five stations that were used for this project can be placed in two groups based on their rainfall and erosive attributes: In the first group are Albion and Beaux Songes, and in the second group, are Arnaud, Trou aux Cerfs and Grand Bassin. Comparisons between these two groups were made in an attempt to discover the role that an elevated topography has on rainfall erosivity. In addition, comparisons between the stations in the respective groups were investigated. The following statistics were used to analyze the data:

- Averages
- Maximums
- Means
- Number of erosive events
- Seasonal variations of rainfall vs. erosivity
- Rainfall vs. erosive rainfall totals
- Rainfall vs. erosivity
- Annual and seasonal characteristics
- Overall characteristics

These results are presented in the following chapter. The statistics show any similarities and differences between the stations and the erosivity values.

#### 4.9 Objective Two Methodology: Calculating $EI_{30}$ using 60, 30, and 6 minute interval data

Yin *et al.* (2007) note that the more detailed the rainfall data used in erosivity calculations, the more accurate the computed  $EI_{30}$  will be. A number of studies have successfully used rainfall data recorded at varying resolutions to calculate rainfall erosivity. These include Capolongo *et al.* (2008) who used 20 minute resolution data, Shamshad *et al.* (2008) who used 15 minute interval data, Santosa *et al.* (2010) who used 10-minute intervals, and Salako *et al.* (1995) who used 7.5 minute interval data. Yin *et al.* (2007) note that in China, hourly rainfall totals are commonly used.

The 6 minute resolution data provided by the Mauritius Meteorological Service provide an interesting opportunity to investigate the value of high resolution data in calculating  $EI_{30}$ . The data were used to investigate if lower resolution data such as the set 30 minute and 60 minute interval data miss the peaks that erosive events experience and the impact that this has on annual erosivity values and *R*-Factor values calculated for the study period. The peak of the storm (the maximum intensity) can occur or extend through the end of one set interval and into the start of the next, thus the peak intensity of a storm is “broken” in the measurements can be missed when longer time intervals are used. As an example, the set period may end at 14h00 and the new recording begins. If the peak 30 minute intensity occurs through this change, the peak is lower, causing recorded intensity values to be lower, thus causing lower calculated  $EI_{30}$  values. Also, the  $EI_{30}$  is calculated with 60 minute data as hourly interval data is often more available than 30 minute or higher resolution data. Note that this is not calculating  $EI_6$  or  $EI_{60}$ .

To investigate this, the data were used to calculate the maximum intensity of the erosive event in three ways:

- First, the maximum 30 minute intensity for an event was calculated using five consecutive 6 minute intervals which had the greatest intensity values (after the methodology of Santosa *et al.*, 2010). Note that this is not the maximum 6 minute intensity but the maximum intensity for any 30 minute period during the erosive event. The peak intensity (maximum 6 minute intensity value) was used along with the four adjacent values in such a way that the maximum intensity of the event over a 30 minute period was selected.

- Second, 30 minute set periods that started and ended at set intervals were used (as some stations are programmed to do). In this case, the period starts at either on the hour or half hour mark between it. As an example:

Start: 07h00 End: 07h30

Start: 07h30 End: 08h00

Start: 08h00 End: 08h30

- Third, the 60 minute interval was used with hourly rainfall totals to calculate rainfall intensity. It was calculated as simply the amount of rain that fell within a 60 minute period. As with the previous method, set time intervals were used, with the difference of using one hour intervals instead of 30 minutes. As an example:

Start: 07h00 End: 08h00

Start: 08h00 End: 09h00

Start: 09h00 End: 10h00

An example of this methodology used to perform the above is provided in the Appendix. The results of these were compared and displayed as graphs to provide a visual representation of the above data analysis. Yin *et al.* (2007) and Renschler *et al.* (1999) derived regression models and factors to make using hourly totals in erosivity calculations more accurate. For this project, the simple 60 minute intensity was used to investigate how erosivity is under- or over-estimated in the study area.

#### **4.10 Objective Three: The Modified Fournier Index**

Although Wischmeier & Smith (1978) highlight the need for high resolution data when calculating rainfall erosivity, such data are often unavailable. As a result, a number of methods have been developed in an attempt to calculate rainfall erosivity when such data are unavailable. These methods include the Richardson *et al.* (1983) exponential model, the Yu & Roswell model (1996), and the Precipitation Intensity Index (Oliver, 1980).



One of the most commonly used methods is the Modified Fournier Index developed by Arnoldus (1980). The Modified Fournier Index (MFI) is based upon the Fournier Index formulated by Fournier (1960) and has been used with success in a variety of environments. These include work by Lujan & Gabriels (2005) in Venezuela, Renard & Freimund (1994) with work in California, USA, and Arnoldus (1977) in Morocco. This index is useful in predicting rainfall erosivity when only long term data are available. The original Fournier was calculated as follows (Fournier, 1960):

$$FI = \frac{p^2max}{P}$$

(7)

where  $p^2max$  is the mean monthly rainfall amount of the wettest month of the year and  $P$  is the mean annual rainfall amount.

The main problem of the Fournier Index was a poor correlation with the R values in the United States, and was thus modified by Arnoldus (1980) to produce the Modified Fournier Index. Much of the research concerning erosivity and soil loss on Mauritius has made use of the Modified Fournier Index (MFI) developed by Arnoldus (1980). The index has been used by Atawoo & Heerasing (1997), Le Roux *et al.* (2005), Nigel & Rughooputh (2010a), and Nigel (2011). The formula, as used for Mauritian research, is as follows (Arnoldus, 1980):

$$EI_{30} = 0.0302 \times (RI)^{1.9}$$

(8)

Where RI=rainfall intensity

$$RI = \sum_{i=1}^{12} (MR)^2 / AR$$

(9)

Where  $MR$ = Monthly Rainfall and  $AR$ = Annual Rainfall

As with the  $EI_{30}$  method, the annual totals are also averaged to give the  $R$ -factor value. The totals calculated using this method with the  $EI_{30}$  results of Objective One is be compared.

This provides a good indication of the value and accuracy of the Modified Fournier Index in calculating erosivity when high resolution data are unavailable.

#### 4.11 Objective Four: Investigating the future

In order to investigate on how climate change may affect rainfall erosivity on the island, the results of the erosivity calculations that were determined by the methods discussed above were recalculated as follows:

For each event, the  $I_{30}$  value and the intensity value used in the kinetic energy formula were increased and decreased by 1%, 2%, 5%, and 10% respectively such that the kinetic energy formula looks as follows

$$E_K = 28.3[1 - 0.52^{(-0.042R.x)}] \quad (10)$$

Where R=Rainfall intensity

$x$ = percentage factor

For each new set of values, the same process discussed earlier in calculating the  $EI_{30}$  values was followed. They too were also set out in tables and graphs (presented in the following chapter) to better describe the future changes in erosivity that the island may experience.

#### 4.12 Limitations and use of the *R*-factor and the kinetic energy formula

The models used in this project to calculate rainfall erosivity do have inherent limitations as there are a number of issues that need to be considered:

Renard *et al.* (1997) recommend that records greater than 20 years be used when dealing with rainfall erosivity of a region. This allows for the cyclic changes in rainfall associated with the ENSO phenomenon to be considered (Hoyos *et al.*, 2005). On Mauritius, it has only been in recent years that the 6 minute tipping buckets were installed in the weather stations used for this project. Thus the six year rainfall period used in this project is limited in representing the long term erosivity that the island experiences, but, was stated in the aim for this project, the focus of this project is to specifically investigate the role of an elevated topography on the characteristics of rainfall erosivity within a tropical maritime environment. The

available data are deemed sufficient for an investigation such as this project, since a number of other researchers have successfully used data in the region of five years to investigate characteristics of erosivity. These include Salako *et al.* (1995) and Capolongo *et al.* (2008) who used a rainfall data from a 5 year period, and Shamshad *et al.* (2008) who used datasets ranging from 5 - 25 years.

There are several additional limitations with regards to the *R*-factor and the Erosivity Index. They include the following:

- The index does not include the erosive forces resulting from thawing, snowmelt and irrigation (Wischmeier & Smith, 1978).
- The formula does not account for erosion resulting from rainfall that is less intense than the set parameters (for example: saturated overland flow resulting from long duration rainfall with low intensities).
- Because EI is an average that is calculated, anomalously high or low values that may have been recorded can skew the results, thus producing inaccurate results.
- Finally, the relationship between rainfall amount and erosivity experienced at a station is site specific, or in the best case, region specific (Lo *et al.*, 1985; Yu, 1999; Hoyos *et al.*, 2005).

In conclusion, this chapter has presented the methodology and instrumentation used in collecting and analyzing the data for this project. The results of the data analysis is be presented in the following chapter.

Chapter four has dealt with the methodology that was followed in analyzing the data that was provided by the Mauritius Meteorological Service for this study as well as the instrumentation used in collecting and analyzing the data for this project. The procedure that was used in calculating and analyzing the information had been discussed following each objective that was set out at the beginning of the project. A number of formulae that were necessary for this project has been provided and explained. The results of the data analysis will be presented in the following chapter.

## Chapter Five: Results and Observations

This chapter presents the results of the data analysis performed following the methodology that was set out for the objectives of the project.

### 5.1 Results of Objective One

*Comparative study of rainfall erosivity, erosive rainfall and events experienced by areas receiving low and high rainfall resulting from the elevated topography in Mauritius*

The total rainfall experienced by each station during the study period and the total depth of erosive rainfall recorded are indicated in Figure 5.1. Total number of erosive events is also presented. It is evident that the percentage of erosive rainfall experienced by the two stations in the driest part of the island is about 40 – 50% of the total rainfall received by the two stations during the study period, whereas the percentage of erosive rainfall of the total received rainfall in the wettest part of the island is between 24 – 35%. However, lowest total erosive rainfall experienced by the stations in the wet regions (Grand Bassin) is still greater than the highest amount of rainfall experienced by the stations in the dry region (Beaux Songes). A further observation is that Grand Bassin had the highest rainfall total for the period, whereas Arnaud had the highest erosive rainfall totals.

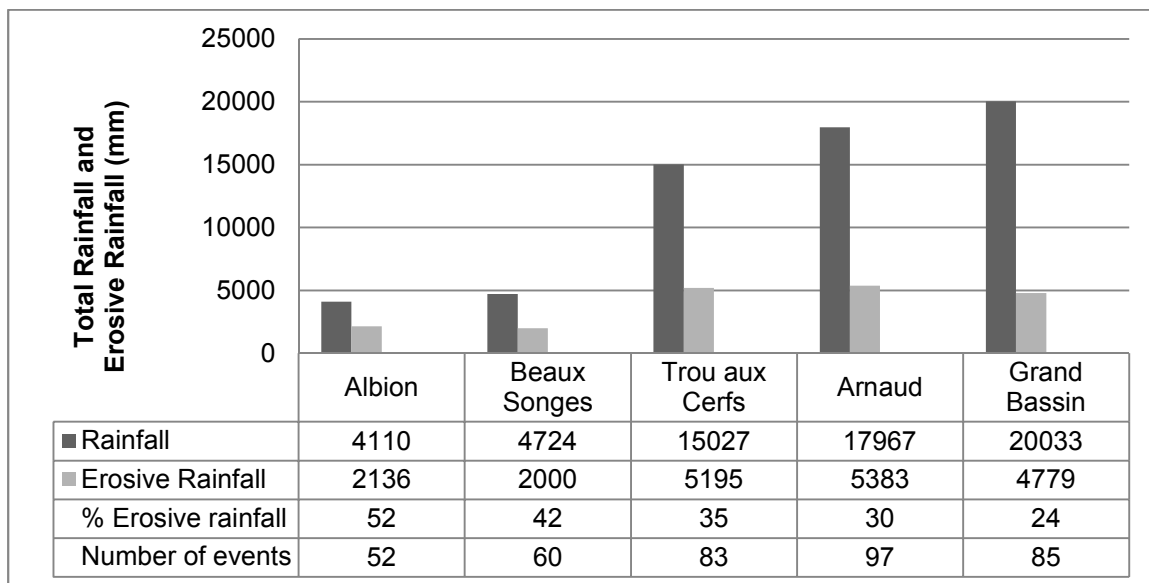


Figure 5.1: Total rainfall and the total depth of erosive rainfall (mm), percentage of erosive rainfall of the total rainfall and the total number of events experienced by each station over the study period.

Table 5.1 shows the percentage of rainfall received by each station during the wet and dry seasons that the island receives, as well as the percentages of the total annual erosive rains experienced. The dry region experiences a general 75/25 ratio of rainfall, whereas the wet region experiences a 55/45 ratio of annual rainfall distribution between seasons. For all stations, more erosive rainfall was received in the wet season than in the dry season. Overall, rainfall is similar over the study area for stations within each rainfall zone, but the total amount of erosive rainfall for this period is much more variable. For example, Trou aux Cerfs received a high amount of erosive rainfall that fell during the dry seasons.

	Annual Rainfall		Annual Erosive Rain	
	Wet	Dry	Wet	Dry
Albion	73%	27%	76%	24%
B.S.	77%	23%	85%	15%
Arnaud	58%	42%	88%	12%
G.B.	53%	47%	79%	21%
T.A.C.	56%	44%	66%	34%

Table 5.1: Distribution of total rainfall between dry and wet seasons for Albion, Beaux Songes (B.S.), Arnaud, Grand Bassin (G.B.) and Trou aux Cerfs (T.A.C.).

### 5.1.1 General description of Erosive Events during the study period

In Figure 5.2, the number of erosive events received on an annual basis for each station, as defined in the Methodology, are presented. No immediate patterns are apparent, but what is observed is the number of events that each station experiences on an annual basis is variable. The highest number of events that was recorded at a station during one year was at Trou aux Cerfs with a total of 27 events. The highest recorded erosive events of Albion and Beaux Songes (the stations in the driest region of the island) is 15. Generally, the stations in the wetter region of the island receive more events than the drier regions, but a number of exceptions do occur. In 2004, 2006, 2007 and 2008 all recorded at least one station in the wet region with more erosive events than the number of events experienced in the dry region combined but some stations in the wet region recorded fewer annual event totals compared to the dry region. In 2004, the highest number of events for the wet region was recorded, while 2005 recorded the most events for the dry region.

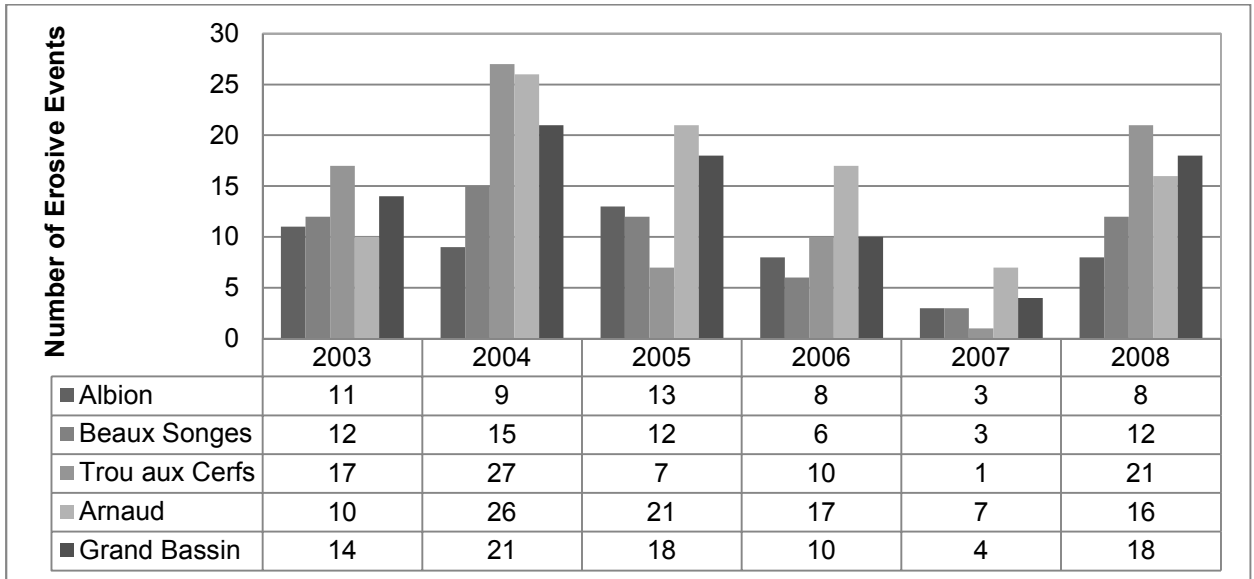


Figure 5.2: Annual erosive event totals for each station 2003 – 2008.

A brief look at the stations in each region reveals the following: For Albion and Beaux Songes, no definite trend in annual totals could be observed except for the lower number of events in 2006 and 2007 due to the missing information that occurred during the high rainfall months in the respective years (this also applies for the stations in the interior of the island). Each of the stations experienced three years where they had the highest number of recorded events. Beaux Songes experienced the highest total number of events with 15 recorded in 2004. The highest recorded events for Albion was 13 in 2005.

The maximum number of erosive events received by the stations in a single year in the central interior is as follows:

- Trou aux Cerfs received 27
- Arnaud received 26
- Grand Bassin received 21

All were recorded in 2004. The number of events received on an annual basis for all stations were variable with no relationship found between the stations with regard to numbers of events on an annual basis.

In Figure 5.3, the total number of erosive events received by each station for the study period is displayed for each station. The greatest number of events recorded was found at Trou aux Cerfs with 97 erosive events. The least is Albion with 52 erosive events. In total, the stations in the wetter region of the island experienced up to 52% more erosive events than the

stations in the dry region. Within the wet region, Trou aux Cerfs experienced around 15% more events than Arnaud and Grand Bassin, the other stations in the wet region.

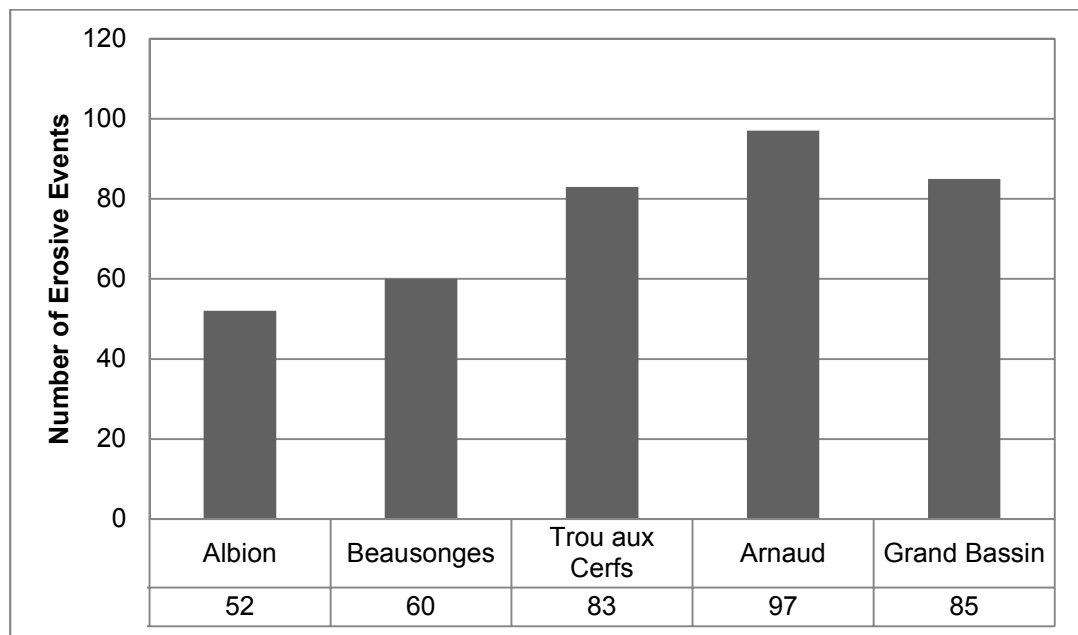


Figure 5.3: Total erosive events experienced by each station for the study period (2003 - 2008).

Figure 5.4 indicates the total number of erosive events experienced each month during the study period at all stations. February and March received the highest rainfall, and the data shows the most number of erosive events took place during these months as well (discussed later). The wet season (November - April) experienced 252 events but the dry season (May - Oct) experienced 57 events. This means that for the study period, the wet season experienced 4.42 times more erosive events than the dry period. These erosive events show that the highest number of events take place during the wet season. It is observed that some events do also take place in the dry season. These erosive events show that the highest number of events takes place during the wet season.

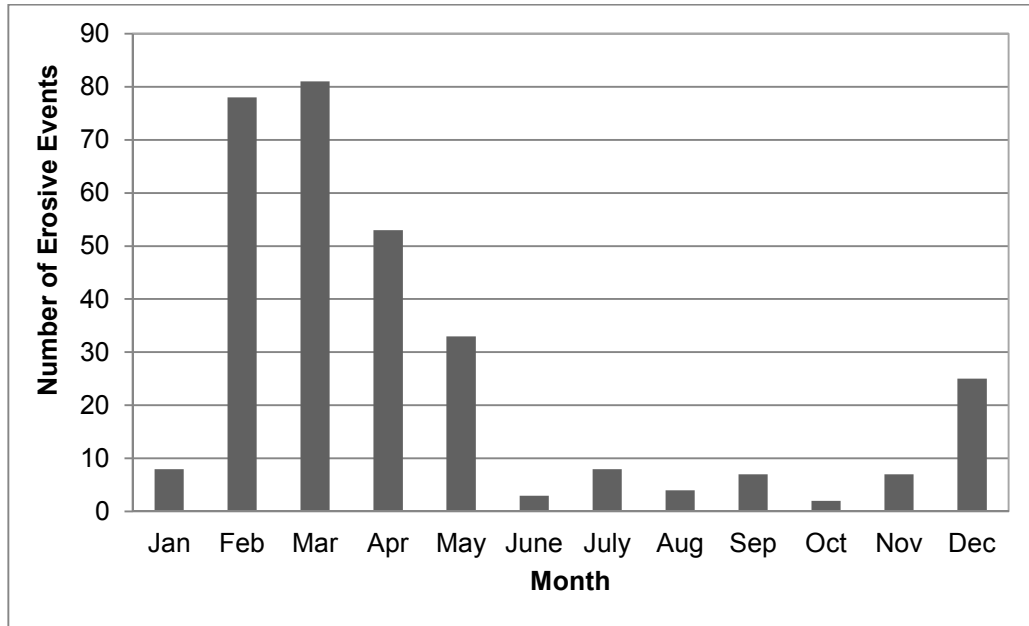


Figure 5.4: Total erosive events experienced by each station during each month for the study period.

### 5.1.2 General description of erosivity and rainfall

Tables 5.2 – 5.6 reveal the varying attributes of rainfall and erosivity of the stations experienced during the study period. The highest annual totals of each attribute for each period are highlighted. Generally, years with the highest rainfall have the highest erosive rainfall amount, with few exceptions. When it comes to the maximum 30 minute erosivity values and total erosivities experienced in the year, no association is apparent between the stations with high rainfall and erosive rainfall. The individual attributes of events therefore are important to consider when dealing with rainfall intensities and erosivity calculations.

Albion	Total rain (mm)	Erosive rain (mm)	% Erosive Rain	Max 30min Erosivity (J mm ha <sup>-1</sup> h <sup>-1</sup> )	Mean Erosivity (J mm ha <sup>-1</sup> h <sup>-1</sup> )	Total Erosivity (J mm ha <sup>-1</sup> h <sup>-1</sup> )
2003	593	374	<b>63</b>	18306	4584	45142
2004	690	281	41	6805	3472	29012
2005	878	456	52	<b>19017</b>	4796	<b>56563</b>
2006	803	412	51	12252	3799	36826
2007	231	143	62	12172	<b>6774</b>	19568
2008	<b>915</b>	<b>471</b>	52	14703	6043	51133
	Total= 4110	Total= 2136	Average= 52		R=	39707

Table 5.2: Annual attributes of rainfall, erosive rainfall and rainfall erosivity for the station at Albion. Maximum values are highlighted.



B.S.	Total rain (mm)	Erosive rain (mm)	% Erosive Rain	Max 30min Erosivity (J mm ha <sup>-1</sup> h <sup>-1</sup> )	Mean Erosivity (J mm ha <sup>-1</sup> h <sup>-1</sup> )	Total Erosivity (J mm ha <sup>-1</sup> h <sup>-1</sup> )	
2003	900	408	<b>45</b>	14334	4204	47037	
2004	867	368	42	5857	2667	37646	
2005	<b>1090</b>	<b>474</b>	43	<b>29701</b>	5640	<b>57389</b>	
2006	611	232	38	14869	4894	28464	
2007	381	121	32	9007	<b>6083</b>	11917	
2008	875	397	<b>45</b>	17428	3938	51584	
Total= 4724			Total= 2000	Average= 42	R=		39006

Table 5.3: Annual attributes of rainfall, erosive rainfall and rainfall erosivity for the station at Beaux Songes. Maximum values are highlighted.

T.A.C.	Total rain (mm)	Erosive rain (mm)	% Erosive Rain	Max 30min Erosivity (J mm ha <sup>-1</sup> h <sup>-1</sup> )	Mean Erosivity (J mm ha <sup>-1</sup> h <sup>-1</sup> )	Total Erosivity (J mm ha <sup>-1</sup> h <sup>-1</sup> )	
2003	2877	799	28	48977	9248	111250	
2004	2960	1209	41	23752	5995	145626	
2005	2172	509	23	36925	12402	83270	
2006	2527	<b>1383</b>	<b>55</b>	<b>97741</b>	<b>19813</b>	<b>221944</b>	
2007	1095	30	3	8598	8598	8598	
2008	<b>3395</b>	1266	37	64647	10272	205812	
Total= 15027			Total= 5195	Average= 35	R=		129417

Table 5.4: Annual attributes of rainfall, erosive rainfall and rainfall erosivity for Trou Aux Cerfs. Maximum values are highlighted.

Arnaud	Total rain (mm)	Erosive rain (mm)	% Erosive Rain	Max 30min Erosivity (J mm ha <sup>-1</sup> h <sup>-1</sup> )	Mean Erosivity (J mm ha <sup>-1</sup> h <sup>-1</sup> )	Total Erosivity (J mm ha <sup>-1</sup> h <sup>-1</sup> )	
2003	2908	655	23	27272	<b>10821</b>	92426	
2004	3172	1146	36	25634	7700	183775	
2005	<b>4003</b>	<b>1409</b>	35	<b>53713</b>	9280	<b>191111</b>	
2006	2595	974	<b>38</b>	23469	7609	117994	
2007	1789	297	17	6721	5072	33431	
2008	3500	902	26	2443	597	163714	
Total= 17967			Total= 5383	Average= 30	R=		130408

Table 5.5: Annual attributes of rainfall, erosive rainfall and rainfall erosivity for Arnaud. Maximum values are highlighted.

G.B.	Total rain (mm)	Erosive rain (mm)	% Erosive Rain	Max 30min Erosivity (J mm ha <sup>-1</sup> h <sup>-1</sup> )	Mean Erosivity (J mm ha <sup>-1</sup> h <sup>-1</sup> )	Total Erosivity (J mm ha <sup>-1</sup> h <sup>-1</sup> )
2003	3856	847	22	28899	10823	130020
2004	3099	865	28	28782	5825	122438
2005	<b>4670</b>	<b>1375</b>	<b>29</b>	<b>64584</b>	12042	194807
2006	2323	549	24	25931	6466	65853
2007	2290	139	6	6853	4690	16382
2008	3794	1004	26	81218	<b>13170</b>	<b>197921</b>
	Total= 20033	Total= 4779	Average= 24		R=	121237

Table 5.6: Annual attributes of rainfall, erosive rainfall and rainfall erosivity for Grand Bassin. Maximum values are highlighted.

Apart from Trou aux Cerfs, years with the highest rainfall totals also had the highest numbers of erosive rain totals. For all stations in the wet region, the years with the highest rainfall also had the highest percentage of erosive rainfall and years that experienced the highest maximum 30 minute erosivity in an event also experienced the highest total erosivity. The highest rainfall and erosive rainfall attributes both for the stations in the wet region and Beaux Songes occurred in 2005. Albion and Beaux Songes experienced the same years with the highest annual attribute values. Thus it appears that the greatest number of erosive events does not always correlate with the greatest erosivity values.

### 5.1.3 R-factor values

Albion and Beaux Songes experience similar amounts of erosivity on an annual basis with some small variation between the two stations (less than 5%). The stations in the wet region also experiences markedly similar *R*-factor values. Trou aux Cerfs and Arnaud experienced very similar *R*-factor values (less than 1% difference) for the time period, but Grand Bassin was found to be 7% lower than the other stations. A definite pattern can be found when considering the stations: In the dry region of the island, *R*-Factor values are much lower than the wet region (between 67 and 70% lower, Figure 5.5 and Table 5.7).

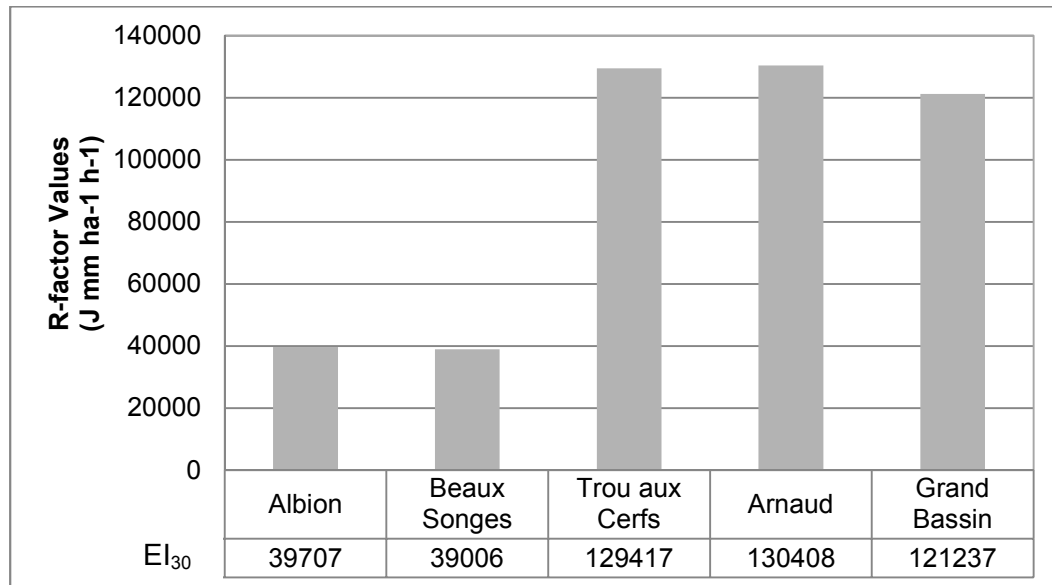


Figure 5.5: R-factor values for all stations calculated for the period 2003 – 2008.

	Albion	B.S.	T.A.C.	Arnaud	G.B.
Albion					
B.S.	2				
T.A.C.	69	70			
Arnaud	70	70	1		
G.B.	67	68	6	7	

Table 5.7: This table presents the percentage difference in the calculated R-factor values between the stations.

Based on raw values, Albion and Beaux Songes experienced values between 39 000 and 40 000  $J\ mm\ ha^{-1}\ h^{-1}$ . In the central interior, values range between 129 400 and 130 400  $J\ mm\ ha^{-1}\ h^{-1}$ . The differences between stations in the dry area are less than 1 000  $J\ mm\ ha^{-1}\ h^{-1}$  and in the wet regions differences are less than 10 000  $J\ mm\ ha^{-1}\ h^{-1}$  indicating that differences between the stations in the central interior are 10 times greater than the erosivity differences in the western edge of the island. Erosivities for each station in each region are now investigated. The stations of Albion and Beaux Songes are discussed first, and the remaining stations attributes discussed thereafter.

#### 5.1.4 Albion and Beaux Songes rainfall erosivity

Figure 5.6 presents the annual erosivity averages for the stations in the dry area. The values peak at 67 767  $J\ mm\ ha^{-1}\ h^{-1}$ . As with the total rainfall and total erosive rainfall values that the stations received, neither station was consistently more erosive than the other. In 2003

and 2008, both stations received almost identical average annual erosivity. The highest erosivity recorded at Albion and Beausonges was 62 352 and 67 676 J mm ha<sup>-1</sup> h<sup>-1</sup> respectively, both for year 2005.

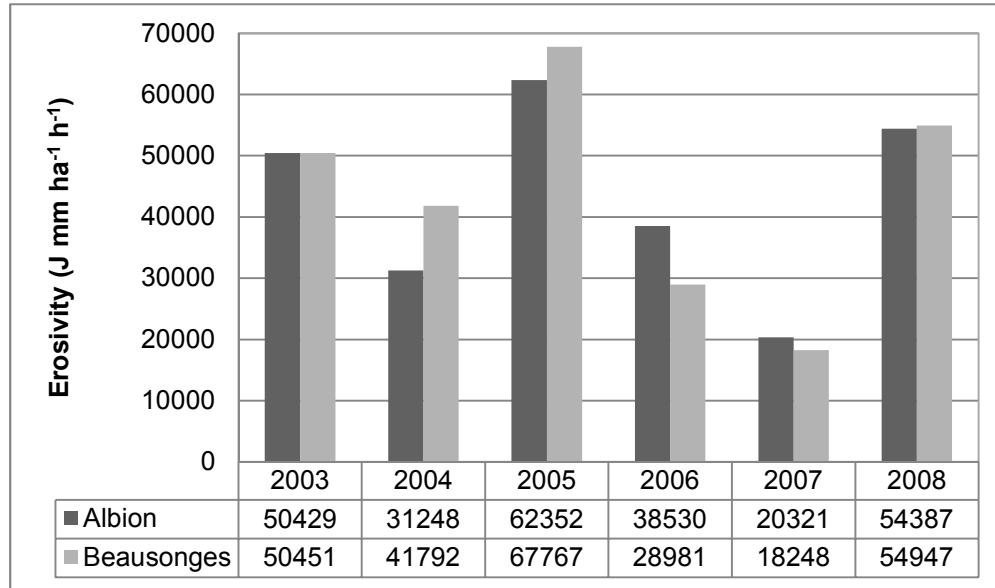


Figure 5.6: Total erosivity experienced at Albion and Beausonges stations.

#### 5.1.5 Trou aux Cerfs, Arnaud and Grand Bassin rainfall erosivity

It can be seen in Figure 5.7 that the erosivity experienced by the stations in the wet region of the island is greater but more variable than the dry part of the island. The highest erosivity that was received during a single year was Trou aux Cerfs in 2006 which can be attributed to Tropical Cyclone Hennie that strayed near the island during the year. However, erosivity over the entire study period for this station is lower than Arnaud but greater than Grand Bassin. The difference between the stations is large during some years; for example, in 2006, Trou aux Cerfs experienced 3.2 times greater erosivity than Grand Bassin.

Arnaud and Grand Bassin, the stations with generally similar attributes, also showed large differences between annual erosivity values indicating that erosivity received annually can be variable even though long term erosivity and rainfall attributes are similar. No tendencies could be found in the erosivity values that each station experienced on an annual basis as each station received a higher amount of erosivity for one or more years. This is partly the reason why long periods of data are needed when dealing with rainfall erosivity.

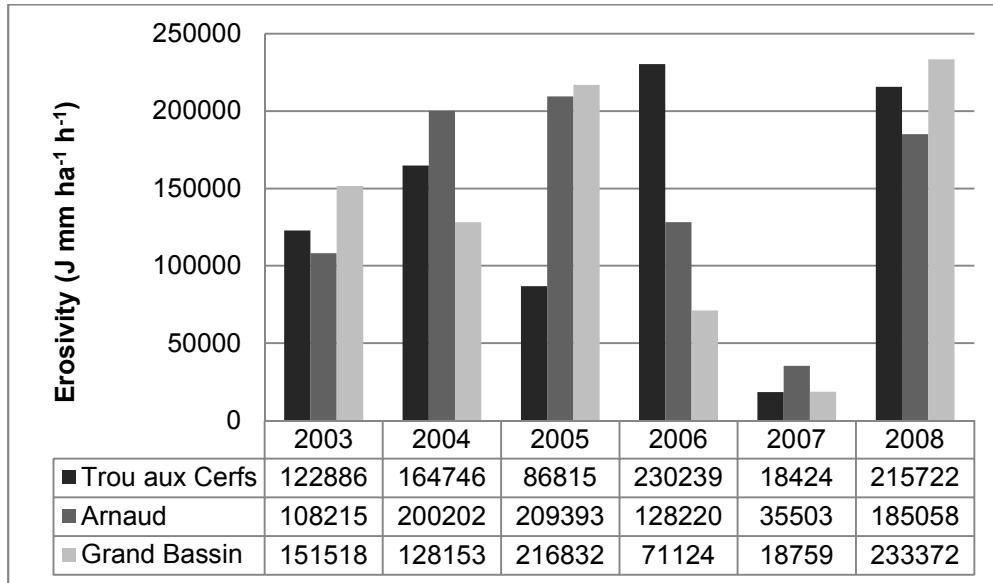


Figure 5.7: Total annual erosivity experienced at Trou aux Cerfs, Arnaud and Grand Bassin stations.

To point out the high seasonality of erosivity, in 2007, only January, February and March had data missing in that year. Erosivity results for this year are markedly low for all stations as these months receive the highest amount of rainfall and erosive events (see section 5.1.1). Incomplete data sets, particularly during the wet season will produce inaccurate results when calculating erosivity.

The erosivity that is experienced in the dry region of the island is around a third of the erosivity experienced in the wetter regions of the island. The differences in erosivity in the wet region were far greater, both in percentage and absolute values than in the dry region. Also, variations between the average annual erosivity values in the wet region are much greater than the variations of the average annual erosivity values in the dry region:

- Largest difference between annual erosivity values in the dry region is 25%.
- Largest difference between annual erosivity values in the wet region is 70%.
- Smallest difference between annual erosivity in the dry region values is <1%.
- Smallest difference between annual erosivity in the wet region values is 3.5%.

### 5.1.6 Additional comparisons

The maximum amount of annual erosive rainfall for all years and for each station was selected for each station and is presented in Figure 5.8. It was found that there is an apparent threshold of how much erosive rainfall can occur within a year. Albion and Beaux Songes experienced 471mm and 474mm respectively, and Trou aux Cerfs, Arnaud, and Grand Bassin with 1383mm, 1409mm and 1375mm respectively, with differences of less than 3% in all stations. This indicates that there is, at least for the study period, a possible limit to the amount of erosive rainfall that can fall within a single year.

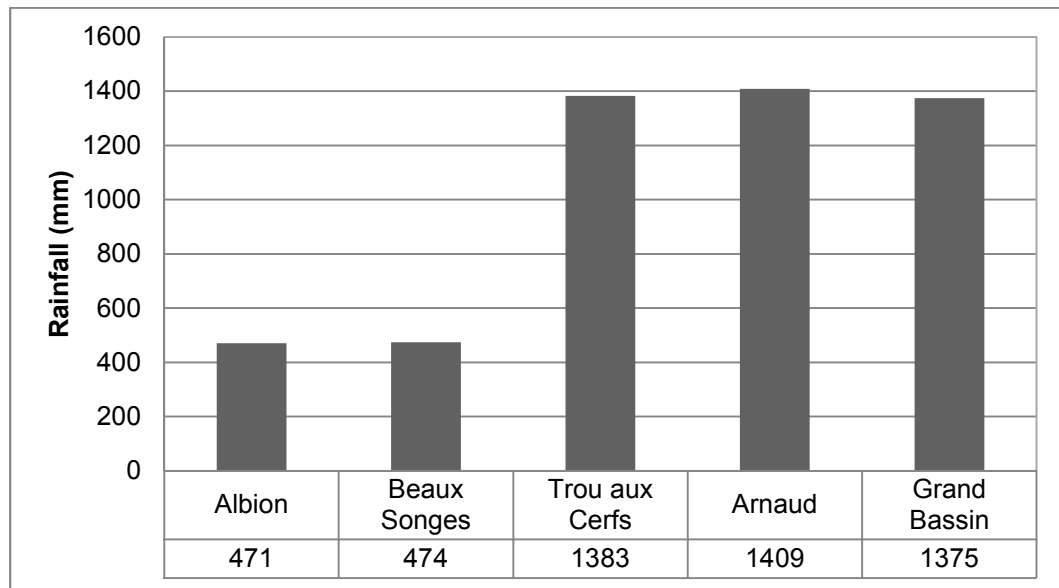


Figure 5.8: Maximum erosive rainfall totals received at the various stations for all years. All values in millimeters (mm).

In Table 5.8, the highest erosivity experienced during any year for each station is presented. The highest recorded was at Trou aux Cerfs during 2006. The highest recorded rainfall occurred in 2008 for this station. It is likely that the high 2006 erosivity value is associated with the tropical cyclone Hennie that passed near the island during that year. Tropical cyclones are associated with high intensities and rainfall. This could indicate that erosivity values are more dependent on the events themselves than on years with the most recorded rainfall and erosive rainfall. In other words, it is possible for a high amount of rainfall to be received by an area, but with low intensities and thus low erosivity values.

Stations	Erosivity ( $J\ mm\ ha^{-1}\ h^{-1}$ )	Year
Albion	19017	2007
Beaux Songes	29701	2007
Trou aux Cerfs	97741	2006
Arnaud	53713	2003
Grand Bassin	81218	2008

Table 5.8: Maximum erosive rainfall totals received at the various stations.

Figure 5.9 indicates the maximum annual rainfall that was received during a single year during the study period. Beaux Songes recorded the highest rainfall in the dry region, and Grand Bassin in the wet region. When Figure 5.8 is compared with Figure 5.9, it is observed that despite the amount of rainfall a station experiences, there is a limit to the amount of erosive rainfall that an area can receive.

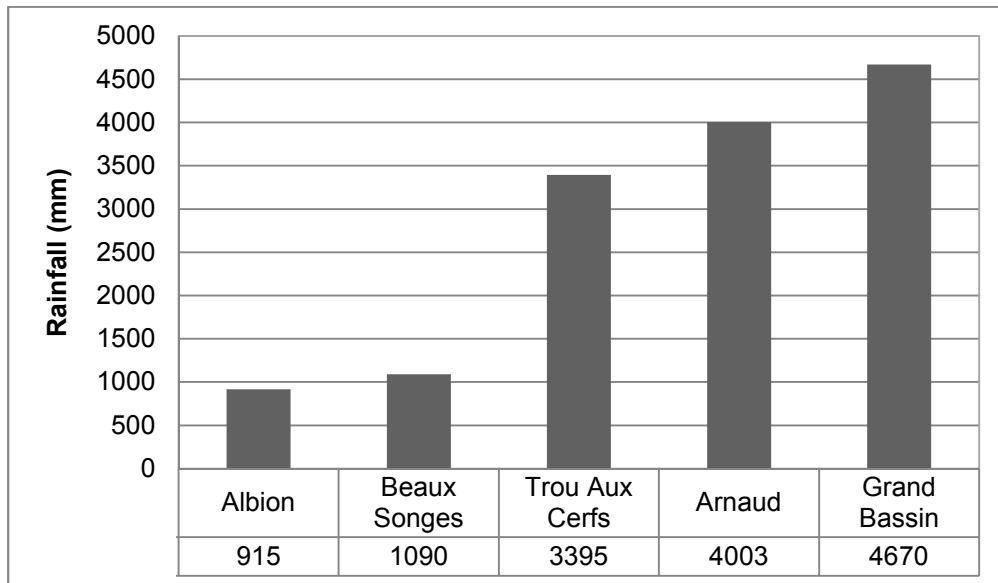


Figure 5.9: Maximum annual rainfall for all the stations.

Differences in the maximum annual rainfall received by the stations occur. The highest annual rainfall was in Grand Bassin, maximum annual erosivity was recorded at Trou aux Cerfs and maximum recorded erosive events during the study period were at Arnaud. Despite the similarity in the total erosivity each station has, each station does experience differing attributes, such as the maximum annual rainfall.

## 5.2 Results for Objective Two

*Analysis of rainfall erosivity in Western Mauritius using periods of 5 consecutive 6 minute intervals, and set 30, and 60 minute intervals*

The amount of erosivity when  $EI_{30}$  is calculated using differing periods of 5 consecutive 6 minute intervals, and set 30, and 60 minute intervals for all stations are provided in Figure 5.11. Visual inspection shows that no matter which resolution is used, that within the same resolution, the calculated erosivity generally has the same relationship, with the major difference of lower values.

For the tables below (see section 4.8):

$EI_{30C}$ : Erosivity calculated spanning 5 consecutive 6 minute intervals covering the peak intensity of the event and adjacent values

$EI_{30S}$ : Erosivity calculated using set 30 minute periods starting at set times

$EI_{30H}$ : Erosivity calculated when set 60 minute periods are used and converted to 30 minutes

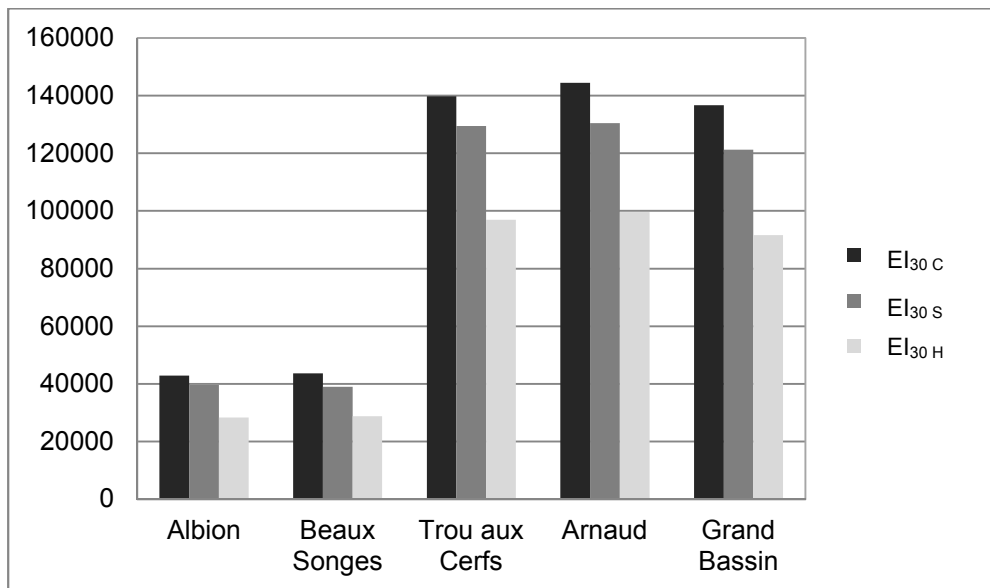


Figure 5.10: Erosivity values calculated for the study period through  $EI_{30}$  using the 5 consecutive 6 minute intervals and the set 30 and 60 minute intervals.



Calculating the percentage erosivity that is underestimated reveals the following (Table 5.9):

- When set 30 minute periods are used (as compared to the 6 minute interval):
  - 10% erosivity is underestimated in the dry region
  - 9 – 14% erosivity is underestimated in the wet region
- When set 60 minute intervals are used (as compared to the 6 minute interval):
  - 38% erosivity is underestimated in the dry region
  - 33 – 42% is underestimated in the wet region

	Albion	B.S.	T.A.C.	Arnaud	G.B.
El <sub>30C</sub>	100%	100%	100%	100%	100%
El <sub>30S</sub>	90%	89%	93%	90%	89%
El <sub>30H</sub>	66%	66%	69%	69%	67%

Table 5.9: The percentage of erosivity accounted for at 6, 60 and 60 minute intervals.

This indicates that, when considering the peak intensities that are missed (when higher resolution data is used), more erosivity is underestimated in wetter regions than drier regions when the consecutive 30 minute intervals are used. The percentage of rainfall erosivity that is underestimated for all stations at the 60 minute interval, however, appears to be the same.

For the stations on the drier region of the island (Figure 5.12), the amount of erosivity that is underestimated is fairly high when considering the low erosivity that already takes place. For the station in the interior of the island (Figure 5.13), the percentage erosivity that is underestimated are similar in extent as the stations in the dry area but the values of erosivity are far greater. Results for all stations are remarkably similar to each other. The dry regions show consistent results with around 10% of erosivity having not being accounted for when set 30 minute intervals are used and 66% erosivity not being accounted for when set 60 minute intervals are used. For the stations in the interior, results are less consistent, but still fairly precise, with between 89 – 93% of erosivity unaccounted for when using set 30 minute intervals and between 67 – 69% of rainfall erosivity when using set 60 minute intervals.

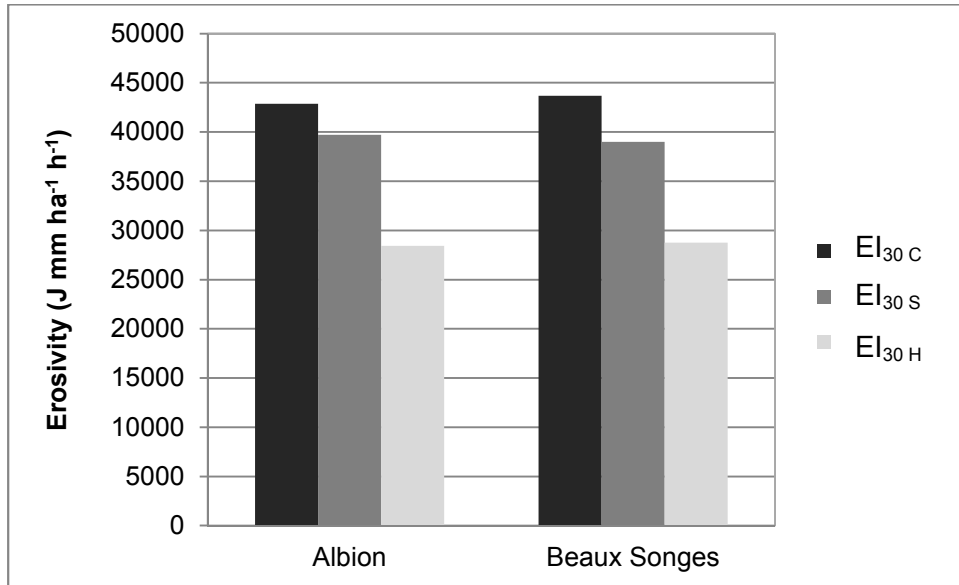


Figure 5.11: Erosivity values calculated for the study period through  $EI_{30}$  for Albion and Beaux Songes using the 5 consecutive 6 minute intervals and the set 30 and 60 minute intervals.

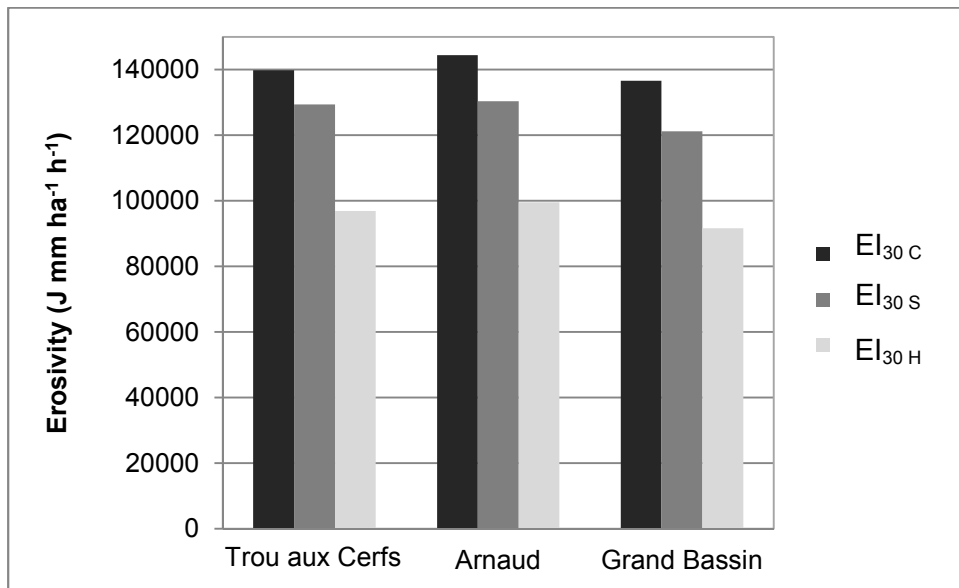


Figure 5.12: Erosivity values calculated for the study period through  $EI_{30}$  for Trou aux Cerfs, Arnaud and Grand Bassin using the 5 consecutive 6 minute intervals and the set 30 and 60 minute intervals.

The relationship between the stations at the three set time intervals remains the same. Despite the fact that actual values for the stations are different, results show that 6 and 60 minute intervals can be used successfully to show the variations of erosivity between the stations. Although absolute values differ, both 6 and 60 minute intervals can also be used to

show the differences between areas with low and high erosivity for all stations. In all cases, there was no more than a 3% difference in relations between the stations for all time intervals indicating that even though absolute values do differ, the relationship between the values in all stations is the same.

### 5.3 Results for Objective Three

*Comparing the use of the Modified Fournier Index to the standard  $EI_{30}$  method in calculating rainfall erosivity*

When the Modified Fournier Index was used to calculate  $R$ -factor values, the following was found: The MFI does capture the low erosivity received in the dry western edge and the high erosivity received in the wet central interior and a somewhat similar relationship between the erosivity received by the stations is evident. As found using the  $EI_{30}$  method, Albion and Beaux Songes have similar erosivity values (difference of <7%). Also, as found with the  $EI_{30}$  method, the interior stations also had similar erosivities, but the similarities were not as evident as the stations in the west (with a difference of <14%). The major difference between the methods used by the 30 minute Erosivity Index and the Modified Fournier Index is in the difference between the absolute values that have been calculated.

The values calculated by the Modified Fournier Index were found to be around 20 times greater than the calculated values of  $EI_{30}$ . For example, 530 000 J mm ha<sup>-1</sup> h<sup>-1</sup> were calculated for Albion when using MFI and 39707 J mm ha<sup>-1</sup> h<sup>-1</sup> were calculated when using  $EI_{30}$ . The results when calculating  $R$ -factor values using the Modified Fournier Index are in Figure 5.14, and the calculated  $R$ -factor values when using  $EI_{30}$  at set 30 minute intervals are in Figure 5.15.

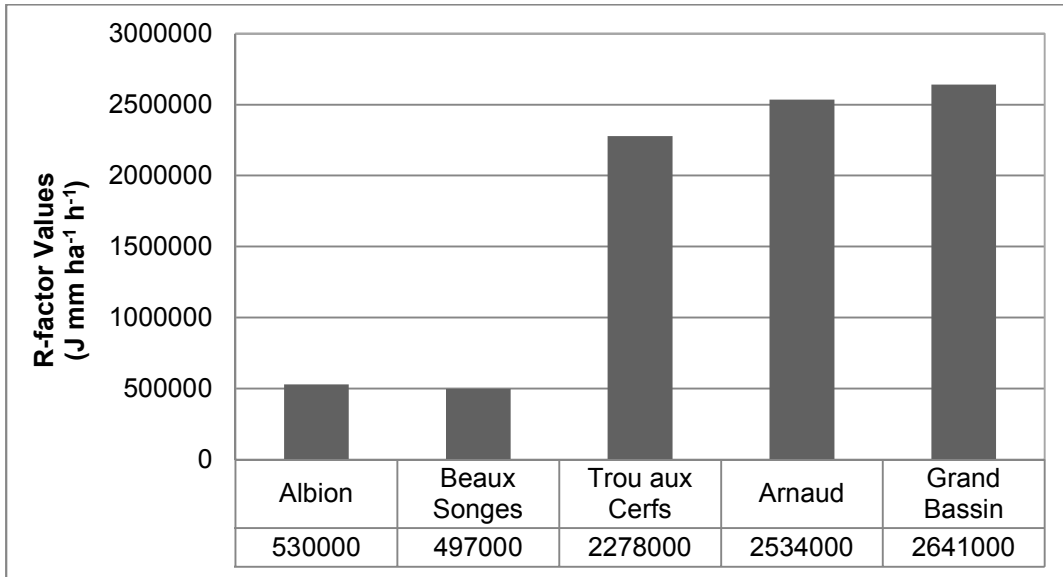


Figure 5.13: *R*-factor values calculated for all stations using the Modified Fournier Index.

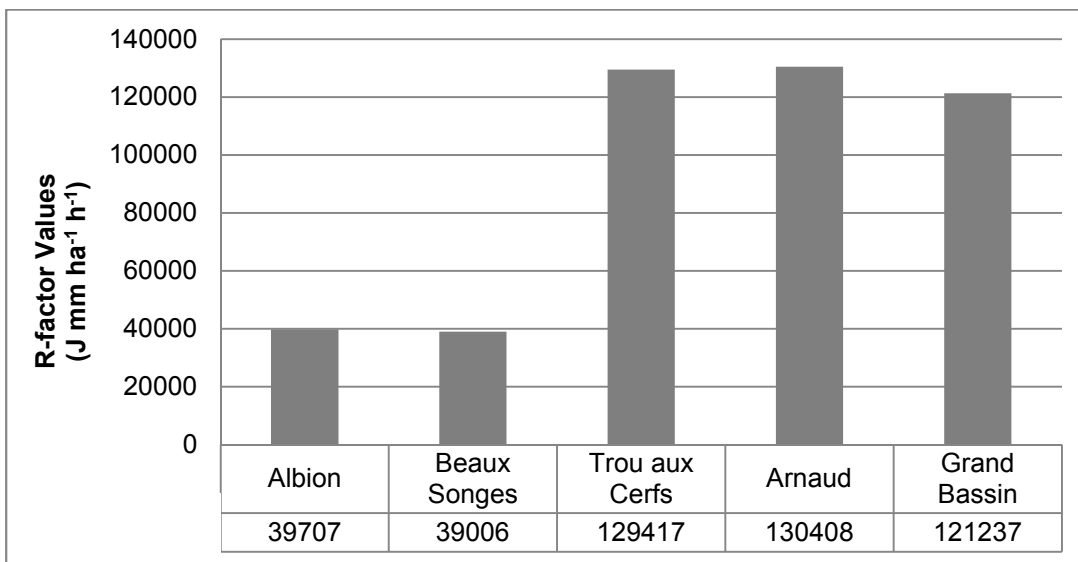


Table 5.14: *R*-factor values for all stations calculated using  $EI_{30}$ .

Investigating the relationships of the erosivity calculated by the two methods, the following was found: Between stations within the same zone, Albion and Beaux Songes had a 2% difference in erosivity values when calculated with  $EI_{30}$  but a 6% difference when using the MFI (Table 5.10 and 5.11). The slight overestimation of erosivity by the MFI method is negligible due to the low erosivity values that occur in this area. In the wet region however, differences between stations range between 4 and 10% when using  $EI_{30}$  and between 5 and 6% when

using MFI. Considering the amount of erosivity experienced in the wet region, this difference is noteworthy. Variability between the erosivity values of the wet region is underestimated when MFI is used. Whereas the average erosivity experienced in the dry area is 5 times as much as in the wet area according to the MFI, the  $EI_{30}$  method approach shows that rainfall in the wet region is only 3 times as erosive as the dry region.

	Albion	B.S.	T.A.C.	Arnaud	G.B.
Albion					
B.S.	6				
T.A.C.	73	78			
Arnaud	79	80	10		
G.B.	80	81	14	4	

Table 5.10: Percentage differences between the stations when using the Modified Fournier index.

	Albion	B.S.	T.A.C.	Arnaud	G.B.
Albion					
B.S.	2				
T.A.C.	69	70			
Arnaud	70	70	1		
G.B.	67	68	6	7	

Table 5.11: Percentage differences between the stations in erosivity when using the  $EI_{30}$  method.

Table 5.12 indicates the results of the same methodology to calculate erosivity using MFI for 1996 by Atawoo (1997) and 1995-1997 by Le Roux (2005) at stations on the island as well as the results calculated using MFI for the stations used in this project. The symbol (c) indicates that the station is located near the coast, and the symbol (i) indicates that it is in the interior of the island. The values are in the same order of magnitude, albeit a lower value, indicating that the results from the methodology used in this project are similar in magnitude. All values below are in  $MJ\ mm\ ha^{-1}\ h^{-1}$ .

Locality	Erosivity	Study
Albion (c)	530	Current
Beaux Songes (c)	497	Current
Trou Aux Cerfs (i)	2278	Current
Arnaud (i)	2534	Current
Grand Bassin (i)	2641	Current
Souillac (c)	1376	Le Roux (2005)
Plaisance (c)	416	Le Roux (2005)
Bel Ombre (c)	407	Le Roux (2005)
Belle Rive (i)	1453	Le Roux (2005)
Curepip (i)	1016	Atawoo & Heerasing (1997)
Vacous (i)	1289	Atawoo & Heerasing (1997)
Plaisance (c)	412	Atawoo & Heerasing (1997)

Table 5.12: Erosivity calculated using MFI in three studies:

This current project, Le Roux (2005) and Atawoo & Heerasing (1997).

#### 5.4 Results for Objective Four

*Investigate the effect of two different climate change scenarios on rainfall erosivity in Mauritius*

After completing the projected calculations for the potential changes of erosivity in the future under two differing climate change scenarios, it is apparent that an increase in the rainfall intensity as well as a decrease will be much more evident in the central interior region of the island. Although some changes are predicted to occur in the dry region, the extent of it is far less than in the wet interior. In Figures 5.16 and 5.17, the increases and decreases at 1%, 2%, 5% and 10% are presented. Note that the differences in erosivity are far greater in the wet region than in the dry. Albion consistently showed a higher erosivity than Beaux Songes in both the increases and decreases, but by only a small increment. However Albion and Beaux Songes also show almost identical increases. Grand Bassin and Arnaud also show almost identical values at the 1%, 5%, and 10% increases.

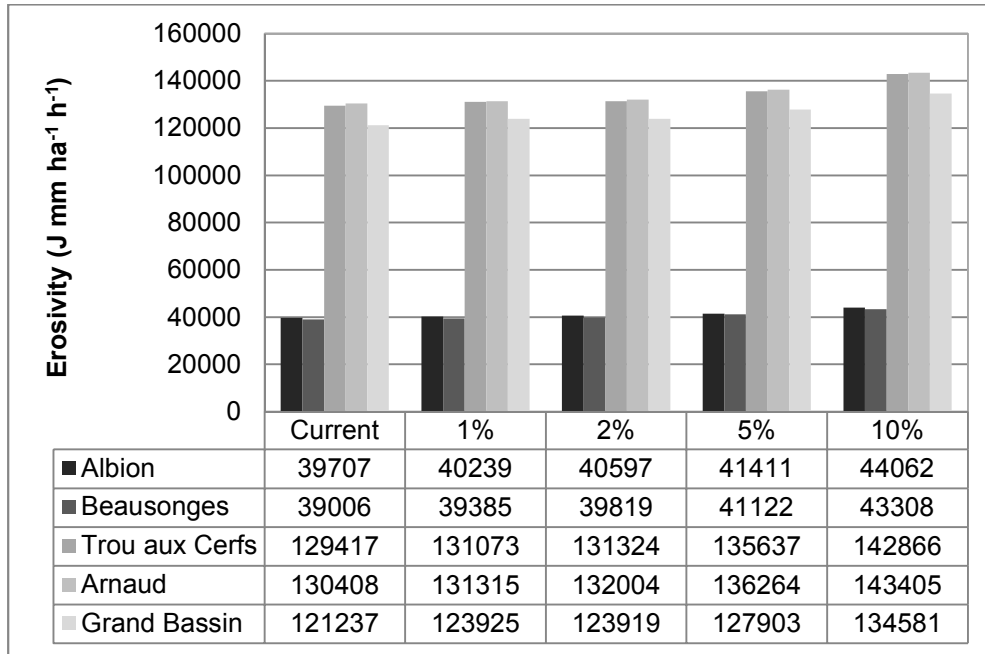


Figure 5.15: Possible increase in erosivity with increase of event intensity at 1%, 2%, 5% and 10%.

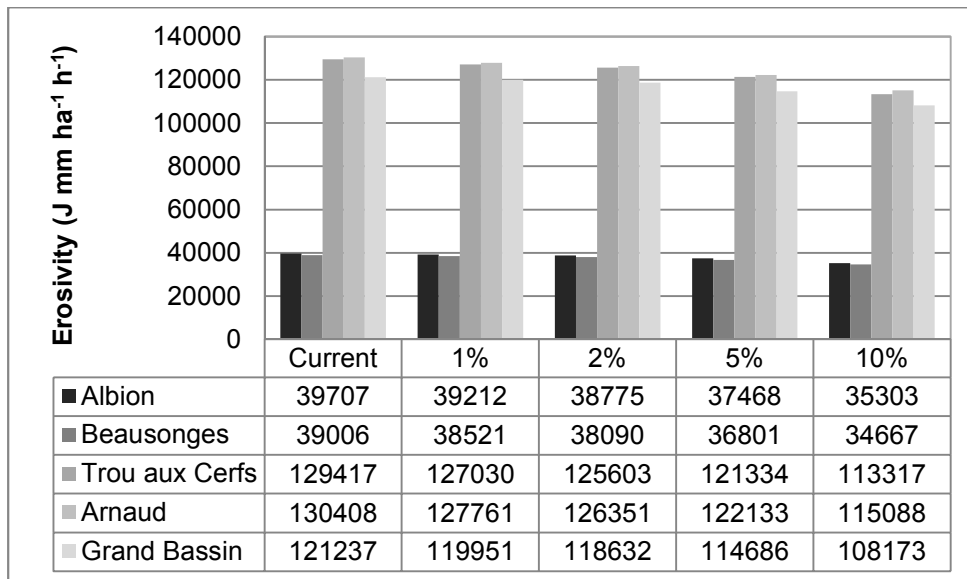


Figure 5.16: Possible increase in erosivity with decrease of event intensity at 1%, 2%, 5% and 10%.

Grand Bassin is predicted to receive the lowest erosivity in the wet region for both climate change scenarios of a projected increase and decrease in rainfall intensity. Erosivity at Beaux Songes is expected to decrease more than Albion if projected rainfall intensities become

less in the future. Arnaud is expected to remain the station receiving the highest erosivity, even if intensities decrease in the future.

The absolute values that erosivity is predicted to increase with the associated percentages are presented in Tables 5.13. It is observed that a decrease in intensity will produce a greater decrease in absolute erosivity than the absolute increase in rainfall erosivity, particularly for stations in the wet region of the island. In the dry region, changes at 1% and 2% are less than  $1000 \text{ J mm ha}^{-1} \text{ h}^{-1}$ , which is low when considering the erosivity experienced in the interior. Individual erosive event intensities therefore are crucial in the amount of erosivity that an erosive event produces. If the increase is in the range of 10%, both the increases in erosivity and the decreases in the dry region are in the region of 4300 and 4400  $\text{J mm ha}^{-1} \text{ h}^{-1}$  which can be potentially hazardous. In the wet region, increases are in the region of 13000 and 15320  $\text{J mm ha}^{-1} \text{ h}^{-1}$  and decreases in the region of 12900 – 13400  $\text{J mm ha}^{-1} \text{ h}^{-1}$ . This increase is around a quarter of the erosivity currently experienced in the dry region. In the wet region, increases of 5 or 10% in intensity will result in potentially higher erosivity.

	Current	1%	2%	5%	10%
Albion	39707	532	890	1704	4355
B.S.	39006	379	813	2116	4302
T.A.C.	129417	1656	1908	6221	13449
Arnaud	130408	907	1595	5856	12996
G.B.	121237	2688	2682	6667	13344

Table 5.13: Increased values of erosivity under future climate change.  
 All values in  $\text{J mm ha}^{-1} \text{ h}^{-1}$ .

The absolute values that erosivity is expected to decrease with the associated percentages are presented in Tables 5.14. Decreases in erosivity will, as mentioned, be greater than the increases when absolute values are considered. Decreases of the intensities of events will be minimal in the dry region, and will be more evident in the central wet region. Around 5 and 10% decreases will also be more noticeable. These increases and decreases are directly related to the rate of soil erosion. An increase in erosivity is likely to be associated with an increase in soil erosion. Conversely, a decrease in erosivity is likely to be associated with a decrease in soil erosion.



	Current	1%	2%	5%	10%
Albion	39707	495	932	2239	4404
B.S.	39006	485	916	2205	4339
T.A.C.	129417	2387	3814	8083	16100
Arnaud	130408	2647	4057	8276	15320
G.B.	121237	1286	2605	6551	13063

Table 5.14: Decreased values of erosivity under future climate change.  
 All values in  $J\ mm\ ha^{-1}\ h^{-1}$ .

### 5.5 A note on tropical cyclones

During the study period, three tropical cyclones (Hennie, Diwa and Gamede) passed near the island. When tropical cyclones Hennie and Diwa passed (03 – 04 March 2006 and 22 – 24 March 2005 respectively), most stations recorded long duration erosive events. Tables 5.15 and 5.16 show the total rainfall, erosivity (rounded to the nearest hundred) and maximum intensity received by the stations during the respective cyclones. No data for cyclone Gamede was recorded.

March 2005	Albion	B.S.	T.A.C.	Arnaud	G.B
Total rain (mm)	28	12	264	431	332
Erosivity ( $J\ mm\ ha^{-1}\ h^{-1}$ )	4 500	1 487	40 000	37 000	58 000
Max 6 min Intensity (mm/h)	54	42	44	34	40

Table 5.15: Rainfall, erosivity and max 6 minute intensity values for stations during Cyclone Hennie.

March 2006	Albion	B.S.	T.A.C.	Arnaud	G.B
Total rain (mm)	0	0	244	81	132
Erosivity ( $J\ mm\ ha^{-1}\ h^{-1}$ )	0	0	23 5000	15 000	23 000
Max 6 min Intensity (mm/h)	0	0	42	34	40

Table 5.16: Rainfall, erosivity and max 6 minute intensity values for stations during Cyclone Diwa.

A very large difference remains between the stations located in the dry area and in the wet area. During the period, little or no rainfall fell in the western region. In the wet region, very high amounts of rainfall fell that were associated with very high erosivity. For all stations that received rain during these periods, intensity values were similar, with the exception of Albion,

with a high intensity short duration event, and Arnaud with lower intensities an associated lower erosivity values compared to Brand Bassin and Trou aux Cerfs.

Chapter 5 has discussed the results of the objectives set out and followed the methodology discussed in the previous chapters. Important findings and analysis have been highlighted and will be discussed in the following chapter. In all cases, the differences in erosivity between the two regions in question were found to be high. Results of the various time intervals indicate some finding which researchers' erosivity may have to consider. The climate change scenarios of future erosivity were also provided with some interesting findings. These will be discussed in depth in the following chapter.

## Chapter Six: Discussion

The size, location, topography, climate and elevation of Mauritius have allowed an investigation of rainfall erosivity within an island environment to be undertaken. The two geographical extremes of rainfall (low and high totals) have provided an opportunity to investigate how elevation can affect the attributes of rainfall erosivity at each extreme. With the results from the previous chapter in mind, this chapter discusses the role that elevation, and the associated orographic lifting, has on the attributes of rainfall erosivity for the period of study. First, the differences in rainfall erosivity and its attributes between the central and western portions of the island are discussed. Initially, the attributes will be discussed individually, but concludes in an integrated discussion. The Modified Fournier Index and the *R*-factor at varying time resolutions are also included. The chapter concludes in a discussion of the possible future of rainfall erosivity and the implications of changes in the rainfall intensity over the island.

### 6.1 Elevation and Rainfall

A definite relationship can be found when looking at the rainfall, erosive rainfall, and event attributes experienced over the study period. They are discussed below:

#### 6.1.1 General rainfall attributes

The first point of discussion is the similarity of rainfall attributes between stations within the same rainfall zones. It is apparent that elevation impacts rainfall on the island. With differences for each region in values less than 7%, it is evident that although minor differences are found, erosivity for the island is consistent within both the geographical rainfall regions investigated in this project. It can be deduced from this that the attributes of rainfall on Mauritius over the six year study period are affected by the island's topography and, more specifically, the orographic forcing that takes place.

Terry & Wotling (2011) note the vital role of orographic effects on rainfall distribution in an area or region. Their work investigated the effect of rainfall on the hydrology of La Grande Island, New Caledonia, a tropical island in the South Pacific which, like Mauritius, is influenced by moist South-East trade winds and a topography that affects the island's rainfall due to this orographic lifting and associated rain shadow effect also resulting in two distinctive wet and dry regions. This confirms the that idea of Nigel (2011) who notes that since the interior has

received more rainfall and erosive events than the coast, that it also receives more intense rainfall than the coastal areas.

### *6.1.2 Erosive events*

Despite the consistency of rainfall erosivity totals experienced by each station in each zone, the number of erosive events experienced on an annual basis at each station is highly variable. It is apparent that years with high event numbers generally have high erosivity events, but stations with the highest event numbers do not necessarily produce the most erosivity. This indicates that individual event intensities and characteristics (such as peak erosivity and duration) are important to consider. Annual event totals for the period are highly variable, with no definite tendencies that can be observed. This can be explained by the fact that the nature of rainfall, storms and erosive events on both the temporal scale and spatial scale are highly variable. On a longer term basis, for the period of study of this project, the interior of the island experienced 38 – 52% more events than the western plains. Erosivity is 67 - 71% higher in the central interior indicating that erosive events in the interior are more erosive, intense and of longer duration.

### *6.1.3 Rainfall totals and erosive rainfall totals*

The dry region of the island received about 20 - 25% of the total rainfall and about 35 – 50% of the erosive rainfall received in the wet region of the island during the study period. The percentage of erosive rainfall (as compared to the total received rainfall) in the in the western plains is between 40 and 50% whereas the interior experiences 24 - 35% erosive rainfall, with a maximum difference of 10% for stations within each region. The lowest total erosive rainfall experienced by the stations in the wet regions (Grand Bassin) is still greater than the highest amount of rainfall experienced by the stations in the dry area (Beaux Songes). The topography and the associated rain shadow affect the total rain and the percentage erosive rain for each region. High rainfall totals do not necessarily mean high erosive rainfall totals. When the results for this project were analyzed, some of the stations in the wet region recorded years where the highest recorded rainfall totals did not have the highest erosive rainfall amount recorded at the station for the study period (section 5.1.7).

#### 6.1.4 Rainfall thresholds

An apparent maximum threshold exists in the amount of erosive rainfall that can fall. This can be explained by erosive events that last a limited duration, as well as a limited amount of time over a single point (such as a weather station). It is also likely that there is a physical limit as to the maximum intensity that an erosive event can have or can be measured. It is possible that rainfall intensity follows a curve on a logarithmic graph (such as the formula used in this project; see section 4.6), and that there is a limit to the amount of erosive rain that can be reached in an erosive event although this limit could be breached during a tropical cyclone over an island. Another possibility is that this threshold may come as a result of limitations of the instruments such as a pooling effect that takes place in the bowl of the rainfall buckets during particular intense rainfall events or a limit of how quickly the tipping bucket systems work. Researchers should be aware of such potential limitations when working with rainfall data.

#### 6.1.5 Seasonality of rainfall and erosive rainfall

Table 5.1 in the previous chapter revealed the seasonality of the rainfall and erosive rainfall that both the western edge and central interior (dry and wet regions respectively) experiences. As confirmed in literature (Nigel & Rughooputh, 2010a; Nigel, 2011), definite wet and dry seasons are experienced. When considering erosive rainfall, it is evident that a much higher percentage for all stations is experienced in winter; but Trou aux Cerfs had a much greater spread of rainfall over both wet and dry seasons indicating that the area around the station experiences more erosive rain during winter than the other stations, both in the dry and wet region.

The variation of erosivity at a seasonal scale is attributed to the high rainfall which is generally associated with erosive events. It is observed that wetter months experience far more erosive events than the dry months. During the study period, 252 events were recorded during all wet seasons and only 57 during the dry seasons, indicating that the wet season experiences over 4 times the erosive events for the period. February and March together had 159 events, more than half of all erosive events experienced during the period, indicating the most erosive rain, and its associated erosivity is likely to occur during this time.

Senepathi *et al.* (2010) investigated the seasonality of rainfall on the eastern portion of the island; they indicate that seasonality of rainfall on a Mauritius is associated with ENSO variability. Changes in the ENSO phenomenon will alter seasonal rainfall, which could change

seasonal erosivity of the island. Changes in circulation over the Indian Ocean basin do affect the island's rainfall. The work by Senepathi *et al.* (2010) suggests that the number of rain days in the wet season will increase. They attribute some variability of long term spatial variation of rainfall to local topography, as discussed in this project.

## 6.2 Elevation and rainfall erosivity

The work in this project confirms the idea that elevation plays a key role controlling the spatial patterns of rainfall erosivity on Mauritius. Hoyos *et al.* (2005) in concluding their work in a tropical region of Brazil note that the spatial patterns of erosivity study show a general trend that is apparently associated with elevation, superimposed on a finer scale of local variability. They emphasize the importance of local processes on rainfall amounts and intensities in areas that have a complex topography. Elevation in Mauritius plays a vital role in affecting the long term attributes of rainfall. These include total erosivity values, total erosive rainfall values and maximum erosive rainfall values. Hoyos *et al.* (2005) also point out that regional elevation and local topography affect the spatial erosivities of an area. It is likely that the same is true for Mauritius. Regional elevation plays a large role in the erosivities that are experienced at a given location, but local topography also affects the erosivities experienced at individual locations (for example, the stations located in differing geomorphological domains). As the results indicate, elevation affects rainfall erosivity in an additional way: differences in rainfall erosivity experienced by stations in the interior are far greater in than the stations in the dry region. The average annual erosivity is more consistent in the dry region. It can be concluded that an elevated topography affects the differences in the rainfall experienced by the stations in each region.

Elevation affects the distribution and amount of rainfall, erosive rainfall and erosive events that the island experiences. The attributes will affect the erosivity that the dry and wet region of the island will each experience. At this point it must be stated that, although longer term erosivity values for each rainfall zone are similar, the individual attributes can be very different. Comparisons of inter region and inter station comparisons follow:

### 6.2.1 Comparisons of high and low rainfall regions erosivity

It is evident that calculated *R*-factor values for the stations within the same rainfall zone are remarkably similar. There is only a 1.8% difference between the *R*-factor values calculated

for each station for the period in the dry region. An interesting observation is Trou aux Cerfs, which had the lowest total rainfall for the study period, had the lowest total erosive rainfall. Arnaud had the highest number of erosive events as well as the highest calculated *R*-factor. Grand Bassin held the highest total rainfall. This highlights a problem with the Modified Fournier Index: High rainfall totals do not necessarily correlate to high erosivity values and are discussed later. However, the only differences between *R*-factor values of the stations in the wet region range from 1 – 7%. This is despite the fact that annual totals for the stations are sometimes very different. The results show that no definite pattern could be found by investigating annual totals, as differing stations received the most total erosivity for different years. Once again this shows the need for long term averages when dealing with rainfall erosivity.

When investigating the data, it appears that erosive events in the wet region are more erosive than in the dry region. This is likely due to the more intense events that occur over stations in the interior, and that the events have longer durations for intense rainfall in the central interior. Higher erosivity is also associated with the number of erosive events (Angulo-Martínez & Beguería, 2009). Albion and Beaux Songes received a maximum of 60 events during the period, whereas the interior received between 83 and 97 events. The number of erosive events is important as Angulo-Martínez & Beguería (2009) note that a few high intense rainfall events can be responsible for the largest proportion of soil erosion and sediment delivery experienced in an area. A greater number of erosive events in a year will be associated with higher annual erosivity.

This is not always the case as Arnaud received the most erosive events, but Trou aux Cerfs received the highest recorded annual erosivity totals. This occurred in 2006 when more than half (55%) of the total rainfall that the station received was classified as erosive. The most rainfall that the station recorded was in 2008 (over 1000mm of rainfall) once again revealing that a high total of rainfall in a year does not necessarily indicate high erosivity as erosivity is dependent on the intensity of the rainfall and not on rainfall totals. This one additional problem that the Modified Fournier Index has: It does not take into consideration the intensities of individual events but only monthly and annual rainfall totals.

The following elements of rainfall were found to have differences associated with elevation:

- Numbers of events
- Erosive Rainfall
- Rainfall

- Erosivity
- Maximum erosivity and maximum mean erosivities

Although the attributes over the study period are similar in many ways, several differences between stations in the same rainfall zones do still remain. They are discussed as follows:

### 6.2.2 *Albion and Beaux Songes*

Albion and Beaux Songes are located in different geomorphic zones (discussed in the following section). As stated in Chapter 4, Albion (5m a.s.l.) is located just a few meters from the ocean, while Beaux Songes (220m a.s.l.) is located 6 km inland from the coast on the lava plains. Despite this fact, both stations experience very similar erosivity values. In 2003, only a  $22 \text{ J mm ha}^{-1} \text{ h}^{-1}$  difference was found between the stations. The largest difference between the stations in erosivity was in 2004 with a difference of  $10\,500 \text{ J mm ha}^{-1} \text{ h}^{-1}$ . Each station at one point had higher erosivity values than the other. Both stations followed a general tendency of increased and decreased erosivity on an annual basis. The differences in annual erosivity can be attributed to the highly spatial and temporal nature of extreme events. It is evident that despite the distance between the stations, the differing geomorphic domains and the altitudinal differences, both stations are subject to the rain shadow effect and experience similar erosivities, rainfall totals and erosive rainfall totals.

### 6.2.3 *Arnaud, Beaux Songes & Trou aux Cerfs*

As with the two stations in the western edge of the island, the three stations located around the interior of the island all have similar erosivities but differences are evident. A closer look at the stations in the interior reveals some noteworthy differences and similarities between the three stations. Over the study period, Grand Bassin (605m a.s.l.) was found to have experienced noticeably less erosivity than that of the other two stations in the interior. The station at Grand Bassin is located on the boundary between the central plateau and the southern uplands. The uplands that are located near those stations may affect the development of erosive events as well as affect the local climate around the station, indicating that the local topography (in the different geomorphic domains) may play a role in affecting erosivity values (by affecting the formation of erosive events).



When investigating the stations, Arnaud (580m a.s.l.) and Grand Bassin appear to share similar traits. Trou aux Cerfs (614m a.s.l.) appears to have different attributes. The calculated *R*-factor values showed only a 1% difference between Arnaud and Trou aux Cerfs, while Grand Bassin was between 6 – 7% lower than the other stations in this region. The erosivity that is experienced between Arnaud and Grand Bassin on an annual basis is very similar.

The consistency between Arnaud and Grand Bassin can be attributed to the annual erosive rainfall amounts rainfall that the stations experience (Figure 5.1). These can be explained by the stations' proximity to the Southern Highlands and the small distance between the stations. It is likely that the stations experienced some of the same events and erosivities during certain erosive events throughout the year. The poor correlation with annual totals with Trou aux Cerfs is due to the distance from the other stations, and the fact that it lies in the center of the Central Plateau (which experienced different rainfall resulting from the flat but elevated topography that it lies in). Despite these differences, as with the stations in the dry region, the differences between the erosivity attributes over the period are very consistent, also indicating that all stations in the region are subject to the orographic lifting that result from the elevated landscape that the stations lie within.

Distribution of rainfall is highly dependent on an island's topography (Senepathi *et al.*, 2010; Hoyos *et al.*, 2005). Terry & Wotling (2011) showed the influence of topography on the hydrology of La Grande Island, elevation and topography were attributed to controlling the spatial distribution of rain depth in the Northern Ethiopian Highlands (Nyssen *et al.*, 2005). Local rainfall amounts are also dependent on elevation in the Cape Vrede Islands located in the tropical Atlantic region of West Africa (Mannaerts and Gabriels, 2000b). The differences between the Arnaud and Grand Bassin attributes can be attributed to the surrounding terrain but also the spatial and temporal nature of extreme events.

#### 6.2.4 Elevation, rainfall and land cover

It is important to consider the following: As discussed in Chapter 3, the center of the island often experiences more than 4000mm of rainfall, and the drier part of the island receives only 600mm of rainfall due to elevation and the associated rainfall shadow effect (WRU, 2007). This is confirmed by some of the values found during the study period of this project. As mentioned, rainfall erosivity is the aggressiveness of rainfall and is the ability of rainfall to detach and move soil on impact, and as such consideration of the existing vegetation is important. In the RUSLE formula, this is considered in the Land Cover factor. Less vegetation

and ground cover which is more likely to be found in the drier regions will be vulnerable to erosion than areas in the central region which has more thicker vegetation, which can deal with the larger rain drops associated with high intensity rainfall, making the soils less vulnerable to direct rainfall.

A number of urban centers also occur in the interior which may negate any erosivity due to road and building surfaces, but may indirectly affect it by channeling water and creating overland flow which could indirectly exacerbate soil erosion in vulnerable areas. Land cover and vegetation can make assessing erosion from rainfall complex (Brooks & Spencer, 1995). This should be considered. Brooks & Spencer (1995) remind researchers that the precise amount of erosion depends on the interaction between the detachment from rainsplash and wash transport. This is due to changes in the net kinetic energy rates and has implications for Mauritius, particularly with respect to the time of year that sugercane, the dominant land cover on Mauritius, is planted, harvested, and grown.

Brooks & Spencer (1995) investigated the implications of rainfall erosivity after logging in Malaysia (also located in a tropical area that is subject to erosive rainfall) and point out that intense rainfall falling through canopy cover can have the same or sometimes, under certain circumstances, actually enhance the erosive power of rainfall (such as canopy concentration). Natural and anthropogenic disturbances should be considered when working with rainfall erosivity. Terry & Wotling (2011) found a similar tendency in La Grande Island (in the tropical South Pacific) as they note that a strong orographic influence is felt on high islands exposed to the south east trade winds, resulting in very high variations in yearly precipitation and corresponding changes in natural vegetation patterns between wet windward areas and drier leeward areas. Nigel & Rughooputh (2010a) reveal that cultivations are at risk of erosion during the intense cyclonic events that the island is subject to. Their risk assessment found that sugercane grown on slopes (which cover 14% of the island) were classified as high erosion areas. An increase in erosivity in this area could exacerbate the problem. Changes with canopy cover due to changes in season and cultivation should also be considered.

### **6.3 Time resolutions**

Results show that when 6 minute interval data is used to calculate  $EI_{30}$ , peaks of intensity are picked up that set 30 minute and 60 minute data do not. These differences are within the range of 7% - 11%. The greatest difference was found at the station in the dry region (both underestimating erosivity by 34%) but the dry region was not that far off (31% and 32%

underestimation) when the set 60 minute interval is used. Yin *et al.* (2007) note that the more detailed the rainfall data are, the more accurate the calculated  $EI_{30}$  will be but they do note that that less estimation error is involved when the interval decreases from 60 to 5 minute intervals. The authors state that it is not necessary to sample less than on a 30 minute frequency to obtain reliable erosivity estimations, when cost-benefit tradeoffs of precipitation measurements is considered (Yin *et al.*, 2007). The 30 minute erosivity developed by Wischmeier & Smith (1958) has been used in many erosivity calculations with success. Researchers should decide the level of accuracy they desire against the time and data available. Considering the monetary cost of high resolution rainfall data and the time needed to sort through the large volumes of data, typical 30 minute resolution data appear to be satisfactory.

If the above resolution is unavailable, the Modified Fournier Index is adequate in calculating rainfall erosivity. However, this is an index and actual raw values calculated by the MFI when compared to the  $EI_{30}$  method are overestimated to a large extent. The reason for this is the MFI relies on monthly and annual totals in calculating the index, and these totals are high in the interior. The  $EI_{30}$  method is a sum of all erosive event erosivities, which adds up to a lesser but more accurate amount. MFI does not deal with any intensity values.

For the island of Mauritius and the research that has been performed on it, when looking at the differences in the relations of rainfall erosivity, it is possible that erosivity values used in current studies may be overestimated in the central interior (which experiences higher rainfall intensities). The drier areas, which experience very low rainfall amounts in comparison with the rest of the island, could cause rainfall erosivity to be under estimated. The MFI does show differences between the two sections of the island well and has value as a calculator of erosivity. Having said this, using hourly data (when converted to 30 minute max intensity) in  $EI_{30}$  calculations were found to be more accurate than MFI. This suggests that even if hourly data are available, it will give a more accurate index than the MFI.

#### **6.4 Modified Fournier Index**

As can be seen in the results presented in the previous chapter (see section 5.5) the Modified Fournier Index is useful in determining rainfall erosivity for a region, however, over a long period, there are some differences when compared to the high resolution calculations using the Erosivity Index method. MFI can be used to show the index of erosivity fairly accurately, but raw values are overestimated. When inspecting the relations between MFI and the  $EI_{30}$ , it is apparent that Grand Bassin is overestimated while Trou aux Cerfs is

underestimated. Having stated this, the MFI does capture the large differences in rainfall erosivity experienced by the two regions. These differences can be attributed to the fact, as mentioned, that high rainfall amounts, on both an annual and monthly basis, do not necessarily mean corresponding high erosivities. In this study, stations with relatively lower rainfall did have the highest erosivity.

As shown earlier in the results chapter (section 5.1), it can be seen that only a portion of total rainfall (between 30 – 60%) is considered erosive. The high values of rainfall that are recorded on a monthly and annual basis can inflate the results calculated by the method used to calculate the Modified Fournier Index.

Although Angulo-Martínez & Beguería (2009) found MFI results as the poorest indication in their work on erosivity in North Eastern Spain, long term annual and mean rainfall data are far more readily available than the preferred high resolution data. Yu & Roswell (1996) show that using the Modified Fournier Index is useful in calculating the *R*-factor with long term data, but also note that the MFI does not significantly improve the *R*-factor estimation relation. They suggest at the very least, MFI (using annual and monthly totals) can be used for assessing relative erosion rates for different management, crops, and soil conditions as well as to indicate the sensitivity of soil loss to the fluctuations in precipitation (Renard & Freimund, 1994; Yu & Roswell, 1996). Introducing factors that can be multiplied into the MFI formula may be helpful to better estimate rainfall erosivity.

## 6.5 Erosivity and climate change

Climate change can affect rainfall erosivity on an island in the following ways: First, considering the two scenarios tested in this study, an increase in intensity (according to the  $EI_{30}$  method) is likely to be associated with a higher erosivity. A key finding from this project is a greater decrease in erosivity is associated with a decrease in intensity than the associated increase of the same percentage. When the nature of rainfall intensity is investigated, this can be better understood. The calculation for event erosivity employs a logarithmic formula. The logarithmic nature of the formula can be seen in Figure 4.9. The formula levels out at  $28.3 \text{ J mm ha}^{-1} \text{ h}^{-1}$  at the maximum intensities measured in an erosive event, as calculated in this project (Figure 4.9). The formula used in the project is designed to more accurately calculate erosivities at higher intensities, but also a limiting factor was placed in the formula as a kinetic energy limit is reached once event intensities exceed  $76 \text{ mm h}^{-1}$ . This means that at high intensities, for example a difference of 5mm/h, the calculated erosivity will be similar, whereas lower intensities

will have a much greater differences for the same amount. Higher intensities therefore will be associated with a limited extent to the erosivity values experienced in higher intensity events.

Second, climate change can affect the characteristics of erosive events, such as its duration, peak intensity (and duration thereof), and raindrop size of the event. This change could potentially be more detrimental than events having only higher intensities. A worst case scenario for the island would be higher intensity events that persist for longer durations and would have severe consequences for an area.

Lastly, changes in sea surface temperatures will affect the degree of evaporation around the island. With a changing climate, the amount energy within the atmosphere for the development of intense erosive events and extreme events will change (IPCC, 2007). This can affect the frequency and strength of the rain creating weather systems in the region. Changes in the sea surface temperatures will also affect the El Niño Southern Oscillation (ENSO) phenomenon, which affects circulation and extreme events around the planet (Lockwood, 2005). This will have the potential to affect annual and seasonal rainfall which may change the seasonality of the rainfall. Longer dry periods may be coupled with periods of intense rainfall. This combination of longer dry periods and higher intensity events can cause severe soil erosion.

The central interior will feel the impacts of climate change more than the dry area of the island in terms of the erosivity that it will experience, but less rainfall intensity may be coupled with lower annual rainfall. Less rainfall in both regions will affect the type and density of the vegetation in both areas. If rainfall erosivity has decreased along with a decrease in rainfall, causing the western regions to experience more drought conditions, this may make the dry regions potentially more vulnerable to rainfall erosivity than an increase would. Thus any decrease in erosivity may not be as beneficial as initially expected.

#### *6.5.1 Implications of changing erosivity*

Changing intensity and erosivity has the potential to alter the current rate of soil loss and land degradation that the island experiences. A decrease in erosivity may be beneficial to the island as decrease in erosivity of the island will be associated with a decrease in the soil loss, as calculated by the RUSLE formula. This will change the soil erosion risk mapping results performed by Nigel & Rughooputh (2010a; 2010b) and results of predicted soil loss by Le Roux *et al.* (2005).

Conversely, an increase in erosivity will increase the risk of soil loss. Areas that are currently classified as medium status could be upgraded to a high risk of erosion. Nearing (2001: 232) states “Historical weather records over this last century show that precipitation is increasing in terms of the number of days of rain and the intensities of rain.” Over the past century, long term mean annual rainfall has decreased. Nearing (2001) emphasizes the importance of extreme events and the most consequential effects of climate change will be in changes of erosive power of rainfall. Nearing (2001) also indicates that, within the United States, some areas will become drier and other areas will become more wet. Also, as rainfall, temperature and atmospheric carbon dioxide levels change, so will soil erosion. This same principle is likely to affect Mauritius. Nowbuth (2010), investigated extreme rainfall events from 1997 – 2001, and supports the hypothesis that the intensities of extreme events will increase, but the number of wet days will decrease. It should be considered when dealing with future changes in rainfall and its associated rainfall erosivity that orographic lifting will still play a role. Local topographic factors and elevation will continue to affect the spatial distribution of higher intensity rainfall over Mauritius.

This project has investigated only the possible increase in the intensity of the erosive events. An increase in duration, frequency and number of events could potentially increase the erosivity that the island experiences greater than an increase in intensity as erosivity depends on these parameters amongst others (including drop size and kinetic energy; Nigel, 2011). Senapathi *et al.* (2010) conclude that there is a strong trend towards the increase of the frequency of rainfall in the island of Mauritius. Such an increase in rainfall will likely be associated with an increase in erosive events. This is potentially hazardous as an increase in erosive events, even if intensities stay the same, will increase the erosivity that the island experiences. They also note that changes in the rainfall patterns over Mauritius will be associated with changes in sea surface temperatures, the El Niño Southern Oscillation (ENSO) and the Indian Monsoon as well as cyclone intensity.

### 6.5.2 Tropical cyclones

With the threat of climate change on the rainfall of Mauritius, some considerations regarding tropical cyclones should be mentioned. First to consider is the changes in the frequency and intensity of tropical cyclones and depressions. An increase of the intensity of tropical cyclones will increase its erosive power, potentially increasing the ability of the cyclone to erode soil. An increase in the frequency of tropical cyclones will have severe consequences

as tropical storms have intense rainfall and do last longer than typical erosive events. A single cyclone event may produce erosivity that is greater than the typical annual erosivity alone. The paths of these systems may be altered due to climate change, which, due to 'climatic dumping' may cause the island to experience longer drier periods, resulting in less formation of erosive rain and erosive events.

With around 3 cyclones being formed in the area every year, cyclones that come near the island can potentially induce erosive rainfall over the interior (Padya, 1984; Cheeroo-Nayamuth, 2000). Conversely, downward orographic forcing can also cause little or no rainfall in the western portion. A direct hit of a cyclone will affect the west region, however, Le Roux (2005) showed intensities of 27mm/h and an erosivity over 1 100 MJ mm ha<sup>-1</sup> h<sup>-1</sup> (as calculated with MFI) at the station at Plaisance. An important note is that it is located in a coastal region and generally experiences erosivities of less than half this value.

Some debate remains surrounding whether tropical cyclones will decrease or increase in frequency as a result of climate change with some climatic models showing less cyclones (Oouchi *et al.*, 2006) while others predict an increase (Webster *et al.*, 2005). If it is accepted that there will be less frequent tropical cyclones but with greater intensities with possibly longer durations due to climate change and warmer sea surface temperatures (Walsh & Ryan, 2000; Webster *et al.*, 2005; Oouchi *et al.*, 2006). Cyclones with greater intensities may well bring rainfall that bears a greater extent of erosivity, which will be detrimental to the island. The island will benefit from less frequent cyclone events, but this may be associated with longer dry/drought periods.

Chapter 6 has presented a discussion of the results that were calculated in Chapter 5. The different extents of erosivity experience in the western plains and the central interior were addressed. Additionally, the use of various time resolutions when using the EI<sub>30</sub> method, erosivity calculated with the Modified Fournier index, and how erosivity may be affected under a changing climate were also dealt with. The project concludes in the following chapter with a summary of the findings and observations gained from the work performed up to this point.

## Chapter Seven: Conclusions

This project has dealt with the attributes of rainfall erosivity ( $R$ -factor) at two geographical extremes of rainfall over a six year period brought about by the elevated topography and associated orographic lifting of the island: the low rainfall region in the western plains and the high rainfall region in the central interior. Calculations were performed following the  $EI_{30}$  method using 6 minute interval rainfall data, and the Modified Fournier Index. Using simple percentage increases, the project investigates future changes in erosivity under different climate change scenarios. A number of conclusions can be drawn with respect to the role that an elevated topography has on the attributes of rainfall erosivity on the island:

### 7.1 Elevation and erosivity

Elevation plays a key role in affecting the erosivity values and attributes of the island as seen in the consistency of the results calculated for the six year period. It has an important role in affecting long term rainfall and erosivity values. Two definite regions are apparent which show marked differences in rainfall and erosivity. The region in the western edge of the island experiences low rainfall and erosive rainfall totals, and erosivity values. The interior of the island experienced very high rainfall and erosive rainfall totals as well as high erosivity. Local topographic factors also play a role in affecting the attributes that individual stations experience (Hoyos *et al.*, 2005). Over the 6 year period of study, when stations within each respective region are compared, attributes are surprisingly similar. These include:

- $R$ -factor values
- Total erosive rainfall amounts for study period (despite differing rainfall totals)
- Maximum erosive rainfall that fell within a year
- $R$ -factor values when the 5 consecutive 6 minute, 30, and 60 minute intervals are used
- $R$ -factor values when the Modified Fournier Index is used

Despite the consistency and similarity of erosivity values, individual attributes of each station (including rainfall and erosive rainfall totals, event numbers and annual erosivity values) are at some points substantially different as individual erosive event intensities and characteristics are important in affecting long term rainfall erosivity. The high variable short term attributes, when looking at purely annual totals are as follows:



- Erosive event totals
- Rainfall totals
- Erosive rainfall totals
- Annual erosivity totals

## 7.2 High resolution data and Modified Fournier Index

Higher resolution data can identify ‘peaks’ in intensity that lower resolution data does not. It was found that in the dry region, about 10% of rainfall erosivity was unaccounted for when 30 minute set time intervals were used in place of 5 consecutive 6 minute intervals covering the actual peak when the *R*-factor was calculated for the six year period. Hourly data missed around 33% erosivity. However, it was found to be more accurate than the MFI method and is recommended that hourly data be used in place of the Modified Fournier Index. This confirms work by Yin *et al.* (2007) who indicate that finer time resolutions provide a better accuracy in calculating erosivity.

The Modified Fournier Index is useful in calculating Erosivity values, but due to the low rainfall totals in the dry regions and the very high totals in the interior, the index is likely to be underestimated in the dry region and overestimated in the wet region. High rainfall totals do not necessarily mean high erosivity. Also, absolute values calculated by the MFI are underestimated. This method is suitable for calculating rainfall erosivity when only annual and monthly rainfall totals are available (Yu & Roswell, 1996). The MFI did pick up the large differences in erosivity between the two regions in question. With daily rainfall data more readily available than finer resolution data (Angulo-Martínez & Beguerí, 2009), MFI is useful when limited data and time constraints call for more time efficient calculations and is useful in predicting the extent of rainfall erosivity but not actual erosivity amounts.

## 7.3 Future erosivity

When considering climate change, the potential exists for increased rainfall erosivity on Mauritius. An increase in the intensity of rainfall events in the future will be associated with higher erosivity values for all stations, but future erosivity values in the central interior will be markedly higher than the erosivity in the drier regions. The drier region will also experience higher erosivity (but not to the extent of the interior) and may also be vulnerable due to the increase in erosivity as the lower density and extent of vegetation in the region may not negate

erosive rainfall as the denser vegetation in the interior does. Changes in short term attributes will likely affect long term values of erosivity. If climate change causes a decrease in rainfall intensity over Mauritius, erosivity in both regions of the island will decrease to a large extent.

Changes in the frequency, intensity, and movement of cyclones in the future around Mauritius will also affect rainfall erosivity on the island. Direct passes of intense cyclones will create high erosivity over the whole island. Additionally, near-passes of a cyclone can potentially enhance orographic forcing causing high erosivity and intense rainfall in the interior.

#### 7.4 Research needs and recommendations

With respect to rainfall erosivity, a number of opportunities still remain in research with respect to erosivity on an island environment. These include the following:

- This project used a dataset which spanned 6 years. It is recommended that further studies be performed using data with time resolutions 30 minute or less for a period spanning more than 20 years following the  $EI_{30}$  method (Renard *et al.*, 1997). This will provide an accurate depiction of the state of rainfall erosivity which, when applied into the RUSLE formula.
- Many islands are subject to tropical depressions and cyclones, which may have the potential to create very intense rainfall events (Lal *et al.*, 2002). There is potential that this may create rainfall erosivity that can exceed the annual erosivity experienced in years that have not received any cyclones. A complete study into the erosivity of a tropical cyclone, both spatially and temporally will give a better understanding of the erosivity resulting from a cyclone.
- Nigel & Rughooputh (2010a; 2010b) used the MAURSerM Model to map rainfall erosivity and soil hazard zones, incorporating calculations using the MFI. High resolution data may be useful in creating more accurate assessments of the spatial distribution of rainfall erosivity and soil hazard risk assessments. Using soil erosion models such as RUSLE or SLEMSA (as used by Le Roux *et al.*, 2005) with high resolution datasets may assist authorities in better managing the limited land resources of the island.
- Perhaps most importantly, incorporating Global Circulation Models and better predicting the effect climate change will have on rainfall and rainfall erosivity will better help

management of the island to better prepare for the future and preserve the island's land and natural resources (Lal *et al.*, 2002).

As seen in this project, rainfall erosivity is both an important and complex element of rainfall induced soil erosion to consider. Since it is not directly controlled by human influence, gaining a better understanding of how to measure, analyze and manage it will benefit decision makers in Mauritius and other islands across the planet.

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## Appendix

### Example of method used in determining EI30

An example of a typical storm event that was selected following the criteria set out in Section 4.6. The following are three examples of the method used in Objective two to investigate the three approaches to determine the Maximum 30 minute intensity (see Section 4.10):

- 1) 5 consecutive 6 minute peak with peak intensity and adjacent values (The highlighted values were the value used for the particular method.)

Date	Time	6 min	6 min	6 min	6 min	6 min	Total
12/01/04	9:00	.	.	.	.	.	.
12/01/04	9:30	.	.	.	.	.	.
12/01/04	10:00	.	.	.	.	.	.
12/01/04	10:30	0.2	1.8	9.2	5.8	6.2	23.2
12/01/04	11:00	7.6	8.2	4.6	3.4	3.2	27.0
12/01/04	11:30	2.8	1.8	0.6	0.4	0.2	5.8
12/01/04	12:00	0.2	0.0	0.2	1.6	0.8	2.8
12/01/04	12:30	0.2	0.2	0.0	0.0	0.2	0.6
12/01/04	13:00	0.4	0.6	1.2	1.4	1.4	5.0
12/01/04	13:30	0.8	0.6	0.2	0.4	0.2	2.2
12/01/04	14:00	0.2	0.2	1.0	0.8	0.4	2.6
12/01/04	14:30	0.2	0.2	0.0	0.0	0.2	0.6
12/01/04	15:00	.	.	.	.	.	.
12/01/04	15:30	.	.	.	.	.	.
12/01/04	16:00	.	.	.	.	.	.

Maximum 30 minute intensity: 37mm/30min (64mm/h)

2) A 30 minute interval with set start and ending point. In this case the time interval between 11:00 and 11:30 was used

Date	Time	6 min	6 min	6 min	6 min	6 min	Total
12/01/04	9:00	.	.	.	.	.	.
12/01/04	9:30	.	.	.	.	.	.
12/01/04	10:00	.	.	.	.	.	.
12/01/04	10:30	0.2	1.8	9.2	5.8	6.2	23.2
12/01/04	11:00	7.6	8.2	4.6	3.4	3.2	27.0
12/01/04	11:30	2.8	1.8	0.6	0.4	0.2	5.8
12/01/04	12:00	0.2	0.0	0.2	1.6	0.8	2.8
12/01/04	12:30	0.2	0.2	0.0	0.0	0.2	0.6
12/01/04	13:00	0.4	0.6	1.2	1.4	1.4	5.0
12/01/04	13:30	0.8	0.6	0.2	0.4	0.2	2.2
12/01/04	14:00	0.2	0.2	1.0	0.8	0.4	2.6
12/01/04	14:30	0.2	0.2	0.0	0.0	0.2	0.6
12/01/04	15:00	.	.	.	.	.	.
12/01/04	15:30	.	.	.	.	.	.
12/01/04	16:00	.	.	.	.	.	.

Maximum 30 minute intensity: 27mm/30min (54mm/h)

3) A 60 minute interval with set start and ending point. In this case the time interval between 10:30 and 11:30 was used

Date	Time	6 min	6 min	6 min	6 min	6 min	Total
12/01/04	9:00	.	.	.	.	.	.
12/01/04	9:30	.	.	.	.	.	.
12/01/04	10:00	.	.	.	.	.	.
12/01/04	10:30	0.2	1.8	9.2	5.8	6.2	23.2
12/01/04	11:00	7.6	8.2	4.6	3.4	3.2	27.0
12/01/04	11:30	2.8	1.8	0.6	0.4	0.2	5.8
12/01/04	12:00	0.2	0.0	0.2	1.6	0.8	2.8
12/01/04	12:30	0.2	0.2	0.0	0.0	0.2	0.6
12/01/04	13:00	0.4	0.6	1.2	1.4	1.4	5.0
12/01/04	13:30	0.8	0.6	0.2	0.4	0.2	2.2
12/01/04	14:00	0.2	0.2	1.0	0.8	0.4	2.6
12/01/04	14:30	0.2	0.2	0.0	0.0	0.2	0.6
12/01/04	15:00	.	.	.	.	.	.
12/01/04	15:30	.	.	.	.	.	.
12/01/04	16:00	.	.	.	.	.	.

Maximum 30 minute intensity: 25.1mm/30min (50.2mm/h)