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Intra-storm attributes and climatology of extreme erosive events on Mauritius, 2004 to 2008

by

Alexia Hauptfleisch

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MASTER OF SCIENCE (GEOGRAPHY)

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DECLARATION

I,____________________________________, declare that this dissertation entitled **Intra-storm attributes and climatology of extreme erosive events on Mauritius, 2004 to 2008,** which is hereby submit for the degree **Master of Science (Geography)** at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

____________________________ ____________________________

SIGNATURE **DATE**

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Abstract

Topographic complexity and island-scale weather systems on Mauritius result in highly variable spatial and temporal rainfall distribution. This, in combination with the intense agricultural activity, predisposes the island to a high risk of rainfall induced soil erosion. Thus it is important to investigate intra-storm attributes of erosive events, as these events are most likely to cause significant degradation and reduced productivity of the soils on the island. Intra-storm analysis allows for the identification of critical intensity peaks in rainfall events that potentially impact the severity of erosion. Six Mauritius Meteorological Services automated weather stations (measuring rainfall at 6 minute intervals) located on the west coast and in the interior providing rainfall data over a 5 year period (2004 to 2008), enabled the first detailed intra-storm analysis on the island to occur. For the purpose of this study, erosive events were defined as a total rainfall exceeding 12.5 mm and a maximum 6-minute intensity exceeding 30 mm/h. The analysis found that there were 444 erosive events during the study period which are responsible for generating the bulk of the rainfall erosivity. A total of 120 erosive events (the top twenty erosive events for each weather station with the highest 'total kinetic energy generated') were analysed to investigate the intra-storm distribution of rainfall depth, extreme rainfall intensity and cumulative kinetic energy. General climatological characteristics and weather circulation patterns were also determined.

Erosive events were found to vary both in rainfall depth and duration, but all the stations indicate a clear exponential distribution of cumulative kinetic energy generated over the duration of the rainfall events. Extreme rainfall intensities display noticeable temporal differences between the stations in different climatic regions on the island. All the stations received more than 80% of the potential kinetic energy content generated by the storms within the first 2500 minutes of the storm, as well as 80% of the cumulative rainfall available. Investigating the distribution of the extreme rainfall intensity (above 30 mm/h) as a function of storm duration, reveals that 57% of the erosive events generate peak intensities within the first half of the storm duration. Erosive events were not restricted to tropical cyclones, but include other weather systems such as cold fronts.

The elevated centre of Mauritius, which is responsible for a high rainfall gradient across the island, influenced the spatial and temporal variability in erosive events. Results indicate that the intra-storm attributes of rainfall events are strongly dependent on the geographic features within the immediate surroundings of the weather stations, and distance between weather stations did not always lead to predictable differences in intra-storm attributes. Although the erosive events on Mauritius share common characteristics, the within-storm distribution shows that no two events are similar and no two stations show comparable event pattern distributions. However, the intra-storm analysis of the erosive events suggests that, despite the spatial differentiation in the structure and nature of the erosive rainfall generalisations can be made regarding the erosion experienced in the coastal and interior regions of the island. The inclusion of more automated weather stations is warranted as this will provide a better representation of rainfall characteristics across the remaining regions of the island. Further research is necessary to determine the relationship between event structure and synoptic conditions experienced on the island.

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Chapter 1 : Introduction

Mauritius is a Small Island Developing State (SIDS) in the Indian Ocean and is particularly prone to erosion from intense rainfall events (Nel *et al*., 2012). On tropical islands erosive rainfall is capable of detaching and transporting large amounts of sediments (Calhoun & Fletcher, 1996) and is associated with rainfall amount, topography and altitude (Nigel & Rughooputh, 2010a). Mauritius, like many tropical volcanic islands, has a distinct elevated interior which acts as an orographic barrier, influencing the rainfall gradient across the island. Different regions of the island consequently receive varying amounts of rainfall as a result of island's topographic features (Dhurmea *et al*., 2009). Soil erosion has long been regarded as an important land denudation process on tropical islands (Cooley & Williams, 1985) and as a consequence of the climate, topography, altitude and the subsequent intense rainfall, the interior of Mauritius is particularly prone to high levels of erosion (Nigel & Rughooputh, 2010a; Nel *et al*., 2012).

Globally changing rainfall patterns are aggravating the risk of soil erosion and this is most evident in counties with highly variable rainfall and strong erosive events (Sanchez-Moreno *et al.,* 2014). On tropical islands, the potential soil loss and erosion risk is not necessarily only dependent upon the amount of rainfall received but rather the physical characteristic of the event, such as rainfall duration, amount, drop-size distribution, terminal velocity, wind speed and inclination (Nel *et al.,* 2013). Rainfall patterns on Mauritius are multi-faceted and complex due to the spatial variability of the topography. Peak rainfall intensities, which influence infiltration and runoff rates, can therefore occur at any point during the rainfall event. This is important factor to consider as rainfall event patterns (i.e. when peak intensity occurs) have differing effects regarding the type of material eroded from different soil types (Parsons & Stone, 2006). Therefore, recognising the intra-storm attributes of erosive events is critical when attempting to understanding the rainfall erosivity and potential soil erosion risks of the events.

The tropical island of Mauritius was selected for this project because it forms part of a larger project on rainfall which stemmed from the earlier work by Le Roux (2005). Le Roux (2005) modelled the potential soil loss in a southern catchment on Mauritius to investigate the extent to which soil erosion is affected by different land use. The results showed that land use change to pineapples and vegetables crops will have a drastic influence on soil erosion. Upon conclusion of the study by Le Roux (2005), it was realised that there was not sufficiently detailed rainfall data to accurately quantify erosivity. Therefore, the new high resolution 6-minute rainfall data received from the Mauritius Meteorological Services afforded the opportunity to conduct studies on storm kinetic energy, erosivity and soil erosion risk of rainfall in Mauritius (Le Roux, 2005; Le Roux *et al.,* 2005; Nigel & Rughooputh, 2010a, b; Nel *et al*., 2012; 2013).

However, despite the aforementioned studies very little is known about intra-storm rainfall attributes and the associated weather systems responsible for the distribution of rainfall parameters. The purpose of this research is thus to investigate the intra-storm attributes of the erosive events on Mauritius. This includes identifying and describing the within-storm distribution of rainfall depth, extreme rainfall intensity, cumulative kinetic energies and general climatological characteristics associated with these events and the potential erosion risk for assisting conservation planning.

1.1. Rainfall induced soil erosion

Soil erosion is the detachment of individual particles from the soil surface by an erosive agent and the subsequent transport of the soil particles to another location (Fornis *et al.*, 2005; Hoyos *et al.*, 2005). Soil erosion is connected to a wider concept termed soil degradation. The loss of topsoil is considered as only one of the major soil degradation problems threatening agriculture throughout the world and involves physical, chemical and biological deterioration (Dardis *et al.*, 1988). Soil degradation includes loss of organic matter, decline in soil fertility, the breakdown of soil structure and changes in salinity and acidity (Haynes, 1997). The leading forces to soil degradation include deforestation, intense cultivation and overgrazing of vulnerable land, pollution, as well as poor soil and water management and all of them reduce the productive capacity of the soils (Le Roux, 2005).

The process of soil erosion is one accomplished through ‘work’, and is achieved in a three-stage process that derives energy from numerous physical sources such as wind, ice and water, gravity, chemical reactions and anthropogenic influences (Lal, 2001). It is the source of energy such as snow, wind or water that controls the type of erosion process. The rate and magnitude of energy providing such forces determines the severity of the erosion process. The three stages of erosion are: (1) detachment of soil, (2) transport, and (3) the deposition of soil (Lal, 2001). Water, predominately through rainfall, is believed to be the foremost agent of soil erosion and includes processes such as runoff, rainsplash, rill and gully development (Chapman, 2005; Hoyos *et al.*, 2005). Other erosion agents such as wind, ice and streams are referred to as aeolian erosion, glacial erosion and fluvial erosion respectively (Morgan, 1995). Despite the common perception that soil erosion is a solely natural process, human activities, such as land cover change and the disturbance of soil structure through cultivation, can also cause and greatly aggravate natural process of erosion (Yang *et al.*, 2003).

Rainfall and its consecutive overland runoff is generally regarded a major driving force of most hydrological and erosional processes through which soil particles are detached and surface runoff is created (Moore, 1979; Nyssen *et al.,* 2005; Nel, 2007). Bergsma *et al.* (1996: 117) define rainfall erosion as: “The rate of soil loss expected in the near future, due to rain erosion, depending on the combined and interactive effects of all erosion hazard factors: climate, relief, soil profile, present erosion, land use and vegetation and cultivation system.” Processes of soil erosion are highly dependent upon rainfall energy, which, in turn relates to intensity and amount of rainfall as well as the size of the raindrops (Jayawardena & Rezaur, 2000). The combination of rainfall intensity and raindrop fall velocity influences soil splash rate (Nel, 2007), therefore, erosion is more intense when runoff and runoff velocity is high (i.e. when hydraulic roughness is low) (Torri *et al*., 1999).

The soil erosion process is complex in nature as it results from interactions between the soil itself, climate, relief, surface cover and land use practices (Hoyos *et al.,* 2005). The total soil loss for any time period is regarded as a function of two attributes: the resistance of the surface cover and soil factors that change daily and the distribution of rainfall events for the time period (Nearing *et al.*, 1990). For example, heavy rain falling on bare soil might cause more erosion than rain falling on well vegetated soil, hence the timing and intensity the erosive rains with respect to soil cover is important (Moore, 1979). Therefore, soil erosion is most accurately understood and predicted using knowledge of how the key soil and plant parameters vary over time and how these changes influence soil erosion (Le Roux, 2005).

While some studies have shown that land cover serves as a protective layer between the rainfall and the soil (e.g. Lal, 2001; Toy *et al*., 2002; Morgan, 2005; Nigel, 2011), land cover can aggravate erosion depending on the above- and below-ground components present at the land surface (Morgan, 2005; Nigel, 2011). Above-ground components of vegetation (leaves and stems) intercept falling raindrops and running water, therefore reducing the amount of energy available to detach soil particles (Morgan, 2005). Below-ground vegetative components (roots) enhance the mechanical strength of the soils and offer resistance against the detachment and transportation by surface runoff (Morgan, 2005). Different types of vegetation cover provide differing degrees of protection and thus, human influence on the land use can alter the rate of erosion to a large extent (Nigel, 2011).

The commencement of agricultural practices led to soil erosion becoming a serious problem globally (Renschler *et al.,* 1999) by causing a reduction in arable land, increased landslide activity and contaminant diffusion by the inflow of sediment to river and ecosystem disturbance (Lee & Heo, 2011). Environmental problems caused by soil erosion exacerbate on-site land degradation as well as increase the sediments and pollutants that adversely affect off-site aquatic ecosystems. Therefore, it is essential to implement conservation measures which successfully reduce the impact of both on- and off-site effects of soil erosion (Nigel & Rughooputh, 2010b). Lal (2001) emphasised that erosion cannot necessarily be prevented but the adoption of soil conservation measures can allow the effects to be reduced to an appropriate level. Hence, the universal aim of soil conservation is a reduction in erosion levels that allow for a sustainable level of agricultural production and grazing (Morgan, 2005).

On Mauritius the hydrological and erosional process at a regional scale are controlled by soil type, climate patterns in relation to topography and land use (Nigel & Rughooputh, 2010b). As a result of the rainfall variability and characteristics Mauritius is particularly sensitive to erosion risks (Nigel & Rughooputh, 2010a). The island's dependence on its agricultural sector renders it vital to estimate and evaluate the amount of soil erosion through soil loss modelling to allow for effective soil conservation, disaster control and water management (Lee & Heo, 2011).

1.2. Soil loss modelling

The estimation and quantification of soil loss has been the subject of studies since the 1940's (Wischmeier & Smith, 1978; Lee & Heo, 2011). Numerous models have subsequently been developed and placed in practise in an effort to quantify soil loss. These include the European Soil Erosion model (EUROSEM) (Morgan *et al.,* 1998), Water Erosion Prediction Project (WEPP) (Flanagan & Nearing, 1995), Mediterranean Rainfall Erosivity Model (MEDrem) (Diodato & Bellocchi, 2010), the Soil Loss Estimation Model for Southern Africa (SLEMSA) (Elwell, 1976) and in the Mauritian context, the Mauritius Soil Erosion Risk Mapping (MauSERM) (Nigel & Rughooputh, 2010a). Each of these models considers a variety of factors and have their own limitations and/or advantages.

The Universal Soil Loss Equation (Wischmeier & Smith, 1978) as well as its reviewed format, the Revised Universal Soil Loss Equation (Renard *et al.,* 1997), is one of the most widely used models in quantifying soil loss. The Universal Soil Loss Equation (USLE) is considered as the first attempt in evaluating and qualifying human's impact on soil erosion through land use changes or using new cultivation techniques (Renschler *et al*., 1999). It was initially developed between 1940 and 1956 to quantify soil loss in the 'corn belt', situated in the Midwestern region of the United States of America, where corn is the primary crop of cultivation. After being altered on numerous occasions, the formula was published in its existing arrangement in the National Runoff and Soil Loss Data Centre under the title 'Predicting rainfall erosion losses- A guide to conservation planning' (Wischmeier & Smith, 1978). Subsequently, all factors of the original formula were re-examined, modified and improved resulting in the creation of the Revised Universal Soil Loss Equation (RUSLE) (Renard & Freimund, 1994) which has been extensively as tools in the prediction of soil erosion in many parts of the world (Renschler *et al*., 1999). For example, it has been used by Kremer (2000); Le Roux (2005); Seeruttun *et al.* (2007) and Nigel (2011) in Mauritius; Onyando *et al*. (2005) in Kenya, Irvem *et al.* (2007) and Erdogan *et al.* (2007) in Turkey and Schiettecatte *et al.* (2008) in Cuba.

(R)USLE erosion model was designed to predict the long-term average annual soil loss carried by runoff from field slopes in specified cropping and management systems including rangelands (Renard & Freimund, 1994; Wang *et al*., 2002). Thus the (R)USLE equation quantifies soils erosion as a product of six factors representing rainfall and runoff erosivity in (R), soil erodibility (K), slope length (L), slope steepness (S), crop type and management practices (C), and supporting conservation practices (P). The equation is (Renard & Freimund, 1994):

$$A = R \times K \times L \times S \times C \times P$$

where A is the rate of soil loss per unit of area (t ha^{-1} $year^{-1}$) and is expressed in the units selected for K and the period selected for R. The rainfall and runoff erosivity factor (R) and soil erodibility factor (K) are the only two factors in the equation with definable units (Renard & Freimund, 1994). Rainfall and runoff erosivity (R) will be discussed in more detail as it is acknowledged as one of the best parameters for predicting the erosive potential of raindrop impact, and in turn of the potential of transport capabilities of runoff generated by erosive storms (De Santos Loureiro & De Azevedo Coutinho, 2001).

The use of the (R)USLE model is advantageous because it has been widely applied and tested over many years due to this its validity and well-known limitations (Renard *et al.*, 1997). These limitations are as a result of being developed from data limited to the Midwest of the United States of America. This subsequently necessitated major adjustments to the key factors of the equation in order for the algorithms of the models to be applicable in other areas (Shamshad *et al.*, 2008). Renard & Freimund (1994) acknowledge that (R)USLE are empirical relationships that are only deemed valid within the range of experimental conditions from which they were derived. However, since (R)USLE represents the major factors affecting erosion, transferring it to locations throughout the world only requires the determination of appropriate values for the different factors for the region in question (Renard & Freimund, 1994). Thus, the use of (R)USLE is applicable in the Mauritian context.

Mauritius' topography, where nearly 31% of the island has slopes >8%, creates areas that are considerably more susceptible to experiencing potentially severe erosion risk (Nigel, 2011). In spite of this only a few erosion risk assessments have been completed probably due to the absence of local legislation concerning soil erosion research, control and conservation and the lack of assessment methodologies (Nigel & Rughooputh, 2010a). Advantages of soil erosion risk mapping include its ability to depict the temporal variations in erosion patterns, to define and priorities focal areas for conservation measures and the promotion of better land use management, agricultural practices and conservation planning (Nigel & Rughooputh, 2010b). The predominant focus of soil erosion risk mapping on Mauritius is on cultivated lands, more specifically sugarcane canopy cover.

The most noteworthy of the soil assessment studies on Mauritius include: Kremer, (2000); Le Roux *et al.,* (2005); Seeruttun *et al*., (2007) and Nigel & Rughooputh, (2010a, b). Kremer (2000) mapped erosion risk for the island by utilising three scenarios of sugarcane canopy cover, those of 0-10, 30 and >70%, using land cover, slope, soil and rainfall data. Kremer's (2000) results indicated that in general erosion risk is low for canopy cover of >70% and *vice versa* (Nigel & Rughooputh, 2010a). Le Roux *et al.* (2005) used the (R)USLE and SLEMSA models within a GIS environment to estimate the soil loss for a river basin with steep slopes. To obtain the rainfall erosivity (R value), Le Roux (2005) utilised monthly and annual rainfall as inputs into a Modified Fournier Index (MFI) developed by the FAO (Arnoldus, 1980) and concluded that erosion rates are generally highest on steep slopes (>20%) in areas with a high annual rainfall (2400mm). Results also predicted that soil loss has a strong inverse relationship with vegetation cover, where infrequently disturbed land use type such as natural vegetation, tea and banana plantations experience low soil loss values (1 to 4 $t.ha^{-1}.yr^{-1}$). In contrast, the frequently disturbed land use types such as intercropped cane and vegetables experience moderate (13 $t.ha^{-1}.yr^{-1}$) to very high (80 $t.ha^{-1}.yr^{-1}$) soil loss rates (Le Roux, 2005). The study, which was done within the context of changing land use, confirms that soils erosion within sugarcane is less than that modelled under other crop types. Findings show that the most vulnerable time for erosion is in the early part of the wet season when there is high rainfall but the vegetation has not fully developed (Le Roux *et al.*, 2005). Hence, certain crops should be confined to low slope angle and be supported by soil management practices (Le Roux *et al.,* 2005). The SLEMSA model provided much higher values of soil loss than the (R)USLE model, due to the high sensitivity that SLEMSA had to rainfall energy (Le Roux, 2005; Anderson, 2012).

In another soil risk assessment study, Seeruttun *et al*. (2007) attempted to measure soil loss using five field sites over four consecutive years in Mauritius. Each site had two plots, one bare and one planted with sugarcane, in order to quantify the impact which sugarcane has on soil loss in Mauritius. The study found that soil loss on bare plots ranges between 0.5-37.6 $ha^{-1}.yr^{-1}$ depending on the soil type and in general, sugarcane reduced soil loss by 80-99%. Seeruttun *et al*. (2007) also found that between 48% and 68% of the soil erosion was associated with cyclonic activity. This study was, however, conducted only on plots containing linear slopes <9% isolated from upslope contributing areas (Nigel & Rughooputh, 2010b).

More recent soil erosion risk assessments on Mauritius (Nigel & Rughooputh, 2010a; 2010b) have indicated that soil erosion on the island is a problem. Nigel and Rughooputh (2010a; b) developed and utilised the Mauritius Soil Erosion Risk Mapping (MauSERM) model to investigate the variability of erosion patterns on Mauritius to establish conservation efforts for the high erosion risk sites and priority action areas. Over half of the area of Mauritius is under intensive cultivation, typically sugarcane plantations, which were found to experience moderate sheet erosion (Atawoo & Heerasing, 1997). The rugged topography, intensive cultivation (predominantly sugarcane) and its tropical climate are the main factors responsible for making Mauritius vulnerable to soil erosion (Nigel & Rughooputh, 2010a).

Mean monthly rainfall and annual data were used as inputs into the Modified Fournier Index (MFI) to determine the erosivity of the island (Nigel & Rughooputh, 2010a). In this case the MFI provides better correlation with the observed erosivity patterns (Nigel & Rughooputh, 2010b). According to Nigel & Rughooputh (2010a), January and February have the highest erosion risk as a result of torrential rains endured during these months, followed by December and March, with the remainder of the year being dominated by low to very low erosion risk. The western portion of the island had low erosivity, which is in accordance with the low annual rainfall that the region observed. The central and eastern parts of the island sustain the highest erosivity on an annual basis, with the majority of the erosivity experienced during the wet season (Anderson, 2012). During the months of high erosivity, sugarcane cultivation found on the steep slopes does not offer much protection against soil erosion from rainfall (Mongwa, 2012).

The studies mentioned above utilised the Modified Fournier Index (MFI) when calculation rainfall erosivity used in the soil erosion calculations, which is dependent on monthly and annual totals (Anderson, 2012). The main reason for using total rainfall in erosion risk assessment is the lack of high resolution data on an island scale (Mongwa, 2012). However, despite numerous studies that have been done on soil erosion risk mapping (Le Roux, 2005; Nigel & Rughooputh, 2010a; b) and erosivity (Nel *et al*., 2012; 2013) on the island, very little is known about the intra-storm attributes of the rainfall. No other study has identified the erosive rainfall event characteristics and intra-storm attributes from the high resolution rainfall data available. As the implication of the erosive events on the potential erosion risk on the tropical island of Mauritius is unknown, a comprehensive intra-storm analysis at an event scale is required to understand the impact that intra-storm dynamics have on potential soil erosion risk.

1.3. Rainfall erosivity (R-factor)

Rainfall is regarded as a crucial factor for erosion processes (Petan *et al*., 2010) as it can potentially detach and transport soil particles through the impact of raindrops striking the soil surface and/or surface runoff generated during a storm (Lal & Elliot 1994; Le Roux, 2005). Rainfall owing to its erosivity is the agent for soil erosion as a result rainfall with higher erosivity causes higher erosion (Nigel, 2011). Rainfall erosivity, unlike some other natural factors such as relief or soil characteristics, is not responsive to human modification. Consequently, it represents a natural environmental constraint that limits and conditions land use and management (Angulo-Martínez & Beguería*,* 2009). Rainfall erosivity is defined as the ability of rainfall and runoff to cause erosion through the detachment and transportation of soil particles (Lal & Elliot, 1994; Obi & Salako, 1995). It is determined mainly through rainfall kinetic energy, a parameter easily related to the rate or total amount (energy) of rainfall, and other physical rainfall characteristics such as duration, intensity, drop-size distribution, terminal velocity and extraneous factors such as wind velocity and slope angle (Obi & Salako, 1995; Nyssen *et al.,* 2005).

Erosivity is generally expressed in terms of rainfall amount and intensity since both determine the potential of rainfall event to be erosive (Hoyos *et al*., 2005). Rainfall kinetic energy is considered the most suitable expression of rain erosivity as it influences sediment transportation and acts as a major factor in initiating soil detachment (Lal & Elliot, 1994; Morgan, 1995). The quantification of rainfall erosivity, through the kinetic energy of a rainfall event, is therefore central to the assessment of soil erosion risk. It is a commonly held theory that a large proportion of soil erosion and sediment delivery takes place during several intense rainfall events (of high kinetic energy) which produce the bulk of soil loss from an island (Rydgren, 1996; Angulo-Martínez & Beguería, 2009). Alternatively, the cumulative influence of more frequent yet lower magnitude events (of lower kinetic energy) might overshadow the effect of the less frequent high-intensity events (Boardman & Favis-Mortlock, 1993; Trustrum *et al.,* 1999). Page *et al.* (1994) argue that while rainfall event magnitude and frequency can be analysed from rainfall records, the cumulative effects of rainfall-induced erosion are more difficult to quantify, particularly in tropical areas where rain events tend to be more intense (Nyssen *et al*., 2005). Intense rainfall in tropical areas, such as Mauritius, has a particularly high erosive potential, and is influenced by the event type and rainfall characteristics which might vary with altitude and topography (Nel *et al*., 2013). The temporal and spatial variability of rainfall erosivity is therefore important to consider in tropical regions, especially due to the existence and interactions of numerous factors, such as the Inter Tropical Convergence Zone (ITCZ), topography (hills) and the ocean, on rainfall variability (Salako, 2008).

Rainfall erosivity can also be dependent on vegetation cover and how it varies over seasons (Jackson, 1972; Moore, 1979). For example, if heavy rainfall events occur at the onset of the wet season when the vegetation cover is sparse and the soil is not well protected, considerably higher levels of runoff and erosion are experienced. Towards the end of the rainy season, vegetation cover provides more protection to the soil, resulting in potentially less runoff and rainsplash occurring. In Mauritius, the soil is considered most vulnerable during the early part of the wet season when the rainfall is at its highest, but the vegetation growth does not yet provide sufficient protection to the soil (Nigel & Rughooputh, 2010b). Therefore, rainfall intensities, storm duration, frequency and seasonal occurrence of rainfall all influence the amount of rainfall erosion potentially experienced by an area (Jackson, 1972).

An interaction also prevails between vegetation cover and slope in influencing the magnitude of rainfall erosion experienced by an area. Even though the influence of slope on soil loss is secondary to that of vegetation cover, Snyman (1999) highlights that as vegetation basal cover lessens, during dry periods or overgrazing, the influence of slope on rainfall erosion increases. Long steep slopes such as those found in the upper catchment and mountainous areas of Mauritius thus render the land extremely susceptible to erosion once the vegetation cover is degraded (Le Roux, 2005). Furthermore, slope steepness can also be increased by the effect of other erosion factors, such as raindrop impact leading to a possible decrease in infiltration, more overland flow and further erosion (Smith *et al.*, 2000). Total soil loss cannot, however, be explained purely by the variation in slope length, slope angle and vegetation cover because of the existence of complex interrelationships between the microtopography, rainfall energy, plant cover and soil properties (Le Roux, 2005).

Rainfall erosivity is one of the six factors in the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978), as well as the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.,* 1997) for erosion prediction, and is the most precisely defined factor of both these equations (Yu *et al.,* 1998). Erosive power of precipitation is accounted for by a rainfall-runoff erosivity factor R, therefore combining the effects of the magnitude, duration and intensity of each rainfall event (Bonilla & Vidal, 2011). Rainfall erosivity is both a numerical description and quantifier of the potential of rainfall to cause soil loss at a hillslope scale (Yin *et al.,* 2007; Lee & Heo, 2011). It is commonly accepted that rainfall and runoff lead to soil loss and subsequently, if all other parameters of the formula are kept constant, soil loss is directly proportional to the rainfall erosivity (Wang *et al.,* 2002). According to van Dijk *et al.* (2002) the amount of soil detached by a particular depth of rain is related to the intensity at which the rain falls. Rainfall erosivity (R or R-factor) is regarded as a dependent of splash detachment and is reliant on the kinetic energy (KE) of the rainfall which varies with drop mass as well as rainfall intensity (Brooks & Spencer, 1995).

In rainfall erosivity studies, the Rainfall erosivity (R or R-factor) is derived by calculating the mean annual sum of individual erosive event erosion index values (EI_{30}). This is determined by the value of the total kinetic energy (KE) and maximum 30 minute rainfall intensity (I_{30}) (Renard *et al.,* 1997; Shamshad *et al*., 2008; Lee & Heo, 2011). The EI_{30} term is the abbreviation for the (KE) multiplied by I_{30} (Renard & Freimund, 1994) and was found to produce the best correlation with soil loss from a rainfall event (Wischmeier & Smith, 1958). EI_{30} calculations make use of breakpoint rainfall intensity data derived from automated rainfall gauges. These data are often manually read from graphical charts from continuously recording rain gauges, which record pairs of values representing time and cumulative depth of rainfall as measured from the charts. Time intervals between these recorded pairs is assumed to represent portions of the storms that demonstrate constant or near constant rainfall intensities (Yin *et al*., 2007). As a result, the recorded points indicate times of apparent “breaks” or variations in the rainfall intensity of the storm (Yin *et al*., 2007). As breakpoint data are rarely available, EI_{30} is often calculated by using fixed interval rainfall data from yearly, monthly and daily rainfall data. Breakpoint rainfall information is, however, becoming more widely available with the development of automatic weather stations (Yin *et al*., 2007). Rainfall data at automatic weather stations that is recorded in fixed time intervals, such as 60 minutes, 15 minutes and even higher time resolution provides the ideal substitution of breakpoint records. Furthermore, the use of high resolution rainfall data is encouraged to determine the maximum 30 minute rainfall intensities for individual storms and heavy storm events (Lee & Heo, 2011), as such information will allow for the thorough evaluation of rainfall erosivity (Bonilla & Vidal, 2011).

Accurate calculation of each storm's rainfall erosivity requires high resolution rainfall data measurements (Wischmeier & Smith, 1978; De Santos Loureiro & De Azevedo Coutinho, 2001). However, these data are not always readily available to calculate the R value (De Santos Loureiro & De Azevedo Coutinho, 2001). Several other methods were established to calculate the rainfall erosivity index (R). Examples include the Fournier Index (Fournier, 1960), Morais *et al.* (1991) modified form of the Fournier index (known as the MMFI), the Grimm-Jones-Rusco-Montanarella (GJRM) model (2003) and the Diodato-Bellocchi Rainfall-Erosivity Model (REM_{DB}) (2007) (Diodato & Bellocchi, 2007). Another approach is to integrate climatic and geographical characteristics, which are not difficult to record and capture variability at both a regional and sub-regional scale, for example monthly average rainfall and geographical characteristics that can be incorporated into an erosivity model (Diodato & Bellocchi, 2007). In a tropical island context, most rainfall erosivity is calculated through annual and monthly rainfall depth in the absence of detailed intensity data (see Nel *et al*., 2013).

The Fournier Index was designed for the west coast of Africa (Fournier, 1960) and has been widely used where only monthly data are available. The Modified Fournier Index (MFI) was developed by Arnoldus (1980) after correlating the Fournier index with R in Morocco and finding poor correlations in general, but higher (R) values when utilising the monthly average as an alternative to the maximum monthly rainfall (Sanchez–Moreno *et al.,* 2014). It was suggested by Renard & Freimund (1994) that the Modified Fournier Index be used in areas where long-term data are not available or in the absence of reliable EI_{30} calculations. Consequently, the Modified Fournier Index has been used to map erosivity and parameterise soil erosion risk as either a single factor, or correlated with R, in several countries, including Spain (Angulo-Martínez & Beguería, 2009) and Mauritius (Le Roux, 2005; Nigel & Rughooputh, 2010a; b). In the Mauritian context, Nel *et al*. (2013) argue that despite coarser time intervals producing less accurate results, the MFI still remain useful in determining the relative spatial relationships of erosivity.

Rainfall erosivity appears to be higher in tropical regions compared to that of temperate regions of the world (Salako *et al.,* 1995; Lal, 1998; Nyssen *et al.*, 2005; Anderson, 2012) as tropical rains are considered more intense and are more concentrated in time than other climates (Lal, 1998; Nyssen *et al.*, 2005). As tropical areas experiences higher amounts and frequency of intense erosive events, the average EI_{30} values in tropical areas are generally higher than those in temperate regions (Hoyos *et al*., 2005). Subsequently, rainfall induced soil erosion particularly effects tropical island environments, such as Mauritius, due to the intense rainfall experienced there (Hoyos *et al*., 2005). It has been noted that the erosive nature of rainfall on volcanic islands is closely related to rainfall depth and intensity, such that a few extreme rainfall events with high rainfall intensity can generate the bulk of the cumulative erosivity, as opposed to frequent events of low intensity (Nel *et al*., 2013). It is therefore imperative to understand and quantify rainfall erosivity in these environments as this process plays an important role in shaping the island's landscape.

1.4. The rainfall intensity and rainfall kinetic energy relationship

Rainfall kinetic energy (KE) results from the kinetic energy of each individual raindrop striking the ground and represents the total energy available for the detachment and transportation of soil particles (Salles *et al.,* 2002; van Dijk *et al.,* 2002; Salako, 2007). Rainfall kinetic energy is expressed as either rainfall energy expended per volume of rain or kinetic energy rate. The KE (the product of mass and fall velocity squared) of raindrops weakens the bonding effects within the soil and provides the energy required to transport the detached particles away from the site of impact (Wang *et al.,* 2014). As rainfall intensity contributes to runoff and sediment generation, the amount of soil detached by a particular amount of rain is related to the intensity because rainfall striking the surface could potentially detach more soil particles when falling at higher intensity (van Dijk *et al.,* 2002; van Dijk *et al.,* 2005; Wang *et al.,* 2014). Wang *et al.* (2014) expresses that though the role of rainfall intensity could be considered as ambiguous when the infiltration capacity of the soil is surpassed during short-duration, high-intensity storms likewise during long-duration, low-intensity storms, both of which may possibly lead to the onset of erosion. Given the right conditions, higher rainfall intensities could cause higher infiltration excess runoff rates thus retaining more sediment in transport as well as actively entraining soil particles (van Dijk *et al.,* 2005). The usage of energy parameters, such as rainfall intensity and rainfall kinetic energy indirectly, are generally accepted as better predictors of rainfall erosivity over a wide range of conditions (Stocking & Elwell, 1976; Wang *et al.,* 2014).

As rainfall kinetic energy (KE) is regarded as an indicator of rainfall erosivity (van Dijk *et al.,* 2002) many empirical and process-based soil erosion models make use of KE as the rain erosivity index (Salles *et al.,* 2002; Fornis *et al.,* 2005). For example, rainfall kinetic energy (KE) is used in splash erosion modelling such as used by Poesen (1985) and in modelling sheet and rill erosion, such as SLEMSA (Elwell, 1976), in EUROSEM (Morgan *et al.,* 1998) or in RUSLE (Renard *et al.,* 1997) as an indicator of rainfall erosivity (Salles *et al.,* 2002). There are two formulas of rainfall kinetic energy which can be used in relation to rainfall intensity. One is kinetic energy per unit time that is often called the rate of kinetic energy expenditure and designated as KE_R (J m^{-2} h^{-1}). The other form is the kinetic energy per unit area per unit depth also termed kinetic energy content and designated as KE (J m^{-2} mm^{-1}) (Fornis *et al.,* 2005). Hence, kinetic energy content is one of the many variants of kinetic energy. Kinetic energy content is the volume-specific KE or kinetic energy 'content' (J m^{-2} mm^{-1}) encountered by 1m^2 surface area per unit depth of rainfall. Other published symbolisations for this variant are KE_B, E_B and KE_{mm} (Brodie & Rosewell, 2007).

Fornis *et al.* (2005) established that there are three mathematical models which are most commonly used to relate kinetic energy content to rainfall intensity, namely the exponential model, the Hudson (1965) model, and the logarithmic model. The respective forms of these models are presented as follows (Fornis *et al.,* 2005):

The logarithmic model:

$$KE = u + w \log I$$

The Hudson (1965) model:

$$KE = b - cI^{-1}$$

The exponential model:

$$KE = z[1 - p \exp(-hI)]$$

Where u, w, b, c, z, p, and h are empirical constraints.

As the exponential model has one parameter more than the logarithmic model it offers more adaptability in tailoring the model to data sets (Fornis *et al.,* 2005). Kinnell (1981) suggests that the exponential model describes the KE – I relationship better than the logarithmic form because the exponential model indicates that there is an upper limit to the kinetic energy content of rainfall. The inclusion of a threshold value, or upper limit, for kinetic energy reduces the overestimation of the rainfall erosivity of low intensity rainfall events and thereby facilitates the calculation of gross erosion as well as accounting for differences in rainfall characteristics inherent to the geographic location of the measuring site (van Dijk *et al.*, 2002). The exponential model allows both forms of KE to be determined precisely from any rainfall event using the KE – I relationship because rain intensity data is widely available and straight-forward to obtain in comparison to KE (Salles *et al.,* 2002). The exponential equation is commonly utilised in tropical areas (van Dijk *et al.*, 2002).

Although van Dijk *et al.* (2002) cites a study by Rose (1960) who originally concluded that rainfall momentum is marginally better as a predictor of soil detachment than kinetic energy, it was demonstrated in a study by Hudson (1971) that momentum and kinetic energy display favourable comparable relationships with intensity for natural rainfall. While it is largely accepted that insight on the kinetic energy of rainfall is important in soil erosion studies, its computation by direct measurements is not as common as the measurement of intensity (Fornis *et al.,* 2005). Direct measurements of rainfall kinetic energy are very uncommon because they require both sophisticated and costly instruments (Petan *et al*., 2010). Thus, the alternative approach is to estimate kinetic energy from rainfall intensity as it can be more conveniently measured and is commonly available in most countries (Fornis *et al.,* 2005).

Rainfall kinetic energy is thus often derived through rainfall intensity (I) data which are widely available by implementing the empirical kinetic energy–intensity (KE – I) relationship (Petan *et al.,* 2010). The KE – I relationship was developed by Wischmeier & Smith (1958) as a linear-log equation and has subsequently inspired many later works (Petan *et al*., 2010). The empirical kinetic energy–intensity (KE – I) relationship was established from rainfall kinetic energy and has been formulated from raindrop size distribution (DSD) measurements performed at certain locations with specific climatic conditions (Petan *et al.,* 2010). Information provided by the drop-size distribution (DSD) measurements in conjunction with the fall velocity measurements or the empirical laws that link terminal fall velocity (V_t) and drop diameter (D), allows for the calculation of rain kinetic energy (Salles *et al.,* 2002). The empirical relationship is effective for a limited range of rainfall intensity, hence before making use of any KE – I relationship in climatically different environment, one should justify its formulation before its implementation (Petan *et al.,* 2010).

As rainfall kinetic energy represents the total energy available for detachment and transport by rainsplash, the empirical relationship between rainfall intensity and kinetic energy is vital for the prediction of erosion hazards (van Dijk *et al.,* 2002). Data on the KE of rainstorms are thus essential in developing and verifying models of soil detachment by raindrop impact on interrill areas (Wang *et al.,* 2014). Relating KE to easily measured rainfall parameters would therefore be a more practical and convenient way to estimate the erosiveness of rainstorms (Wang *et al.,* 2014). Rainfall events with intensities greater than 25mm/h are more likely to be erosive and the amount of rain falling at higher intensities may also be important in contributing to higher levels of soil erosion (Elwell & Stocking, 1973; Moore, 1979). Moore (1979) found that in tropical regions, which frequently experience high intensity rainfall events, as kinetic energy increases so does rainfall intensity up to about 75mm/h and believes that this relationship could underestimate the kinetic energy of tropical storms by as much as 10 per cent (Salako, 2007). The effect of events with different rainfall intensities on soil erosion risk in sugarcane fields was studied by the Mauritius Sugar Industry Research Institute (MSIRI) (Le Roux, 2005; Nigel, 2011). On bare sugarcane interrows the soil loss rate averaged low values between 0.2 and 5 $t.ha^{-1}.yr^{-1}$ at a rainfall intensity of $90mm.h^{-1}$. According to the MSIRI study a threshold rainfall of about $60mm^{-1}$ is present above which erosion starts to occur. While the MSIRI research provides valuable information, it was only conducted on a few sugarcane fields on two soils types (Low Humic Latosols and Dark Magnesium Clay) with slopes ranging from 7 to 13% and therefore it has limited application to other parts of the topographically complex island (Le Roux, 2005).

1.5. The orographic effect on rainfall distribution and erosivity

The classical depiction of orographic precipitation is a mountain range in the midlatitudes whose axis lies perpendicular to the prevailing wind direction (Roe, 2005). Orography is the influence of mountain topography on subaerial weather conditions, creating spatial and temporal variation of rainfall (Terry & Wotling, 2011). It is well established that topography plays a major role in the development of cloud and rainfall through orographic lifting (Terry & Wotling, 2011; Tobin *et al*., 2011). The best known relationship of the orographic effect is rainfall increasing with elevation (Prudhomme & Reed, 1998). Orography occurs when air lifts as it flows over mountains triggers convective instability and enhances the chance of rainfall, consequently more precipitation falls on the windward compared to leeward slopes (Terry & Wotling, 2011). Accordingly, in the leeward side of major mountain barriers that occupy latitudes with consistent prevailing winds, the familiar 'rain-shadow' effect is observed (Terry & Wotling, 2011).

In regions characterised by complex orography and precipitation gradients, such as often found on volcanic islands, topographic forms can trigger rain storms by extracting atmospheric moisture through orographic precipitation mechanisms (Johansson & Chen, 2003; Boni *et al.,* 2004). Orographic precipitation is particularly evident on mountainous islands, such as Mauritius, where maritime winds in predominant direction and high-elevation topography cause adiabatic cooling through forced uplift. This creates a greater possibility for rain production by producing a cloudy environment that reduces evapotranspiration losses (Custrodio *et al*., 1991; Terry & Wotling, 2011). Depending on the size of the topographical feature and efficiency of the rainfall release processes the windward side will experience an increased in precipitation because the forced lifting of the approaching air masses causes the discharge of rainfall and a potential increase in precipitation with elevation (Johansson & Chen, 2003). Accompanying this is the 'rain shadow' effect on the leeward side (Nel *et al*., 2012). A proportion of the heavy rainfall experienced on Mauritius appears to be induced by the elevated central plateau (Nel *et al.*, 2012). Such orographic influences on the spatial and temporal distribution of rainfall and moisture gradient also have important implications for water resource availability and provision (Terry & Wotling, 2011). In places where a major topographic barrier interacts intensely with narrow zones of mesoscale convective systems then unusually heavy rainfall and the generation of significant flood events may occur (Terry & Wotling, 2011).

Topography, from a small hill to a large-scale mountain range, influences all scales of atmospheric motion (Bender *et al*., 1985). In the case of a landfalling tropical cyclone, the topography of the specific terrain being transversed has a vital impact on certain aspects of the rainfall event's behaviour such as the event's movement, rate of decay and rainfall distribution. Strong relationships have been proven between the total rainfall associated with landfalling tropical cyclones and the local distributions of orography. Therefore the maximum hourly rainfall is generally higher in the mountain upslope regions (Bender *et al.*, 1985).

On a global scale numerous studies have been conducted in different climatic environments, including Alpine and Tropical regions, on the impact that topographical features have on rainfall distribution. In the tropical regions, namely Tropical South Pacific (TSP) and the volcanic island of Tahiti, a strong orographic influence is apparent, resulting in considerable variation in yearly precipitation that corresponds to substantial changes in the natural vegetation patterns (Terry & Wotling, 2011). In both regions topography is recognised as being the major influence on the spatial distribution of precipitation. Wotling *et al.* (2000) speculated that topographical relief is directly proportional to rainfall intensity and hence the steeper the relief, the higher the rainfall intensity. To prove this some deterministic modelling at event-scale was carried out in order to help predict the variations in space of rainfall intensities (Wotling *et al.,* 2000). Notwithstanding this study, Diodato (2005) noted that the very little is known about precipitation pattern in mountainous areas of tropical region because of the complex topography.

Studies conducted in the Alpine regions of Sweden (Johansson & Chen, 2003) and the Himalayan Mountains (Bookhagen & Burbank, 2006) found that precipitation distribution is as strongly influenced by topography as in tropical regions. Topography and relief not only cause high rainfall bands over mountains but also directly influence the rainfall characteristics (Bookhagen & Burbank, 2006). Nyssen *et al*. (2005) noted that topographical aspects such as steep overall slope gradient and valley aspects control the spatial distribution of annual rain depth. The development of high intensity rainfall events as a product of topography plays a fundamental role in the type and depth of rainfall and subsequently the rainfall erosivity within a region.

An increase in rainfall and rainfall erosivity with altitude is, however, not always evident. The anticipated increase in rainfall with altitude was not apparent when comparing rainfall totals measured at different stations, covering an altitudinal range of 1060m to 3165 m.a.s.l, in the KwaZulu-Natal Drakensberg, South Africa (Nel & Sumner, 2007) where an inverse relationship was found between altitude and the associated maximum rainfall intensity. Though the mean kinetic energy produced during individual events was similar throughout the area, the high altitude stations in the Drakensberg recorded lower maximum rainfall intensities and fewer high intensity events than the lower altitudes stations (Nel & Sumner, 2007). Individual events at all altitudes in the Drakensberg could potentially detach soil, however, at higher altitudes on the escarpment a lower percentage of rain falls as erosive events producing lower cumulative kinetic energy and total rainfall erosivity than at stations on the foothills. Nel & Sumner (2007) explain that the altitudinal differences in cumulative kinetic energy and cumulative erosivity is due to the lack of erosive rainfall events during early and late summer at the high altitude stations on the escarpment, while lower altitudes experience considerably more erosive rainfall events during this period.

Other studies conducted in mountainous areas display similar results to those found by Nel & Sumner (2007). Hoyos *et al*. (2005) found that rainfall intensity in the Columbian Andes appears to be affected by elevation, with consistently lower rainfall intensity (I_{30}) values at the rainfall stations with the highest altitude. A similar relationship was found in Honduras, Costa Rica and Sri Lanka and in all cases there is an inverse relationship between rainfall erosivity and elevation, with the latter increasing to approximately 1750m, followed by a decrease to lower values at the highest elevation (2120m) (Hoyos *et al.,* 2005).

This is attributed to fewer large raindrops being formed by accretion and coalescence at higher elevations (Hoyos *et al.,* 2005).

Since many tropical volcanic islands have an environment where there is an altitudinal and temporal difference in rainfall due to the nature of the topography and its orographic effects, a few extreme rainfall events with high rainfall intensity can generate the bulk of the cumulative erosivity (Nel *et al.,* 2013). The stage at which the erosive events experience the high rainfall intensity also affects the amount of sediment eroded, total soil loss, type and particle size distribution of soil that is eroded. It is therefore necessary to identify and understand the impact of rainfall event profiles on the severity of the erosion experienced in tropical island environments such as Mauritius.

1.6. Importance of 'event profiles' on infiltration, runoff and soil erosion

As rain falls onto unsaturated soil, a certain amount of the total rainfall infiltrates into the soil, at the same time the deficit (total rainfall minus total infiltration) will run-off the surface (Xue & Gavin, 2008). Water percolating into the slope increases the water content of the soil and reduces the in-site suction, thus decreasing the infiltration rate of the soil (Xue & Gavin, 2008). Rainfall intensity is a fundamental control of interrill runoff and erosion (Parsons & Stone, 2006). Although it is generally assumed that runoff is inversely related to infiltration, and the influence of rainfall intensity can be understood through its effect on infiltration (Xue & Gavin, 2008), this assumption is too generalised. First, spatial heterogeneity of infiltration characteristics vary with soil type, such that of the soil surface may experience increased infiltration with increased rainfall. Second, increased rainfall intensity may lead to the formation of soil crusts thereby reducing infiltration. The influence of soil permeability is also important to infiltration and runoff generation (Parsons & Stone, 2006).

Nonetheless the proportion of the total rainfall resulting in infiltration and run-off varies continuously during a rainfall event (Xue & Gavin, 2008). Rainfall events commonly demonstrate repeated fluctuations in intensity, such that peak rainfall rates in an event can exceed the mean event rate by an order of magnitude (Dunkerley, 2008). The occurrence of peak intensity can be at any instant during a rainfall event, and these events can be classified according to where the peak falls within the event duration (Dunkerley, 2008). Commonly accepted terminology includes describing the rainfall event by its leading quartile, such as first quartile events, fourth quartile event- similar to that developed by Huff (1967) or using uniform intensity, advanced peak, intermediate peak and delayed-peak distributions according to Zhang *et al*. (1997).

An 'event profile', as a general description, is used to refer to the pattern of temporal fluctuations in intensity during a rainfall event (Dunkerley, 2008). Distinct rainfall intensity fluctuations are neglected by the majority of published studies on soil hydraulic properties such as infiltrabillity and soil erosion processes (Dunkerley, 2012). Event profiles are critical as the stage in which an event receives its peak intensity impacts on the severity of the erosion experienced and the amount of sediment eroded, the total soil loss and the particle size distribution of the eroded sediment (Parsons & Stone, 2006). Subsequently, intra-storm attributes of the rainfall events become vital in identifying the influence the 'event profile' has on the rainfall erosivity and the potential soil erosion risk which an event causes. Xue & Gavin (2008) emphasise that the depth of infiltration and runoff is sensitive to the rainfall event profiles, as event profiles showing an early peak generate more infiltration and less runoff than events with late peaks in duration. This leads to higher runoff rates, soil loss and larger particle sizes being eroded (Parsons & Stone, 2006). Therefore, in some cases the rainfall event profile and not the mean rain rate most noticeably control the relative magnitudes of infiltration and runoff in a real event (Dunkerley, 2012).

An intra-storm analysis on extreme erosive events was conducted in the KwaZulu-Natal Drakensberg by Nel (2007) who determined that although the extreme events exhibit temporal variability in rainfall depth, more than 80% of rainfall generated by extreme events was received within the first 300minutes of the events. Rainfall intensity received from the extreme events also exhibits temporal variability and none of the extreme events displayed constant intensity over time (Nel, 2007). This is significant as Parsons & Stone (2006) indicated that rainfall events with constant-intensities yield lower soil loss than the events with varying-intensities. The 'event profile' in relation to the rainfall event intensity also influences the clay-content of the eroded materials (Parsons & Stone, 2006). A study by (Stocking & Elwell, 1976) indicated that the magnitude of the peak intensities within the 'event profile' is most critical to the erosional process and sediment transport peaks in response to intense rainfall (Nel, 2007). Though it is generally accepted that the erosivity of a rainfall event is affected by the intra-storm distribution of the rainfall intensity, it has only recently been incorporated into soil-erosion models (Parsons & Stone, 2006).

Despite previous studies investigating storm kinetic energy and erosivity on Mauritius, no studies have investigated the intra-storm distribution and the general climatology of rainfall parameters in tropical island environments. Therefore, the general aim of this study is to investigate the within-storm distribution of rainfall depth, extreme rainfall intensity and cumulative kinetic energies on the tropical island of Mauritius in the Indian Ocean.

1.7. Aim and Objectives

1.7.1. Aim

The aim of this research project is to conduct an intra-storm analysis of the rainfall characteristics and general climatology of erosive events on Mauritius. To achieve the above, the following objectives have been set out:

1.7.2. Objectives

i. To identify the top twenty erosive events (based on the 'total kinetic energy generated') between 2004 to 2008 at six automated weather stations situated in the western and central regions of the island.
ii. To describe the general rainfall and climatological characteristics of the top twenty erosive events at each automated weather station;
iii. To provide a comprehensive intra-storm analysis of each event;
iv. To contrast the spatial and temporal differences between the automated weather stations.

1.8. Project Outline

This research project is divided into six chapters. In this chapter an introduction and literature review on the concept of rainfall induced soil erosion, rainfall erosivity and the relationship between rainfall intensity and kinetic energy within the context of a tropical island environment with an elevated central interior was presented. Chapter 2 provides information pertaining to the study area and the background to the geographic location and extent of the island, the geological history, geomorphology, climate as well as the pedology and land use of the island. Chapter 3 outlines the methodology followed and used in the analyses of the data used in this project. Chapter 4 presents the results produced following the described methodology, followed by a detailed discussion and interpretation of the results in Chapter 5. Finally, Chapter 6 highlights the main conclusions drawn from this project as well as the recommendations and suggestions for future studies.

Chapter 2 : Study Area

Mauritius is located in the Indian Ocean basin and forms part of the Mascarene Islands, along with Reunion and Rodrigues (Johnson *et al*., 2010). The island is located between the latitudes 19˚58.8'S and 20˚31.7'S and the longitudes of 57˚18.0' E and 57˚46.5' E (Figure 2-1), near the edge of the southern tropical belt (Dhurmea *et al.,* 2009). Mauritius is approximately 800km east of Madagascar and nearly 2000km off the coast of continental Africa (Ng Cheong *et al.,* 2009). The closest island is the French island of Reunion located 200km to the southwest (Johnson *et al*., 2010).

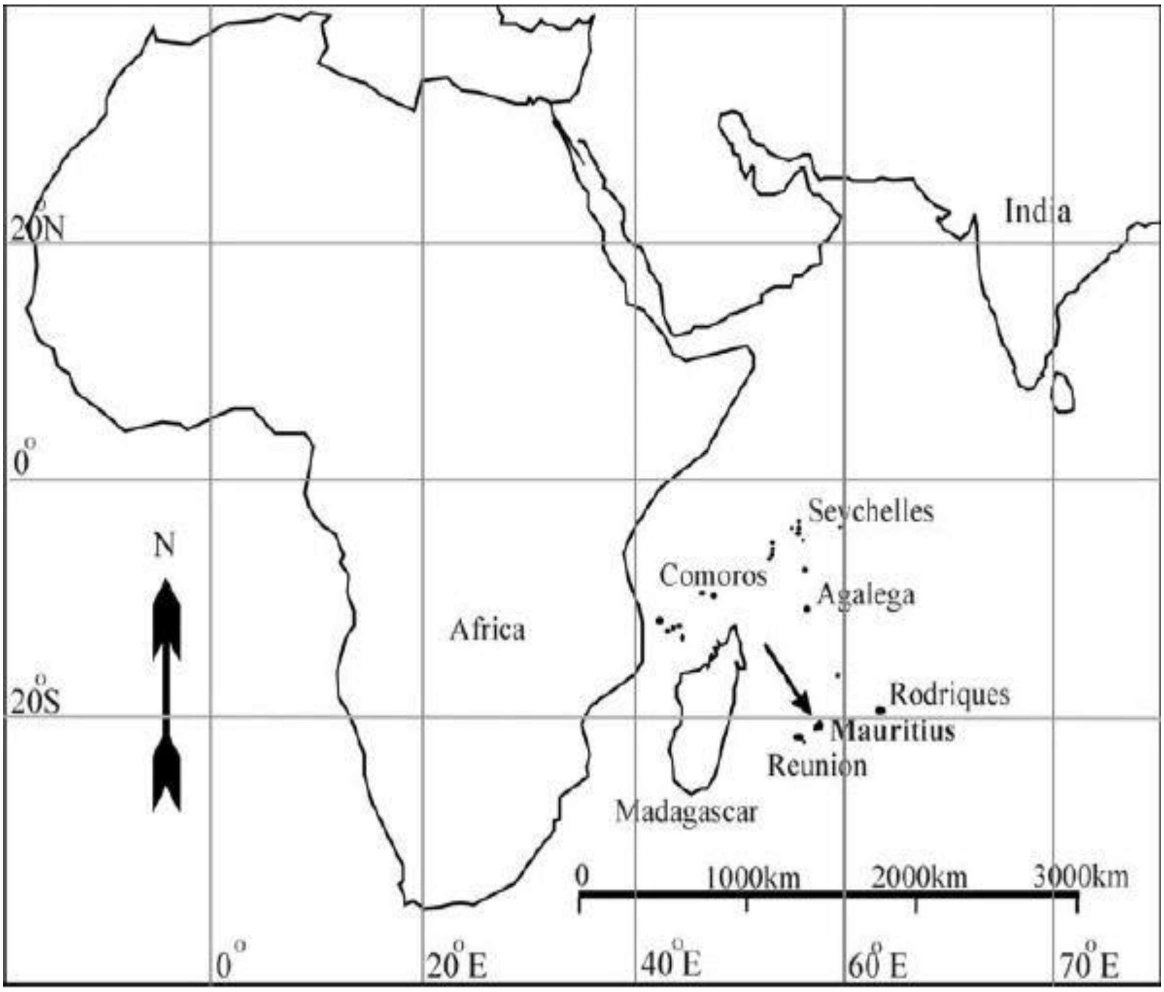


Figure 2-1: Location map of Mauritius (after Saddul, 1995)

The island's topography is defined by mountains and hills, plateaus, river valleys and plains (Nigel & Rughooputh, 2010a). Mauritius is elliptically shaped with a land area of

1860km^2, a major axis running NNE to SSW direction of approximately 61km and a minor axis of approximately 46km running in a NNW to SSE direction (Ng Cheong *et al*., 2009; Figure 2-2). The island's coastline is 372 km long (Nigel, 2011) and has a maximum elevation of 828m.a.s.l at Piton de la Petite Rivière Noir. Port Louis is the capital of Mauritius, and Curepipe is a major population centre in the interior. Main airport is Sir Seewoosagur Ramgoolam International Airport (SSR Airport) located in the south eastern region of the island (Figure 2-2). Mauritius' most distinctive feature is the central plateau, at an approximate elevation of 600m (Staub *et al.,* 2014), bordered by the remnants of the primary shield volcano, rising steadily towards the southwest of the island (Nigel & Rughooputh, 2010b; Figure 2-2). The physical template and characteristics can be summarised as follows.

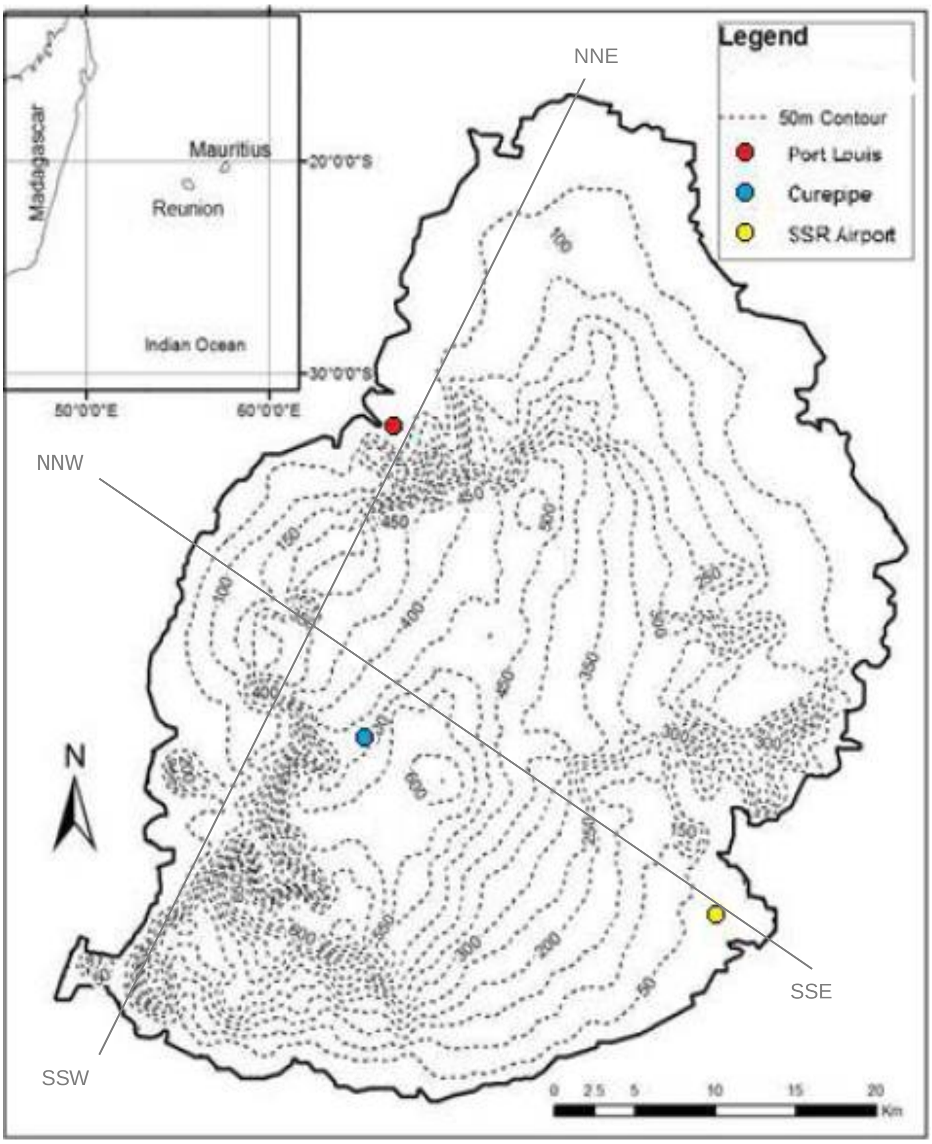


Figure 2-2: Locality and elevation map with the location of the capital Port Louis, SSR International Airport and Curepipe, a major population centre (Anderson, 2012). Island transect details are shown in Figure 2-3.

2.1. Geology

All of the Mascarene Islands are the summits of great volcanic cones that emerged out of the ocean floor. Mauritius is composed from remnants of a massive shield volcano covered by younger volcanic rocks. The geology can be described as being entirely of volcanic origin and is composed of basaltic rock with differing densities due to the intricate nature of its formation, except for the beaches, coral formations of the reefs, the alluvial deposits at the coast and the limited extents of alluvium (e.g. estuary of Black River) (Proag, 1995; Le Roux, 2005; Newsome & Johnson, 2013). The brief volcanic chronology of Mauritius, described by Proag (1995), is the result of two major activity periods separated by a gap of 5.5 million years:

- Emergence and Older Series : 10 to 5 million years ago giving rise to the old lavas
- Intermediate and Younger Series : 3.5 million years to 25,000 years

Hence, according to Proag (1995) the formation of the island should be considered in four volcanic phases:

1. The Breccia Series or Emergence Period of the island 10 to 6.7 Million Years (MY) Before Present (B.P.)
2. The Old Series – Old Lavas (6.2 to 5million years)
3. The Intermediate Series – Early Lavas (1.5 million years)
4. The Younger Volcanic Series – Late Lavas (700,000 to 25,000 years)

Emergence period of the island, 10 to 6.7 million years ago, started as a rift in the ocean floor that acted as an eruptive fissure emitting volcanic product such as tuff, boulders and breccia flows, hence this brecciated series corresponds to the first phase of the old series (old lavas). The original foundation of the island, characterised by a bulge in the structure, was made up of pillow lava. Subsequently, a 500,000 year period of relative calm followed, causing subsidence to occur in the centre of the island as the underlying magma decreased in pressure (Proag, 1995).

During the second phase or Old Lavas, 6.2 to 5 million years ago, the island developed a circular, shield shape characterised by a single volcano. The established part of the big strato-volcano is a vast dome of 40km diameter; 900m high elevation emerged out of the ocean. Poorly developed minor structures of 5-30m thick compact basalts were radially emitted from the strato-volcano and covered most of the lava from the Emergence Period (Proag, 1995). While this period was marked by occasional periods of lava flow (50-100m thick) the summit of the shield stretched out and crumbed, creating a caldera of 24km in diameter (Proag, 1995).

Intermediate series or Early lava developed following a period of relative geological calm (approximately 1.5 million years), coupled with intense erosion and volcanic activity from smaller vents. This period lasted from 3.5 to 2 million years ago (Proag, 1995). Early Lava is comprised mostly of compact olivine basalts along fissures and vent, and is exposed only in the south west of the island. Early Lavas responsible for shaping the central uplands and coastal plains were emitted from approximately 25 vents across the central uplands at 20˚N, corresponding to a series of fault lines on the island. Lava emitted during this series make up 35% of Mauritius and very compact in their composition (Proag, 1995; Nigel, 2011).

It is believed that the intermediate phase ended about 1.9 million years ago, and was subsequently followed by a period of inactivity extending over 1.2 million years (Proag, 1995). Renewed eruptions occurred between 700,000 to 25,000 years and relate to the last period of volcanic activity on the island. These lava flows erupted from a chain of approximately twenty vents, where Curepipe Point is the largest and highest (685 m) (Saddul, 1995). This activity corresponds with the younger series, or the Late Lavas (1.9 million to 25,000 years ago). Late Lavas occupy the greatest part of the island and are distinguishably from the Early Lava through their highly vesiculated appearance (Saddul, 1995). This period experienced sea levels fluctuations and intense cutting of valleys and gorges that altered the topography of the island (Proag, 1995). Non-volcanic materials such as coral reefs, sandy beaches, sand dunes and some consolidated coral and shell debris in isolated remnant raised beaches are also present. The outcome of the collapsed caldera and recent lava follows gave rise to the topography of the island, comparable to that of most tropical islands (Saddul, 1995).

2.2. Topography and hydrology

Mauritius' topography has been described as a central upland surrounded by mountain ranges, isolated peaks and plains forming a bowl with chipped rims, filled with younger lavas (Proag, 1995). According to Parish & Feillafe (1965) Mauritius has three clear topographic patterns corresponding to the age of the parent lava (also see Proag, 1995). First, the Old Lava Series gave rise to the mountain ranges that contain the highest peaks culminating on the south west side of the island within the Rivière Noire- Savanne mountain range that has Piton de la Petite Rivière Noir as its peak at 828 m.a.s.l. Second, the

Intermediate Lavas correspond with the gentle rolling topography and deeply incised rivers with terraces and stabilised gullies. Third, the topography consistent with the Late Lavas are characterised by several rocky areas that are almost completely absent of surface drainage and are dominated by the vents that gave rise to them.

The elevated central region, also referred to as the central uplands or central plateau, lies higher than approximately 600m and directly influences the island's climate. This elevated region is as a result of historical geological processes as well as more recent erosive processes involved in the formation of the island. Figure 2-3 shows the island profiles from SSW to NNE, and NNW to SSE. The central plateau of elevated region is evident on the SSW to NNE transect as well as Curepipe point (approximately 685m) which is the largest and highest volcanic point on the island. Location of the island profile transects is indicated on Figure 2-2.

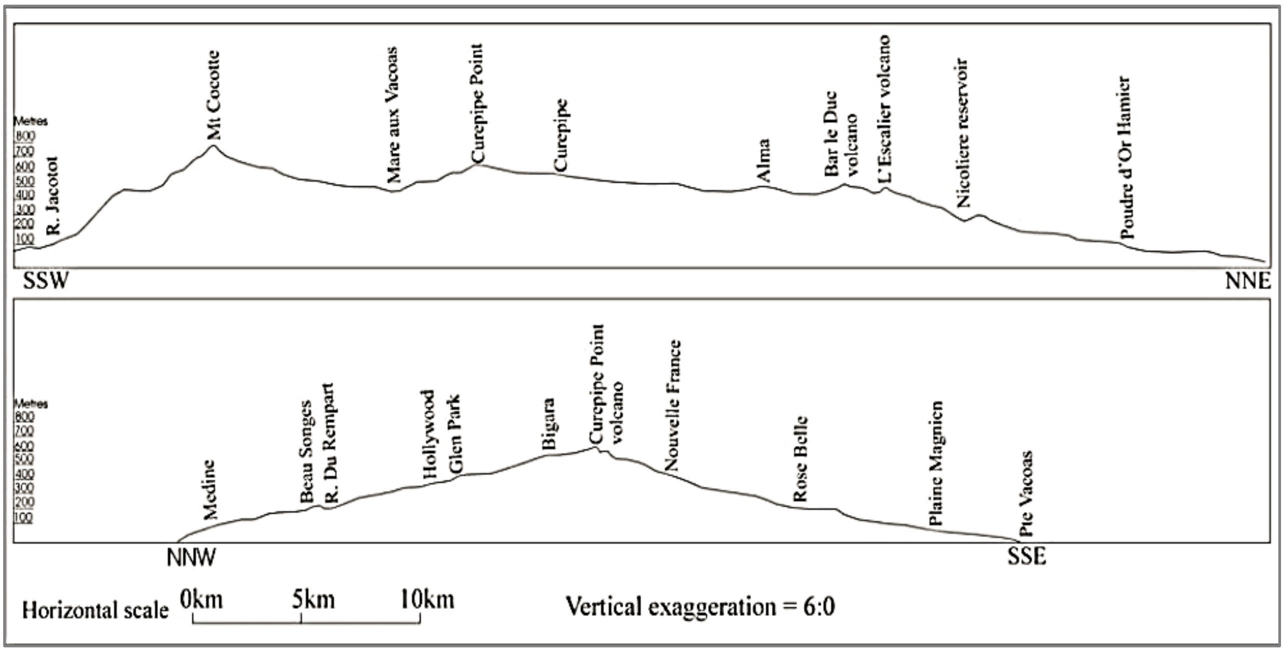


Figure 2-3: Island profiles from SSW to NNE, and NNW to SSE (after Saddul, 1995; taken from Le Roux, 2005). Location of the island profile transects is indicated on Figure 2-2.

Topography of Mauritius is characterised by five geomorphological domains (Proag, 1995; Saddul, 1995; Figure 2-4):

1. The 'mountain environment', was formed by massive lava flows of the Old Lava Series that resulted in a discontinuous ring encircling the central uplands, with isolated peaks and plains forming a bowl with chipped rims (Proag, 1995). As a consequence of this formation, three distinct mountain ranges exist:
    - The Port Louis-Moka-Long Mountain Range in the northwest

- The Black River-Savanne Mountain Complex and,
- The Bamboo Mountain Massif.

2. The central plateau, also referred to as the 'central uplands', is comprised of land contained by the caldera of the island, and includes flat terrain to subdued plateau like topography to a variety of undulating uplands, with a mean elevation of between 300 to 400m, rising to approximately 600m along the dissected plateau in the southern part of the island and gently sloping relief that merges into the coastal lowlands of the east.
3. The 'southern uplands', where the Early Lavas are situated, can be characterised by terrain consisting mostly of multi-formed segments of convexo-concave slopes and comprises all the land above the 500m contour.
4. The 'recent lava plains' areas all lie below the 200m contour and include the coastal plains and inland slopes, with undulating slopes between 2 – 13% as well as vast expanses of rocky surfaces.
5. The 'coastal environment' contains sandy beaches, the lagoon, rocky coastline and coral reefs just below or above sea level. Coral reefs surround the island except along the western and southern coast and at the mouth of some rivers (Saddul, 1995; Proag 1995).

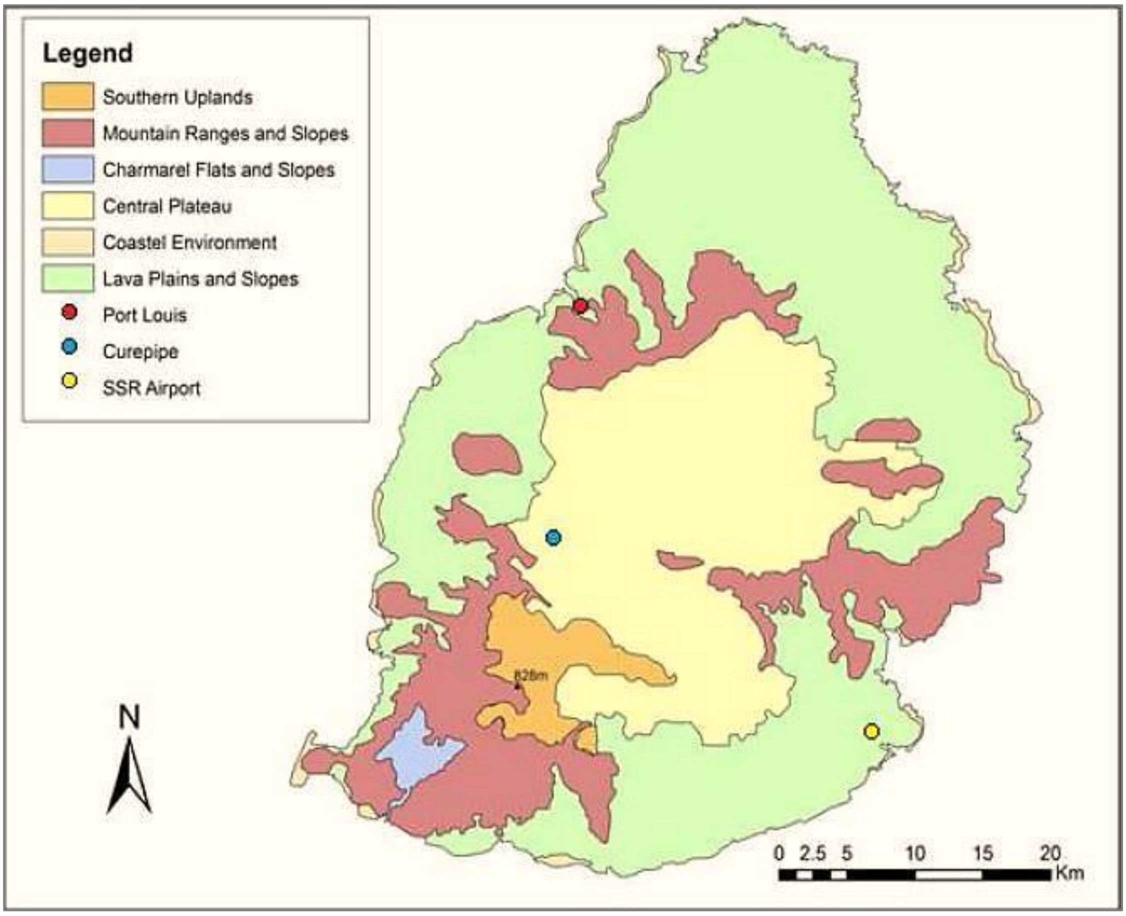


Figure 2-4: Main geomorphological domains on Mauritius (after Saddul, 1995; taken from Anderson, 2012)

The structure of the hydrological resources on Mauritius is largely dependent upon its predominantly basaltic geology. However, the complex nature of the island's formation gave rise to basalt of various densities ranging from the impermeable compact basalt to highly porous basalt. The latter acts as a water collector therefore aquifers of Mauritius have a high permeability in excess of 10^{-5}m/s (Proag, 2006). Hence, the texture and type of formation from the different volcanic activities determines the natural infiltration rates, the contribution of rainfall recharge to aquifers and also the amount of runoff. There are five main aquifers on the island and groundwater plays a major role in sustaining flows in the rivers (Proag, 2006).

Mauritius is drained by several river systems spread on the gently rolling topography of the Intermediate Lavas of the Recent Volcanic Series (Nigel, 2011). The majority of the rivers spring from the central plateau and flow radially to the sea, yet their distribution is highly irregular (Proag, 2006). Mauritius has been divided into catchment areas or riverbasins comprising: 25 main basins, each corresponding to a main river, and 22 minor ones and coastal zones drained by several streams (Proag, 1995). Catchment areas vary in size from 3 – 64km^2 (Proag, 1995). The island has two natural lakes: Grand Bassin and Bassin Blanc together with eleven reservoirs, Mare aux Vacous, as seen in Figure 2-5, being the largest. Proag (1995) noted that the northern, eastern and south-eastern parts are deprived of surface drainage and lack the presence of major rivers due to the low gradient of these areas.

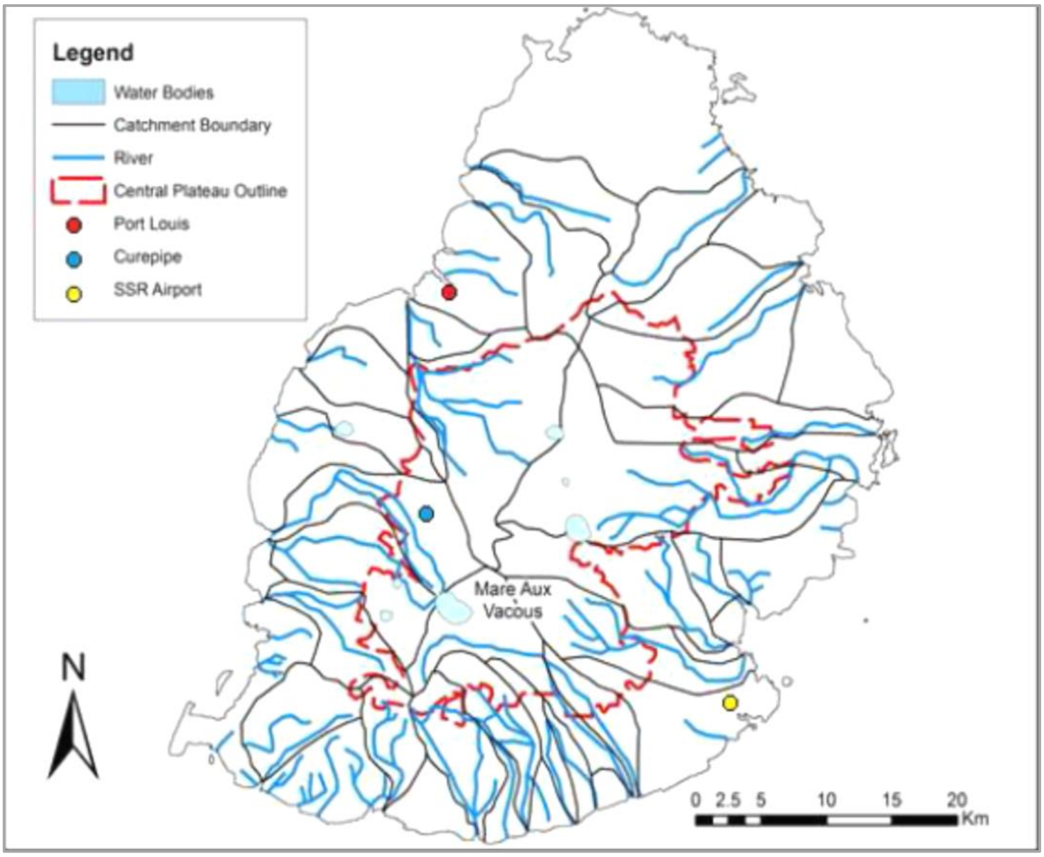


Figure 2-5: Catchment boundaries, major rivers and water bodies on Mauritius (WRU, 2007; taken from Anderson, 2012)

2.3. Pedology (soils)

Remarkably similar geology, climate, soils and cropping characteristics between Mauritius and some parts of the Hawaiian Islands led to the acceptance of a classification system used for soil survey of the territory of Hawaii for the island of Mauritius (Parish & Feillafe, 1965; Arlidge & Wong You Cheong, 1975; Williame, 1984; Proag, 1995; Le Roux 2005; Nigel, 2011; Anderson, 2012). The classification of soil types are based on Great Soil Groups with subdivisions and Families based on differences in rainfall or parent materials portrays the soil types of Mauritius in relation to their age or development stage (Pears, 1985 cited in Proag, 1995: 21; Le Roux, 2005; Figure 2-6).

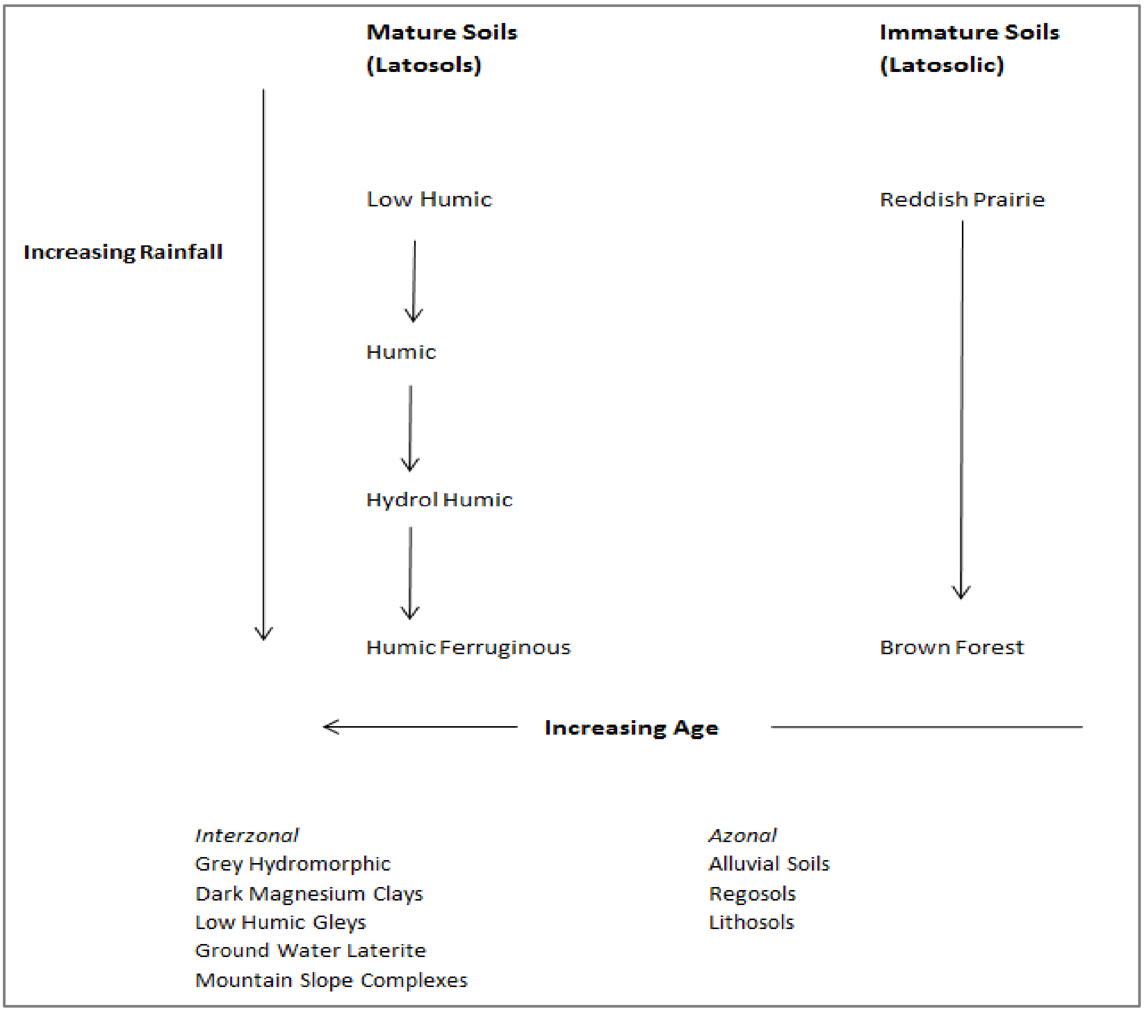


Figure 2-6: Classification of Soils in Mauritius (Proag, 1995)

Boundaries between soil groups are diffuse, and are differentiated by chemical rather than morphological criteria. Mauritian soils developed virtually exclusively on olivine basaltic lavas or highly vesiculated basaltic lava (Proag, 1995). As a result of the basaltic origin of the soils, no series subdivisions occur (Williame, 1984; Le Roux, 2005). Subsequently, the soils of Mauritius can be placed in two categories: Mature ferralatic soils (latosols), and immature latosolic soils (Figure 2-6). First, Mature Latosols originate from the decomposition of basaltic lava rock, and can be further sub-divided into families- Low Humic, Humic, Hydrol Humic and Humic Ferruginous that characterize areas of similar climate and topography, thus similar soils. No undecomposed minerals are present in this soil complex. Second, the Immature soils (Latosolic), are characterized by the presence of angular clasts and gravel of vesicular lava, thus these soils contain minerals that are still in the process of weathering (Proag, 1995).

Mauritius' natural soil fertility composition is low because of a noticeable deficiency in nitrogen, phosphate and potash (Proag, 1995). Soil fertility decreases with increasing rainfall and age of the parent material (Figure 2-6). Additionally, rainfall increases with elevation, and therefore, a vertical zonality of fertility occurs which is correlated with the vertical zonality of Mauritian soil. For example, the Latosolic Reddish Prairie soils are less fertile at high rainfall levels with excessive drainage and shallow depth, than Humic Latosols occurring at low rainfall levels and limited drainage (Proag, 1995; Le Roux, 2005).

The soils found on Mauritius offer a good example of zonality. Zonality is the progressive intensity of weathering and soil development with increase in the intensity of soil forming factors, notably rainfall. Soils susceptibly to heavy rainfall are variable. Subsequently, the islands soils are classified further into three soil orders: Zonal, Intrazonal and Azonal soils. Proag (1995) describes the Mauritian soils as follows (also see Le Roux, 2005; Nigel, 2011): Zonal soils developed predominately from the Intermediate Lava under mean annual rainfall of 1000 – 4000mm of rain. Intrazonal soils developed on the Late Lavas under conditions where the effects of climate and vegetation are obscured by local factors of the environment such as relief, drainage and composition of the parent material. Azonal soils have little or no profile development, apart from some accumulation of organic matter in the surface horizon. Further discussion of these soil groups can be found in Parish & Feillafe (1965), Arlidge & Wong You Cheong (1975), Williame (1984), and Proag (1995).

The three soil orders are distributed across the island, the Zonal Soils constitute approximately 33% of the island's surface area, Intrazonal soils makes up 36% and Azonal soils makes up 18%, with the remainder of the island covered in various water bodies (Nigel, 2011) as shown in Figure 2-7.

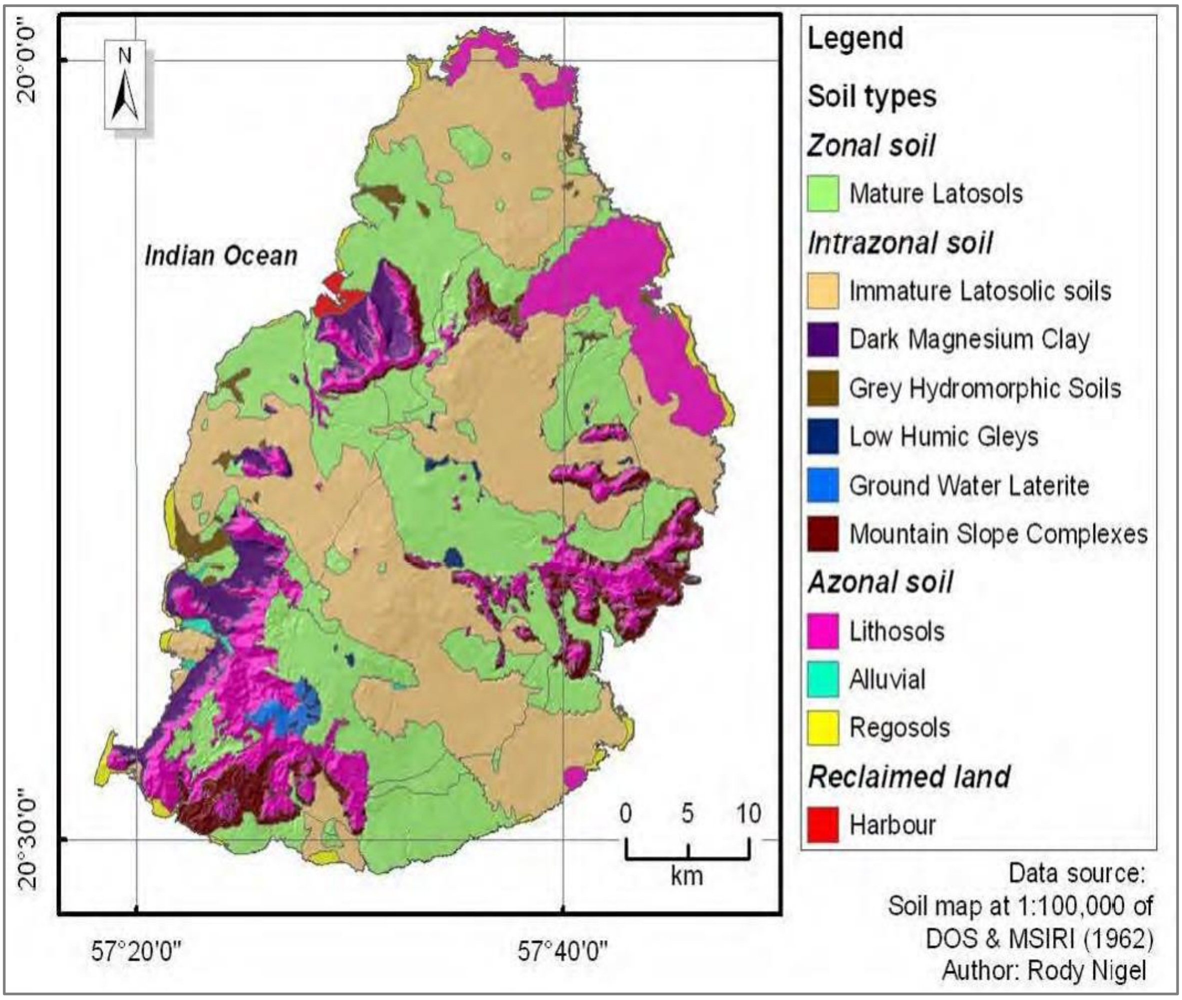


Figure 2-7: Soil map of Mauritius from DOS and MSIRI (1962), taken from Nigel (2011)

2.4. Climate and weather

Mauritius has a tropical maritime climate that is influenced by the surrounding Indian Ocean (Saddul, 1995). The island is under the influence of atmospheric circulation, developing from the two primary zones: a low pressure zone in the north and a high pressure zone in the south (Williame, 1984; Nigel, 2011). Substantial variations in rainfall and other climatic characteristics are due prominently to differences in elevation, distance from the coast, windward-leeward locations, cold fronts, the position of the Inter Tropical Convergence Zone (ITCZ), occasional convective storms and seasonality (Fowdur *et al.*, 2014). The average annual temperature is 22˚C: July being the coolest month with temperatures ranging from 16˚C in the central uplands to 22˚C in the coastal areas (Proag, 1995). February is the warmest month with temperatures varying from 20˚C (central uplands) to 28˚C (coastal).

Average sunshine per day varies between 7 and 8 hours depending on the season (Padya, 1989).

For the majority of the year, Mauritius lies within the South East Trade Winds but throughout the warm and rainy summer months (November to May) the most important climatological features are tropical cyclones and depressions associated with the seasonal movement of the ITCZ (Dennett, 1978). However, during the comparatively dry winter period, (April to October) the South East Trade Winds dominate and are accompanied with few rainfall events, which are associated with frontal systems (Nigel, 2011).

Another importance influence on weather patterns of Mauritius is the spatial and temporal distributions of mean Sea Surface Temperature (SST). Typically, the mean SST is higher on the western part of the tropical and subtropical Indian Ocean, and is largely related to the warm westward-flowing south equatorial current. The SST near Mauritius varies from 22˚C in September to 27˚C in March. Even though intra-annual variations in SST are small, they indicate seasonal changes such as summer being the hot and wet season, and the winter is warm and dry. Inter-annual variations in the mean SST are also reasonably small (Padya, 1989; Nigel, 2011).

2.4.1. Weather systems in Mauritius

Eight weather systems prevailing over Mauritius during a typical year have been identified by Fowdur *et al.* (2014). These are windfields over Mauritius, cyclonic activity, ITCZ, cold fronts, anticyclones, sea breezes, easterly wave perturbations in the lower troposphere, and cloud masses derived from upper level winds. Particular focus has been given to cyclones, due to their destructive nature and high kinetic energy and subsequent erosive nature. The weather systems are described below:

2.4.1.1. Windfields over Mauritius

Mauritius is located at the edge of the tropics, within the belt of trade winds. Winds on the island are influenced by two main regimes, The South East Trade Winds (easterlies) and the North West Monsoon Winds (westerlies). Westerlies occur predominately in the summer months when the ITCZ lies over the south of Mauritius. The months April to May are dominated largely by easterlies (Fowdur *et al*., 2014). Padya (1989) identified that by the end of June, the easterlies show an expansion southwards. South east trade winds (easterlies) supply the dominant moisture advection and combined with topographic uplift and sea-breezes are responsible for the steep rainfall gradient and the west coast rain-shadow effect which impacts upon erosion risk and rainfall erosivity distribution (Fowdur *et al*., 2014; Staub *et al*., 2014).

2.4.1.2. Cyclonic activity

Mauritius typically experiences storms ranging in intensity from tropical depressions to tropical cyclones in any single cyclone season, yet intense or very intense tropical cyclones are relatively rare (Parker, 1999). Cyclonic events are considered erosive in nature and are a climatic factor of substantial importance to agricultural production in Mauritius (Proag, 1995). There are, on average, 11 atmospheric depressions each summer that develop in the south western part of the tropical cyclone belt in the Indian Ocean (Padya, 1989). Due to the island's position in the Indian Ocean, cyclones most commonly form northwest of Mauritius and follow relatively erratic paths in a south-westerly direction (Figure 2-8) (Padya, 1989). The incidence of intense or very intense tropical cyclones aligning on the main island of Mauritius is estimated at between 1:8 and 1:15 years (Parker, 1999).

The cyclonic period traditionally extends from November to March. Average rainfall during these tropical cyclones is 245mm, but variations are largely dependent on the nature and intensity of the cyclone and on the distance of the cyclone while passing the island (Le Roux, 2005; Nigel, 2011). Typically, rainfall amount is highest (>300mm/day) when the tropical cyclone passes close enough for the island to fall under the influence of the inner convection band and when the passing is not so close, the rainfall amount is moderate but substantial (Padya, 1989; Nigel, 2011). From 20-22 January 2002, Mauritius was hit by the most recent very intense cyclone (Dina) and saw 488mm of rain being recorded at Vacoas during the event with wind gusts of 209km/h. As is evident in Figure 2-8 each of the major cyclone events has a specific trajectory.

During the study period, 2004 – 2008, numerous tropical cyclones passed within the vicinity of Mauritius (Météo-France, 2015). Four of the most noteworthy cyclonic events included Darius (classified as a 'Severe Tropical Storm' or Class I cyclone) from 31 December 2003- 03 January 2004. The second most noteworthy event during this period was Hennie (classified as a 'Severe Tropical Storm' or Class I cyclone) in March 2005 (22-24th). Hennie passed 60km South East of the island and had maximum wind speeds of 112km/h. Third was Diwa (also classified as a 'Severe Tropical storm' or Class I cyclone) in March 2006 (3-4th) and passed 220km North North West of the island with winds as high as 126km/h. The fourth was Tropical Cyclone Gamede during February 2007 (22-25th), which passed 230km North West of the island with windspeeds as high as 158km/h (MMS, 2014d).

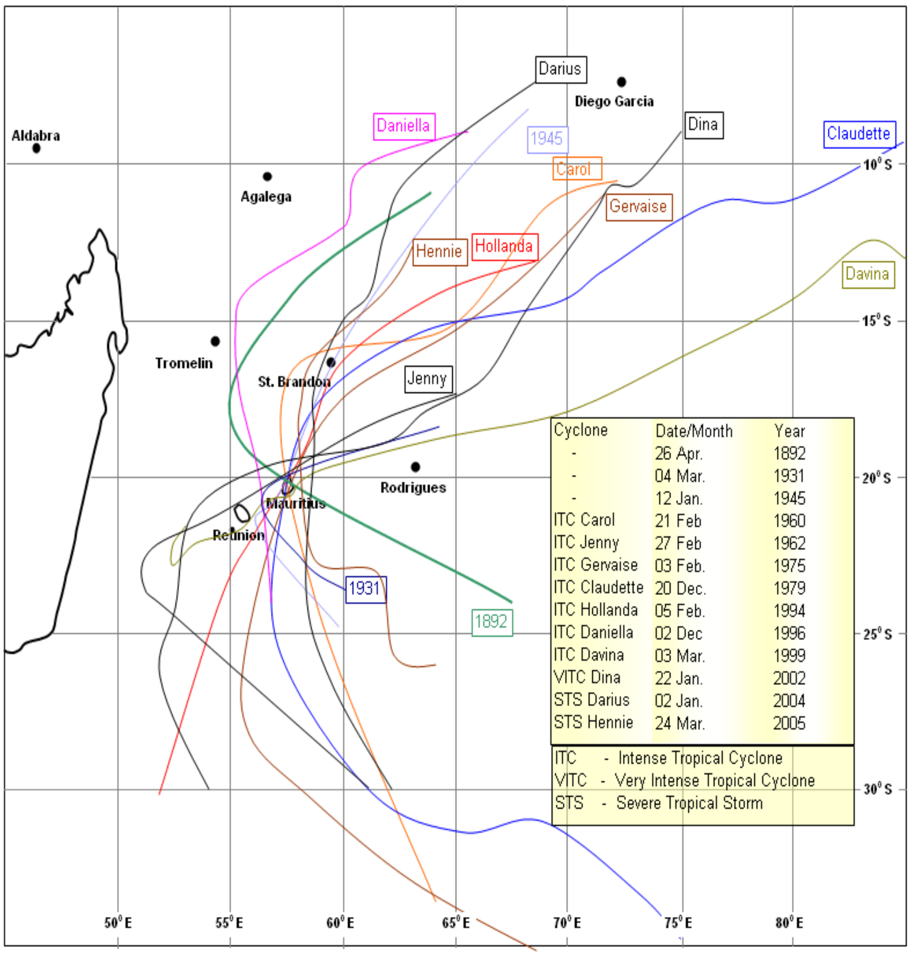


Figure 2-8: Trajectories of most severe tropical cyclones affecting Mauritius from 1892-2005, with 2004-2008 cyclones presented in the text (MMS, 2014d).

2.4.1.3. Inter Tropical Convergence Zone (ITCZ)

The ITCZ is considered a meteorological boundary between the northern and southern hemispheres. It is also regarded as a boundary where the North West monsoon winds (westerlies) and the South East Trade winds (easterlies) converge. Very little transfer of mass and energy occurs across the ITZC in the atmosphere and the commonly accepted opinion is that the ITCZ arranges itself in such a way that the thermal processes taking place in the atmosphere achieve equilibrium on each side of it. Subsequently, the ITCZ affects the weather in Mauritius in the summer months of January to February and occasionally December and March, during its southerly seasonal migration (Fowdur *et al*., 2014).

The ITCZ is closest to Mauritius between January and March when warm season depressions affect the island by causing high rainfall (Staub *et al.*, 2014). Under the influence of the ITCZ, even the west coast which is sheltered from the south-easterly trade winds experiences convection showers. Although the month of April in Mauritius is known as the transitional month at the end summer, wet-season conditions and higher rainfall persist on the elevated central plateau and the eastern mountains (Padya, 1989; Staub *et al*., 2014). The winter months, May to October, are drier than the summer months as the ITCZ is located north of the equator.

2.4.1.4. Cold fronts

Two air-masses have been recognised in the southern Indian Ocean: the Maritime Tropical air mass to the north over the warmer seas and the Maritime Polar air mass over the cooler waters to the south of the Oceanic convergence. Each air mass has distinct characteristics from the source region and the boundary between the two distinct air masses is constantly moving. An active advancing cold front is when a general northward movement of the boundary between the maritime polar and maritime tropical air masses occurs. Such occurrences of colder air originating in the far south often reach Mauritius, except during the warmer parts of summer, namely January and February (Fowdur *et al*., 2014). Throughout the winter months (May to October), the passage of cold fronts is generally associated with an increase in convective activity and subsequent rainfall over Mauritius, particularly in areas with orographic characteristics (Padya, 1989).

2.4.1.5. Anti-cyclones

At the longitude on which Mauritius is found, the sub-tropical belts of anticyclones are situated near 30˚S in the winter, retracting pole-ward to about 35˚S in the summer. The strongest anticyclones occurring in winter have a central pressure exceeding 1040 HPa (Fowdur *et al*., 2014). During the winter period the majority of the rainfall is caused by the resultant advection from orographic uplift due to the presence of anticyclones (Padya, 1989).

2.4.1.6. Sea breezes

Sea-breezes occur when the land heats a layer of air close to the ground surface causing the warm air to rise. As this process continues, a deeper and warmer layer develops over the land surface. Eventually, the temperature of the surface layer has risen sufficiently to produce a significantly lower pressure over the land than over the sea which experiences a relatively higher pressure. The subsequent pressure difference initiates a breeze from the sea to the land. Fowdur *et al*. (2014) explain that as a rule, in Mauritius, a 'prevailing' east-south-east wind is subject to its own synoptic space and time variation. Therefore, over the east and south coastal area, the sea breeze will help to accelerate the low-level trades and will affect their direction. On the eastern side of the country, the winds produced by sea-breeze can be felt strengthening during the mid-morning and continues blowing as long as the land is kept warmer than the sea by insolation. Occasionally, the whole stretch of sloping land in the south and south-east, continuing three to four kilometres inland, is shaded by clouds the entire day and precipitation can be experienced (Fowdur *et al*., 2014).

2.4.1.7. Easterly waves perturbations in the lower troposphere

Perturbations of the lower troposphere, give rise to heavy rainfall over parts of Mauritius during the summer months, regardless of the depth of the surface easterlies. Perturbations of this nature, even when characterised as shallow, have a distinct wave-like character and are commonly encountered in the south-west Indian Ocean, between 70˚E and 50˚E. Winds related with these perturbations range in the order of 5-8ms^{-1} The thunderstorms develop from the perturbations generally cause considerable amount of rainfall (Fowdur *et al*., 2014).

2.4.1.8. Cloud masses and upper level lows

Frequently, Mauritius and its neighbouring islands also experience cloudy and rainy conditions without an identifiable synoptic system being detected. In such cases, satellite imagery depict the cloud system as either small clouds patches (2 degrees or so in diameter) in a line with an almost meridional (north-south) orientation or large masses (ten degrees in width). These air masses have varying degrees of activity. On occasion heavy rainfall and active thunderstorms take place during these synoptically unexplained weather systems (Fowdur *et al*., 2014).

2.4.2. Rainfall

2.4.2.1. Mean annual rainfall depth and spatial variations

Rainfall on the island is seasonal and spatially variable with a wet season from November to April and a dry season from May to October. Annual mean rainfall for the island is approximately 2112mm, with 70-79% being recorded in the rainy summer season (Le Roux, 2005; Nigel & Rughooputh, 2010b). The long-term mean annual rainfall indicates that the eastern side of the island receives approximately 1200mm rainfall, with the elevated central receiving up to 4000mm, and only 600mm on the western coast (WRU, 2007). Figure 2-9, taken from Nigel (2011) below shows a rainfall map for Mauritius produced by Seul (1999) using data consisting of the mean annual rainfall over a period of 30 years (1961-1990) for 194 gauging stations. It should be noted that the number of rainfall stations on Mauritius has since increased to in excess of 256 stations (MMS, 2014a).

Mauritius as a land mass enhances rainfall averages across the island. The raised interior of the island is responsible for the noticeable spatial difference in rainfall from east to west on the island.

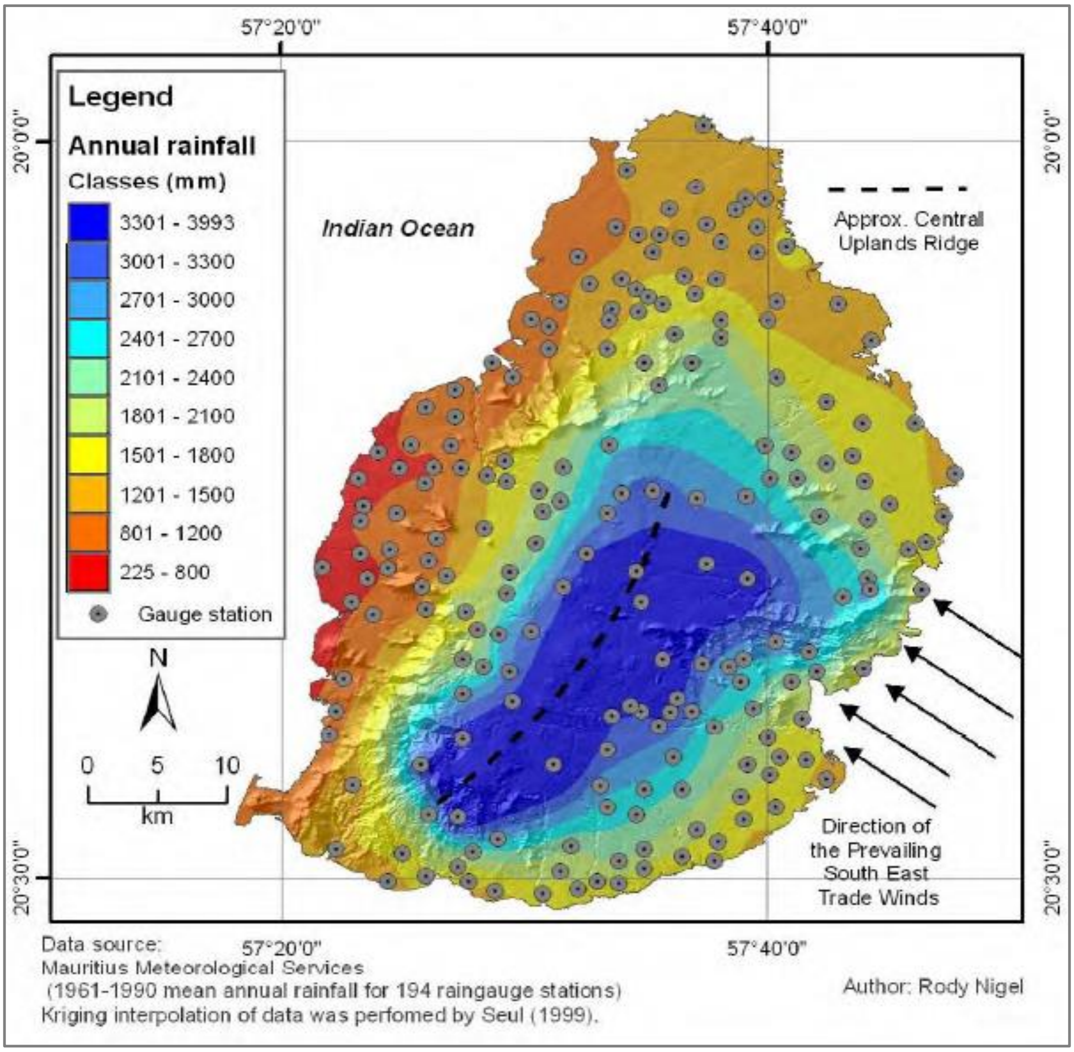


Figure 2-9: Mean rainfall (1961-1990) and mean annual rainfall amount (Nigel, 2011)

Spatial variations of the rainfall on Mauritius are attributed to orography created by the eastern mountain ranges and the 'ridges' of the central plateau. The plateau acts as a barrier to the South East Trade Wind which divides the plateau into two regions, the windward and leeward regions. Higher totals of rainfall are received on the windward side and a 'rainshadow' is evident on the leeward side (Nigel, 2011). The western part shows the effect of the depletion of water vapour on the windward slopes, with the descent of the air of the leeward slopes (Fowdur *et al.*, 2014). Hence, Padya (1989) noted that the eastern and southern regions have fairly similar rainfall patterns throughout the year as they receive the oceanic air with its high moisture content intact, benefiting from the forced uplift resulting from its passage over the sloping lands and hills. Rainfall days a year are always greater than 200 for zones where the annual rainfall amounts exceeds 2000mm and decreases progressively in drier zones to reach about 60 rainfall days a year on the western coast (Nigel, 2011). Consequently, it is the combination of the orographic effect in conjunction with the frictional effect of air movements that is responsible for the local rainfall on the island (Padya, 1989).

The effect of relief on the spatial distribution of rainfall across Mauritius is shown in Figure 2-10, where an exaggerated vertical scale section is made on a cross-section from Beau Vallon on the south-east coast to Medine in the west. This reveals the striking effect that relief has on the spatial rainfall distribution; with the transect lying roughly in the direction of the prevailing south-easterly trade winds. The curve shows that the annual rainfall is about 1200mm on the south-east coast and increasing to over 4000mm ahead of the highest ground of the Central Plateau, then slowly decreases to around 600mm at Medine in the west making the asymmetry of the rainfall distribution across the island strongly apparent (Rughooputh, 1997). Therefore, rainfall significantly increases from the coast to the interior. This rainfall gradient is due to the orographic effects caused by the south-eastern mountain range and the central uplands (Fowdur *et al.,* 2006).

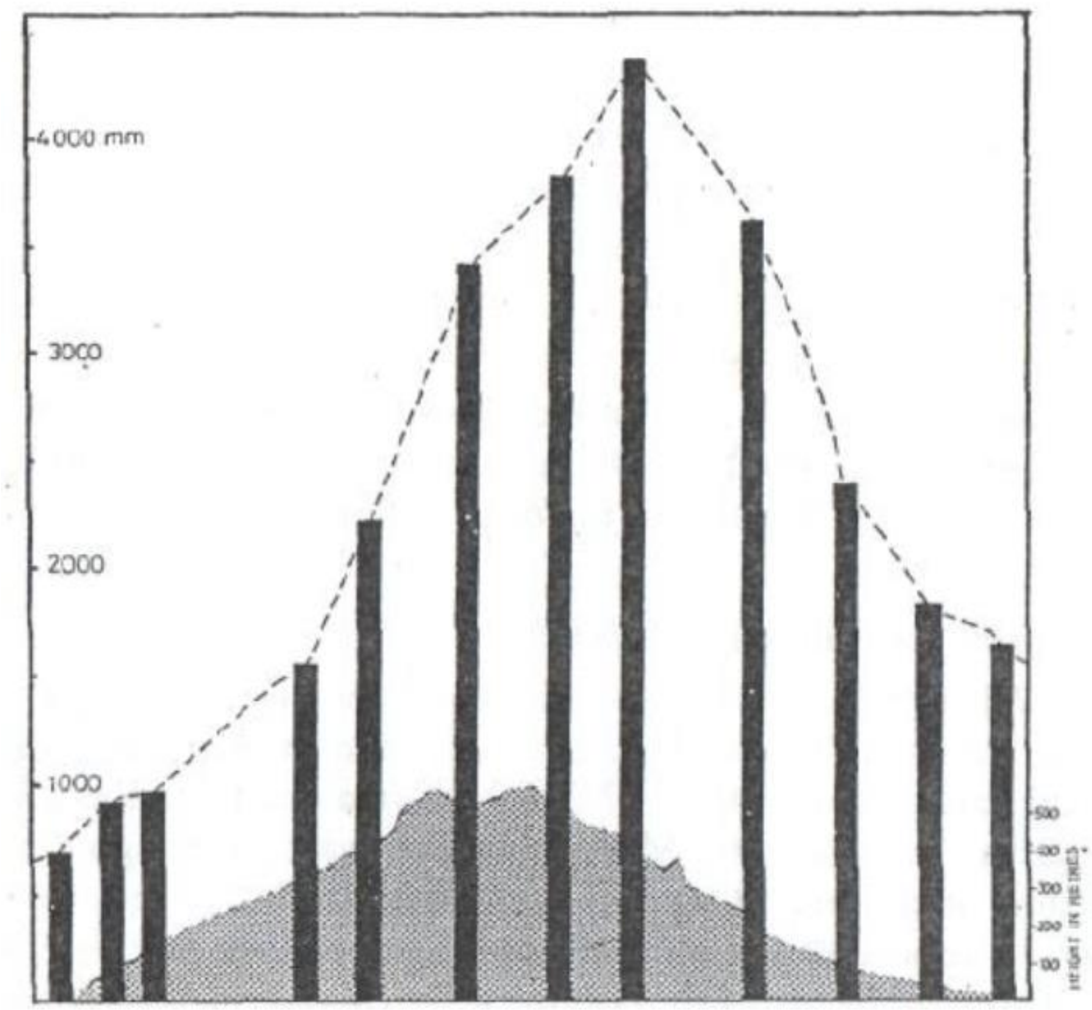


Figure 2-10: The effect of relief on rainfall with annual rainfall along a 40km ESE-WNW line at selected sites (Padya, 1989)

2.4.2.2. Inter- and intra-annual variations in rainfall

Rainfall on the island is of great importance as it is the only source of water for rivers, agriculture and human needs as water from the ocean is not exploited for the population. The inter-annual variations in rainfall amount are substantial due to the passage of cyclones, which could increase the “normal” monthly rainfall amount received by 2-3 times (Willaime, 1984; Padya 1989, Nigel 2011).

Annually, the wet season occurs between November until the end of April, with February being both the hottest and wettest month, and the dry season from May to October, with October being the driest month (Proag, 1995; Nigel & Rughooputh, 2010b). Approximately 60-70% of the mean annual rainfall is received during summer, and 30% of the mean annual rainfall is received during winter thus rainfall is seasonal (Nigel & Rughooputh, 2010b). Nearly 40% of the annual total rainfall falls between January and March, coinciding with the southward migration of the inter-tropical convergence zones towards the subtropical latitudes and the occurrence of tropical cyclones (Staub *et al*., 2014). Rainfall on the island most commonly comes from the orographic lifting of the moisture found around the circulation of weather systems that move over the island as well as the occasional cyclones and depressions (Dhurmea *et al*., 2009).

In addition to these seasonal movements, the summer period is also influenced by tropical cyclones, most of which do not make landfall (Padya, 1989). The winter season is subjected to the south easterly trade winds and frontal systems (Padya, 1989). Potential soil erosion is highest during the early part of the wet season when there is high rainfall present and the vegetation cover is not yet adequate to protect the soil from erosion (Morgan, 2005). Drought conditions can be experienced if the island lies outside the path of these tropical depressions (Proag, 1995).

2.4.3. Climate classification

Mauritius’ climate is described by Proag (1995) and Saddul (1995) as humid, subtropical and maritime as a result of its location at 20˚S latitude, small size, lack of extreme elevations and distance to continents. Owing to variations in diurnal exposure, elevation and distance from the sea, a succession of island scale climatic regions or microclimates exist (Nigel, 2011). Notwithstanding the small size of the island, Padya (1989) identified at least 27 microclimates caused by substantial variations in the climatic characteristics of Mauritius. Hence, the raised topography of the island results in orographic lifting occurring, contributing to the creation of several micro-climates (Nigel & Rughooputh, 2010a). Utilising the variations in temperatures and rainfall from one region to another allows for climatic subdivisions of the island into three general zones: subhumid, humid and superhumid. The subhumid zone is restricted to low altitudes on the western coast and the northern plains and receives less than 1250mm per annum. The humid region receives precipitation between 1250mm and 2000mm per annum and characterises the intermediate altitudes in the west and north as well as the low altitudes in the east and south, and the superhumid region which prevails above approximately 400m (450m in the west) where rainfall exceeds 2000mm per annum. Humid regions have a rainfall evaporation balance, while evapotranspiration exceeds precipitation in the subhumid regions (Le Roux *et al*., 2005).

The microclimate zones are attributable to orographic lifting: 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 (Fowdur *et al*., 2006; Nigel & Rughooputh, 2010a). On average, the humidity across the island is 80% which remains constant throughout the year. Humidity is higher in the southern central regions, which consists of the central plateau, the highlands and lowest near the coast. The microclimatic zones and humidity influences the indigenous vegetation within regions (Anderson, 2012).

2.5. Land use and vegetation

Mauritius was described by 17th century travellers as an island with tropical forests and jungle from mountain tops to the sea (Parish & Feillafe, 1965). The present land use and vegetation has been heavily influenced by people (Nigel, 2011). Prior to colonization in 1638, the island was completely covered by wet and dry evergreen forests, shrub and plain savanna. However, subsequent to human colonization approximately 95% of the native vegetation area has been removed, including the complete destruction of the native palm savannah. There are 6 forest-living native passerines remaining on the island that are protected by legislation. The main vegetation remaining on the mountain slopes in the south-western and central-eastern is the moist montante tropical evergreen forest, as well as dry forests which dominate the rain shadow regions (Safford, 1997). Due to inadequate regeneration of the native vegetation in conjunction with the high invasion rate of the exotic vegetation and urbanisation has left the native vegetation is a stressed state (Lorence & Sussman, 1986) evident in the tiny isolated fragments of vegetation remaining today. A study done by Saddul (2002) indicated that 55% of the island’s land was classified as cultivated, 27% was forest, 11% was scrub, 6% was urbanized and the remaining 1% accounting for miscellaneous land uses.

Vast amounts of Mauritius's indigenous vegetation, such as ebony forests, bois d' olive and aloes have been removed to accommodate the extensive cultivations which occur on the island, including sugarcane, tea, vegetables and fruit plantations (Nigel & Rughooputh, 2010b). In 2012, 85% of the arable land (approximately 69000ha) was used for sugarcane cultivation (Soobadar & Kwong, 2012), despite the Mauritian government promoting a policy of agricultural diversification (Le Roux, 2005). The Mauritian economy is heavily dependent upon the export of sugarcane and its bye-products, hence the high percentage of cultivation. Soil loss under sugarcane is, however, relatively low compared to other vegetables as the soil under the sugarcane is not disturbed during harvest and a dense cover is provided within less than two months after regrowth or planting (Le Roux *et al.,* 2005). Good land management is vital as erosion hazard maps show that potential soil erosion increases greatly when the canopy cover of sugarcane decreases (Kremer, 2000).

The two regions under investigation in this project have noticeably different types and densities of vegetation cover due to the different rainfall regimes they are subjected to. The western region (receiving approximately 600mm annually) where the automatic weather stations of Albion and Beaux Songes are situated is comprised of shrub-like, grassy and sparse vegetation. The central interior (receiving approximately 4000mm annually) where Arnaud, Monbois, Grand Bassin and Trou aux Cerfs are situated has discernibly denser and lusher vegetation. The difference in vegetation cover and density is evident from Figure 2-11 and Figure 2-12. These photographs were taken on the same day in June 2010.

Figure 2-11: Landscape near the station at Albion (Photo taken 28 June 2010)

Figure 2-12: Landscape near Trou aux Cerfs (Photo taken 28 June 2010)

This chapter has provided background information for this study, including information on the geological history, geomorphology and topography of the island. The vegetation and land use occurring on the island was also presented. A description of the climate and weather affecting the island has been included, with particular emphasis on the rainfall and the eight weather systems prevailing over the island as identified by Fowdur *et al*. (2014). The unique pedology and hydrology of the island was also briefly discussed to provide the context in which the next chapter will continue. To summarise, Mauritius is a diverse island in terms of a number of factors including topography, climate and weather as well as location, resulting in the development of several microclimates. These microclimatic areas are reflected in the diversity of the natural vegetation across the island. The next chapter will provide the methods and station data used in this project.

Chapter 3 : Station Data and Methodology

The purpose of this chapter is to outline the methods and materials used for this project. It describes the research design followed in the analysis of the data, as well as highlighting some of the limitations incurred in the methodology. In addition, this chapter presents the equipment used in obtaining the data used in this project, and lastly the analyses that were undertaken. As presented in chapter one, the objectives that were set out are to:

- Identify the top twenty erosive events (based on the 'total kinetic energy generated') between 2004 to 2008 at six automated weather stations situated in the western and central regions of the island.
- Describe the general rainfall and climatological characteristics of the top twenty erosive events at each automated weather station;
- Provide a comprehensive intra-storm analysis of each event;
- Contrast the spatial and temporal differences between the automated weather stations.

3.1. Station data

Mauritius has in excess of 256 weather stations spread across the island, covering a total area of 1860km^2 (Proag, 1995). Monitoring the climate variables on Mauritius is done using three different types of weather stations; namely agro-meteorological stations, climatological stations and synoptic stations. Agro-meteorological stations monitor and record standard climatological data which relates to agriculture, livestock breeding and forestry. Synoptic stations make meteorological weather observations including all meteorological parameters at fixed time intervals and their recorded observations are exchanged at the Global Telecommunication System of the World Meteorological Organisations. The ordinary climatological stations (approximately 30 automatic weather stations) record rainfall and well as other climatic parameters such as evaporation, humidity, sunshine duration, temperature and wind are measured by these stations (MMS, 2014a).

To investigate the intra-storm attributes of the erosive events at the respective stations on Mauritius, high resolution automatic rainfall data from six stations for the period 01/01/2004 to 31/12/2008 (5 years) were provided by the Mauritius Meteorological Services (MMS) (Figure 3-1). The area of interest for this project includes the central interior and the west coast. Two sites on the west coast of the island fall within the rainshadow, one on the coast at Albion (12m.a.s.l) and one approximately 4km from the coastline at Beaux Songes (225m.a.s.l) (Table 3 – 1) were selected. Data were also obtained from rainfall gauges on the Central Plateau area at Arnaud (576m.a.s.l), Monbois (590m.a.s.l), Grand Bassin (605m.a.s.l) and Trou aux Cerfs (614m.a.s.l) (Table 3 – 1).

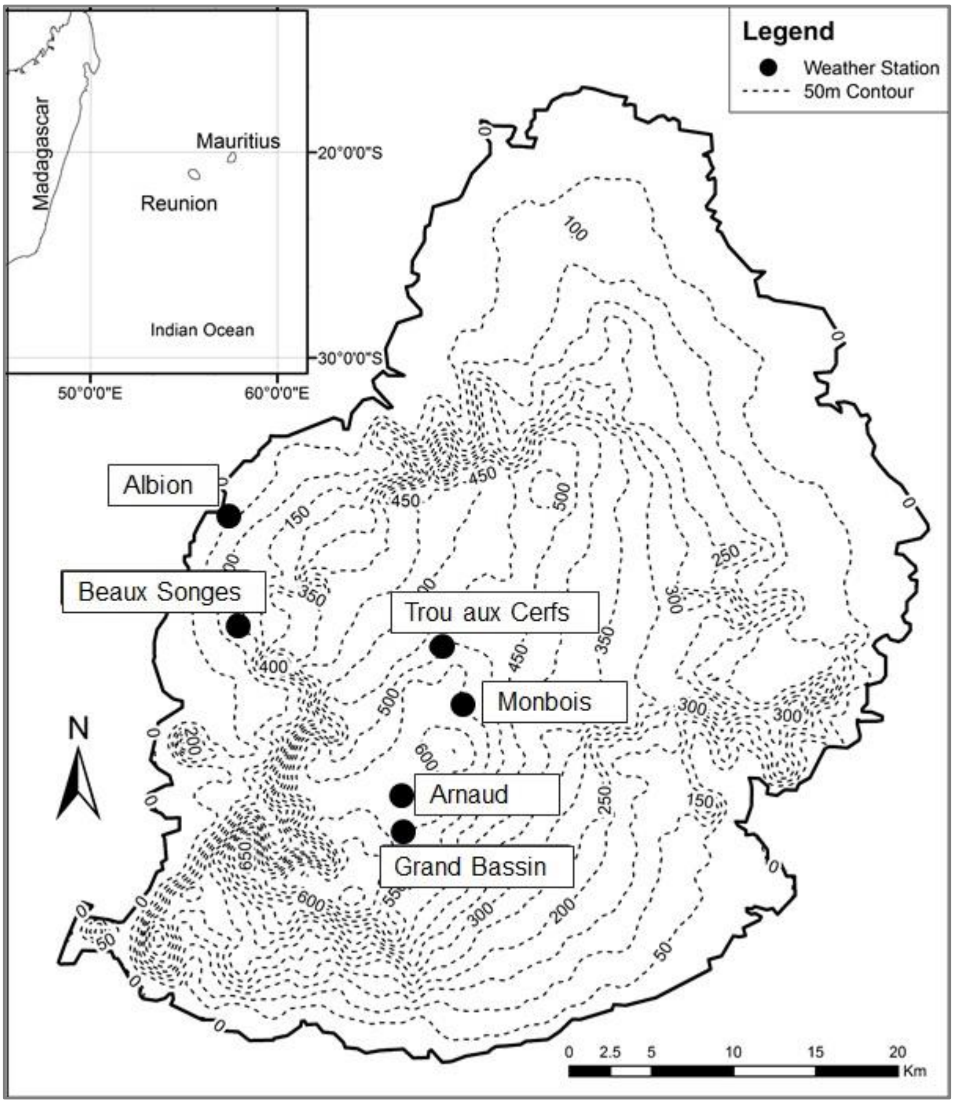


Figure 3-1: Location of selected automated weather stations.

The automatic weather stations used for this study are located at different altitudes to account for differences in rainfall and associated rainfall erosivity due to orographic lifting (Table 3-1). Therefore, the analysis of the intra-storm attributes conducted at the two climatological extremes of Mauritius provides the best coverage of the area of interest from the available data. As the eastern portion of the island (or elsewhere) did not contain any automated weather stations at the time of the study, no data were available to complete the altitudinal cross-section. However, the data that were made available sufficiently covered the driest and wettest rainfall regions of the island.

Table 3-1: Location, altitude and climatic information of the automatic weather stations (also see Anderson, 2012; Mongwa, 2012; Nel *et al.*, 2012)

Station	Location	Latitude	Longitude	Altitude (above sea level)	Rainfall Region
Albion	West Coast	20˚12.75’ S	57˚24.0’ E	12m	Semi-arid
Beaux Songes	West Coast	20˚16.68’ S	57˚24.48’ E	225m	Semi-arid
Arnaud	Central Plateau	20˚22.8’ S	57˚29.52’ E	576m	Super-humid
Monbois	Central Plateau	20˚19.8’ S	57˚31.68’ E	590m	Humid
Grand Bassin	Central Plateau	20˚24.0’ S	57˚29.52’ E	605m	Super-humid
Trou aux Cerfs	Central Plateau	20˚17.82’ S	57˚31.02’ E	614m	Super-humid

Two previous rainfall studies were undertaken on Mauritius using the data sets. Anderson (2012) found a difference in rainfall erosivity experienced on the interior and rain-shadowed west coast and reported that stations on the west coast recorded 25% of the erosivity experienced by the stations in the elevated central interior. Large differences in the number of erosive events, rainfall depth, erosive rainfall totals, seasonality and annual erosivity total were noted (Anderson, 2012). The study by Anderson (2012) concluded that the changes in erosivity occurred with changes in rainfall intensities caused by the orographic effect of the interior. The other study was undertaken by Mongwa (2012) who found that erosive events on the west coast and central plateau are remarkably different with regards to frequency, total rainfall generated, duration, total kinetic energy and total erosivity of individual events. Yet the mean kinetic energy, mean and maximum rainfall erosivity (EI_{30}) and maximum intensities (I_{30}) from the individual erosive events do not show this distinct differentiation. Both studies (Anderson, 2012; Mongwa, 2012) speculated on the influence that the elevated central interior has on the spatial and temporal distribution of rainfall across the island. Thus, by incorporating another rainfall station and analysing the intra-storm attributes of the erosive events, this study attempts to highlight and also explain the anomalies identified in the previous studies.

3.2. Research instruments

Rainfall data with a high temporal resolution are necessary for accurate calculations of rainfall erosivity (Yin *et al*., 2007). Rainfall records used in this project were collected at the stations by the Mauritius Meteorological Services at six minute intervals using the Précis-Mécanique R01-3030 Pluviometer with tipping bucket (Figure 3-2). Automated weather stations are positioned away from any other surface to avoid the readings being influenced by additional rain splash from other nearby structures as well as limiting any vibrations from nearby activities or structure from influencing the readings. Total rainfall amounts every six minutes are downloaded by the system into a Microsoft Excel file. The weather station's tipping bucket contains deflectors which are able to reduce losses of rainfall received during high intensities and also record continuously in both wet and dry conditions. The bowl has a diameter of 230mm, collecting area of 1000cm^2 and a thin rim which minimizes rainfall splash as well as other weather related errors such as wind, wetting and evaporation induced losses (Lanza *et al.,* 2005; Alexandropoulos & Lacombe, 2006).

Figure 3-2: Example of the automatic rainfall bucket used by the Mauritius Meteorological Service (MMS) to record rainfall data. Also see Anderson (2012) and Mongwa (2012).

Each separate weather station recorded information at the site including rainfall totals, rainfall intensity (rainfall received every 6minutes), temperature, wind speed and pressure as a separate Microsoft Excel file on a daily basis. Individual files were subsequently "stitched" together so that all the months for a single station are consolidated into a single Microsoft Excel spreadsheet, and all the years for each station is placed into a single Microsoft Excel file for convenience (Nel, pers comm). Rainfall and non-rainfall days were separated and non-rainfall days were then removed from the data set. For this project, a rainfall day was fixed as a day which received ≥1mm of rainfall during a 24 hour period.

For calculation purposes, erosive rainfall events were separated from non-erosive events the latter which are subsequently omitted. This is routinely done as it enormously eases the calculation of rainfall erosivity, particularly in terms of reading and digitising rainfall charts (Xie *et al.,* 2002). Wischmeier & Smith (1978) suggested that rains of less than 12.5mm should be omitted in erosion index computations (these parameters will be discussed later in further detail). Although natural intensity variations are present from one event to another, consensus prevails between various studies (Stocking & Elwell, 1976; Renard & Freimund, 1994; Xie *et al*., 2002) that a maximum intensity of 25mm/h can be used as a practical threshold for separating erosive and non-erosive rains. If non-erosive events are counted, the rainfall erosivity could be either over- or under- estimated (Xie *et al.,* 2002). Hence, the objective of determining a practical threshold is to omit non-erosive rains to reduce calculation requirements while obtaining the most accurate possible value for erosivity (Xie *et al*., 2002).

3.3. Missing, unreliable and incomplete data

The following records were incomplete at all the stations records; June and July records from 2004, November and December from 2006, and January, February and March 2007. However, as these records were unavailable from all the stations, direct inter-station comparisons could still be made as those data do not affect the scope of this project (also see Anderson, 2012; Mongwa, 2012).

As rainfall and its intensity is natural highly variable, no statistical extrapolation methods were used to fill gaps created by missing data. Extrapolating the rainfall data could lead to inaccurate results by over-estimating the number of erosive rainfall events and thus decreasing the accuracy of the results presented in the next chapter. Additionally, several rainfall events were excluded from the data as the rainfall recorded during the event was extraordinarily high and can be attributed to errors in the equipment used to collect the data. These particular events were considered as anomalous as triple digit rainfall totals were recorded within a 6-minute period with no other rainfall recorded within several hours before or after the event (see also Anderson, 2012; Mongwa, 2012; Nel *et al.,* 2012; 2013).

3.4. Objective One: Identification of the top twenty events

3.4.1. Identifying an erosive event

Rainfall data in this project were separated into erosive events to calculate rainfall erosivity (see also Anderson, 2012; Mongwa, 2012; Nel *et al.*, 2012; 2013). The definition of an erosive event has been well recognized within the literature. Parameters were established for this project in order to determine an erosive event. Wischmeier & Smith (1958) specified that for substantial amounts of soil erosion to occur rainfall intensities larger than 25mm/h are required. Stocking & Elwell (1976) categorised a distinct erosive event when the total rainfall exceeds 12.5mm within a 30 minute period, with a maximum 5-minute intensity exceeding 25mm/h and the event isolated by a 2 hour rain free period between erosive events. This definition was used by Nel (2007), Nel & Sumner (2007) and Nel *et al.* (2010) to identify erosive events in the KwaZulu Natal, Drakensberg of South Africa.

As rainfall on Mauritius is logged every 6 minutes the definition by Stocking & Elwell (1976) was adjusted so that rainfall events are considered to have the potential to erode soil on Mauritius when the total rainfall exceeds 12.5mm within a 30 minute period, maximum 6-minute intensity exceeding 30mm/h and is isolated by at least a 2 hour rain free period (see also Nel *et al,* 2012; 2013). An event was also classified as being erosive if 6.3mm of rain occurred within 15 minutes (Wischmeier & Smith, 1978; Diodato, 2005; Angulo-Martínez & Beguería, 2009). The definitions have also been used in numerous studies including Nel *et al.* (2012), Anderson (2012); Mongwa (2012) and Nel *et al.* (2013) to identify erosive events in Mauritius. After applying this definition, the data series from the 6 automated weather stations used in this study, over the five year period, contained 444 erosive rainfall events.

3.4.2. Determining rainfall event kinetic energy

Rainfall intensity can be measured directly, however measurements of kinetic energy and raindrop sizes are often unavailable, hence the reliance on the empirical relationships between rainfall intensity and kinetic energy (Nel & Sumner, 2007). A number of equations have been established to calculate kinetic energy from rainfall intensity (van Dijk *et al*., 2002; Nel *et al.*, 2012; Nel *et al.,* 2013). Wischmeier & Smith (1958) used measurements of drop size characteristics as well as terminal velocity to derive the relationship between rainfall intensity and kinetic energy. The relationship suggested by Wischmeier & Smith is a logarithmic function in the form:

$KE = 11.87 + 8.73Log10R$ where the intensity is in mm/h. (1)

Studies in Zimbabwe done by Elwell & Stocking (1973) have shown that for subtropical climates the kinetic energy of rainfall can be predicted by the following equation:

$KE = (29.82 - 127.51/I)$ in J m^{-2} m^{-1} where the intensity is in mm/h. (2)

This equation was also used in the SLEMSA (Soil Loss Estimation for Southern Africa). Following a critical appraisal of the literature established on the relationship rainfall intensity-kinetic energy (R – KE), based on average parameter values which were derived from the best datasets, van Dijk *et al*. (2002) provided the following equation to predict storm kinetic energy content from rainfall intensity data:

$KE = 28.3[1 - 0.52\,exp\,(-.042\,R)$ where the intensity *R* is in mm/h. (3)

Consequently, for comparison with other studies on Mauritius, either of the abovementioned equations would be sufficient for estimating the kinetic energy contents. In order to provide for consistency with global studies, the equation (3) by van Dijk *et al*. (2002) was used here to assess the 6-minute incremental kinetic energy content derived from rainfall intensity.

A uniform drop size distribution is assumed during the analysis of kinetic energy. In order to calculate the total event kinetic energy (KE) produced during each individual erosive rainfall event (J m^{-2}), the 6-minute kinetic energy content, multiplied by the quantity of rain (mm) falling in that specific 6 minutes to give the 6-minute kinetic energy. Each of the 6-minute kinetic energy values generated during the event is then summed to give the total kinetic energy during each individual event (Nel, 2007; Nel *et al*., 2013). Wischmeier & Smith (1978) determined that erosivity can be determined by the product (EI_{30}) of the total kinetic energy (KE) of the storm multiplied by its maximum 30-minute intensity (I_{30}). This equation has been used both globally and in the Mauritian context as part of the Revised Universal Soil Loss Equation (RUSLE) to assess the spatial distribution of erosivity (see also Le Roux, 2005; Le Roux *et al.*, 2005; Nigel, 2011; Nel *et al*., 2012; 2013). To ensure consistency with previous erosivity studies in Mauritius, the rainfall erosivity potential was determined by the product (EI_{30}) of each erosive event (J mm m^{-2} h^{-1}).

To investigate the intra-storm changes in rainfall attributed received from an erosive rainfall event, the 20 events with the highest 'total kinetic energy generated' at each station were used for analysis, hence a total of 120 events are analysed in detail.

3.5. Objective Two: General rainfall, climatological characteristics and weather circulation patterns associated with the top twenty erosive events

The six automated weather stations can be placed into two broad groups based upon their general rainfall and other climatological characteristics. In the first group are Albion and Beaux Songes, and in the second group, are Arnaud, Trou aux Cerfs, Grand Bassin and Monbois. In an attempt to discover the role that an elevated topography has on the intra-storm attributes of the events, comparisons were made between the two groups. Additionally, comparisons between the stations within in the two groups were investigated. The following characteristics were identified for each of the top twenty erosive events at each station and utilised to analyse the data:

- Rainfall depth (mm),
- Rainfall event duration (minutes),
- Seasonality and date of event
- Maximum Rainfall Intensity (I_6) and (I_{30})
- Erosivity (J mm m^{-2} h^{-1})
- Kinetic Energy Content (J m^{-2})
- Means including storm depth, storm duration, kinetic energy content and erosivity

There are several weather systems of varying scales and amplitudes that affect the island's weather due to its location and topography (Fowdur *et al.*, 2014; Staub *et al.,* 2014). Unfortunately, in the absence of detailed synoptic data it was not possible to link the erosive events directly to the exact synoptic weather systems occurring during the time of the event. However, some assumptions could be made using the climatological information available from the Mauritius Meteorological Services Monthly Bulletins of Climatological Summaries, Mauritius Meteorological Services website (MMS, 2014a) as well as the Météo-France Réunion (Météo-France, 2015) website. The table below (Table 3-2) provides a summary of the synoptic circulations or weather systems in Mauritius according to Fowdur *et al*. (2014). A representative symbol is used for each weather system or synoptic circulations. Using

Fowdur *et al*. (2014) weather systems in conjunction with synoptic data available from Météo-France (2015) and Mauritius Meteorological Services (MMS, 2014a) websites an attempt was made to classify the erosive events into potential weather systems. The lack of island and event scale synoptic data was a limitation to classifying the weather systems. However, from the data available, an effort has been made to classify the events in order to understand the event scale synoptics.

Table 3-2: Weather Systems in Mauritius (Fowdur *et al.,* 2014) as representative symbols applied to the erosive events

Synoptic circulation or Weather System in Mauritius (Fowdur *et al.*, 2014)	**Representative symbol**
Windfields over Mauritius	WF
Cyclonic Activity	C
Intertropical Convergence Zone	ITCZ
Cold fronts	CF
Anticyclones	AC
Sea breezes	SB
Easterly Waves Perturbations in the Lower Troposphere	EW
Cloud Masses and Upper Level Lows	CM
Weather system unknown	U

3.6. Objective Three: Intra-storm analysis of each event

The intra-storm analysis was undertaken based upon the methodology developed and used by Nel (2007). In order to conduct the intra-storm analysis the top twenty events with the highest 'total kinetic energy generated' at each station were chosen from the available data. Rainfall kinetic energy (KE) represents the total energy available to detach and transport soil particles (Salles *et al.,* 2002; van Dijk *et al.,* 2002; Salako, 2007). While Nel (2007) utilised ten erosive events at four automated weather stations in the Drakensberg mountains, KwaZulu Natal, South Africa, this study considered the top twenty erosive events at 6 automated weather stations given the longer duration (2004 to 2008) of the available data. Hence, a total of 120 erosive events were analysed in detail. For the purpose of this study the top twenty erosive events at each station will be referred to as the erosive events or simply the events.

3.6.1. Intra-storm distribution of rainfall depth

3.6.1.1. Storm rainfall depth and cumulative rainfall generated over time by the erosive events

Following the equation by van Dijk *et al*. (2002), the above formula (3), the six-minute kinetic energy content (KE) of each individual event at each station was calculated and the cumulative kinetic energy as a percentage was plotted. This was done in order to identify the distribution pattern of the cumulative total kinetic content of the rainfall over time. Following the method established by Nel (2007), a well-defined distribution of cumulative total kinetic content of rainfall over time was anticipated. The graph was subsequently be used to identify the time in minutes at which the stations would have received approximately 80% of all the potential kinetic energy content generated by the storm. This represented the maximum (duration) threshold over which all the extreme events would be analysed in further detail. Once that point has been identified, the six-minute increment rainfall depth of each individual storm measured at each station was plotted for the analysis of the intra-event temporal distribution of the rainfall and further comparative reasons.

3.6.1.2. Storm rainfall depth as a function of storm duration

To test for rainfall generation as a function of rainfall duration, the six-minute rainfall depth of each individual event measured at each station was plotted as a percentage of rainfall duration. Each erosive event was divided into quartiles namely: First Quartile (Q1), Second Quartile (Q2), Third Quartile (Q3) and Fourth Quartile (Q4). Due to the high variability in event duration, all the storms were plotted as a percentage of the rainfall duration in order to conduct a comparative analysis between the quartiles and identify the point during the storm when the peak rainfall was generated. The rainfall variability of each event was also highlighted in this process.

3.6.2. Intra-storm distribution of extreme and peak rainfall intensity

3.6.2.1. Timing of the extreme rainfall intensity generated by the erosive events

Following the modifed definition of an erosive event by Stocking & Elwell (1976), rainfall events on Mauritius have the potential to erode soil when the total rainfall exceeds 12.5mm within a 30 minute period with a maximum 6-minute intensity exceeding 30mm/h and a 2 hour rain free interval. Thus, the 120 erosive events analysed have a maximum six-minute intensity exceeding 30mm/h. To test at what stage within an erosive event the rainfall intensity has the potential to exceed the infiltration rates and become erosive, the intra-storm variations of the six-minute intensity exceeding 30mm/h were considered (adapted from Stocking & Elwell, 1976).

3.6.2.2. Timing of extreme rainfall intensity as a function of storm duration

To test for the timing of the extreme rainfall intensities (above 30mm/h) as a function of rainfall duration, all the extreme intensities of each individual event measured at each station were plotted as a percentage of rainfall duration. Each event is divided into quartiles, Q1 through Q4 as explained above. This was done to identify when peak rainfall intensity was recorded. The point was considered important as Parsons & Stone (2006) established that a constant-intensity erosive event yields lower soil loss than the varying-intensity events, and sediment eroded from the constant-intensity event had lower clay content than that from the varying-intensity erosive events. Moore (1979) indicated that under natural event conditions the peak sediment transportation coincides with the peaks in rainfall intensities. Stocking & Elwell (1976) also found that the magnitude of peak intensities is most critical to the erosion process. A study by Parsons & Stone (2006) found that events which had their peak intensities towards the end of the event duration had the highest peaks in runoff rates, soil loss and displaced the largest particle size in the eroded soil and therefore linear relationship between rainfall intensity and runoff is generally assumed.

3.7. Objective Four: Contrast of spatial and temporal differences between the automated weather stations

As a result of the topography of Mauritius, well-defined spatial trends in relation to rainfall across Mauritius are acknowledged in previous studies (Dhurmea *et al*., 2009; Nel *et al.,* 2012; 2013; Staub *et al.,* 2014). Associated with the topographic uplift and other factors is the steep rainfall gradient and distinct west coast rainshadow effect, thus influencing the spatial and temporal rainfall variability present on the island. The six automated weather stations used in the project have been placed into two broad groups based upon their general rainfall, erosive and other climatological characteristics identified in objective two. In the first group are Albion and Beaux Songes within the low altitude region, and in the second group, are Arnaud, Monbois, Grand Bassin and Trou aux Cerfs within the high altitude region. While no other station data were available, these automated weather stations represent the regions of the island which receive the highest and lowest rainfall totals. To discover the role that an elevated topography has on the intra-storm attributes of the erosive events, an attempt will be made to contrast the spatial and temporal differences between the automated rainfall stations of the two groups. Concurrent events identified in objective two will also be discussed.

In summary, this chapter presented the methodology followed when analysing the high resolution automatic rainfall data provided by the Mauritius Meteorological Service along with the instrumentation utilised in the collection of the data for this project. The procedures undertaken in calculating and analysing the information to reach each objective set out in the beginning of this project were also discussed. The formulae necessary for this project was also provided and explained. The results of the data analysis will be presented in the next chapter.

Chapter 4 : Results

The following chapter presents the results from the data analysis performed. The results component is comprised of four main sections, first the general storm and rainfall data as well as the general climatological characteristics of the top twenty erosive events (based on 'total kinetic energy generated') at each automated weather station are presented. Second, the intra-storm distribution of rainfall depth was analysed by identifying the storm depth generated over time by the erosive events as well as the storm rainfall depth as a function of storm duration at the respective station in Mauritius. Third, the intra-storm distribution of the extreme and peak rainfall intensity was analysed through the timing of the extreme rainfall intensity (above 30mm/h) generated by the erosive events. The timing of the extreme rainfall intensity (above 30mm/h) as a function of storm duration at the respective stations is also analysed. Finally, the climatic drivers and temporal analysis of the events are presented.

4.1. General storm and rainfall data and general climatological characteristics

As rainfall data used in this project are logged every 6-minutes, the definition by Stocking & Elwell (1976) was adjusted accordingly, so that erosive events have a total rainfall exceeding 12.5mm within a 30 minute period with a maximum 6-minute intensity exceeding 30mm/h and a 2 hour rain free interval (see also Nel *et al.,* 2012; 2013) or if 6.3mm of rain occurred within 15 minutes (Wischmeier & Smith, 1978; Diodato, 2005; Angulo-Martínez & Beguería, 2009). After applying this definition, the data series from the six automated weather stations, over the five year period, contained a total of 444 erosive rainfall events. Of the 444 total erosive events, the low altitude west coast station recorded 42 events at Albion (12m.a.s.l), and 46 events at Beaux Songes (225m.a.s.l). Whilst on the central plateau, 116 events at Arnaud (576m.a.s.l), 77 events were identified at Monbois (590m.a.s.l), 104 events at Grand Bassin (605m.a.s.l) and 59 events at Trou aux Cerfs (614m.a.s.l), noticeably fewer than the other high altitude stations on the Central Plateau.

The events (ranked highest to lowest 'total kinetic energy generated') at the west coast stations of Albion and Beaux Songes represent 48% and 43% of the total erosive events that took place at these stations respectively. Therefore, approximately half of all the events measured at these low altitude stations are erosive in nature. However, the top twenty erosive events at the Arnaud and Grand Bassin stations only account for 17% and 19% of the total erosive events respectively. Consequently, a higher proportion of the rain at the coast stations is considered highly erosive and only a correspondingly smaller percentage at the high altitude stations situated on the elevated central plateau of Mauritius.

Although Nel (2007) used ten erosive events at four automated weather stations in the Drakensberg, KwaZulu Natal, South Africa to perform the intra-storm analysis, this study considered the twenty erosive events at each automated weather station given the longer duration (2004 to 2008) of the available data. The twenty events with the highest 'total kinetic energy generated' at each station were selected to conduct the intra-storm analysis, therefore a total of 120 erosive events were analysed in detail (Table 4-1). For the purpose of this study the top twenty erosive events at the six automated weather stations, referred to as the erosive events or simply the events, are ranked according to highest 'total kinetic energy generated' (highest to lowest total kinetic energy generated) see Table 4-2 to Table 4-7.

The 120 erosive events (Figure 4-1) analysed in this study had an average duration of 1451 minutes (24 hours and 18 minutes) with the longest event of 4932 minutes (82 hours) happening at the Monbois automated weather station (Table 4-5; event no. 8) and the shortest event of 36 minutes occurring at Trou aux Cerfs (Table 4-7; event no. 11). The mean rainfall depth of the events is 117.04mm, with the lowest rainfall depth totalling 27.2mm at Albion (Table 4-2; event no. 20) and the highest rainfall depth equalling 615mm at Trou aux Cerfs (Table 4-7; event no. 1).

In Figure 4-1, 87.5% of the 120 events have a total storm duration of less than 3000 minutes and 95% of the events have a rainfall depth of less than 300mm. The outlying events in Figure 4-1 can be attributed to cyclonic activity, with the exception of the outlying point with the high rainfall depth and very short rainfall duration which corresponds to event no. 1 at the Trou aux Cerfs automated weather station. The total rainfall depth (Table 4-1) generated by the 120 events was 14045.2mm, with the automated weather station of Grand Bassin (Table 4-6) contributing the most erosive rainfall 3222.2mm (23%), followed by the automated weather station at Arnaud (Table 4-4) that contributed 3006.8mm (21.5%), then Trou aux Cerfs weather station 2808mm (20%), followed by the weather station at Monbois 2304.6mm (16.5%), and lastly the coastal stations of Albion 1406.4mm (10%) and Beaux Songes 1297.2mm (9%) (Table 4-3).

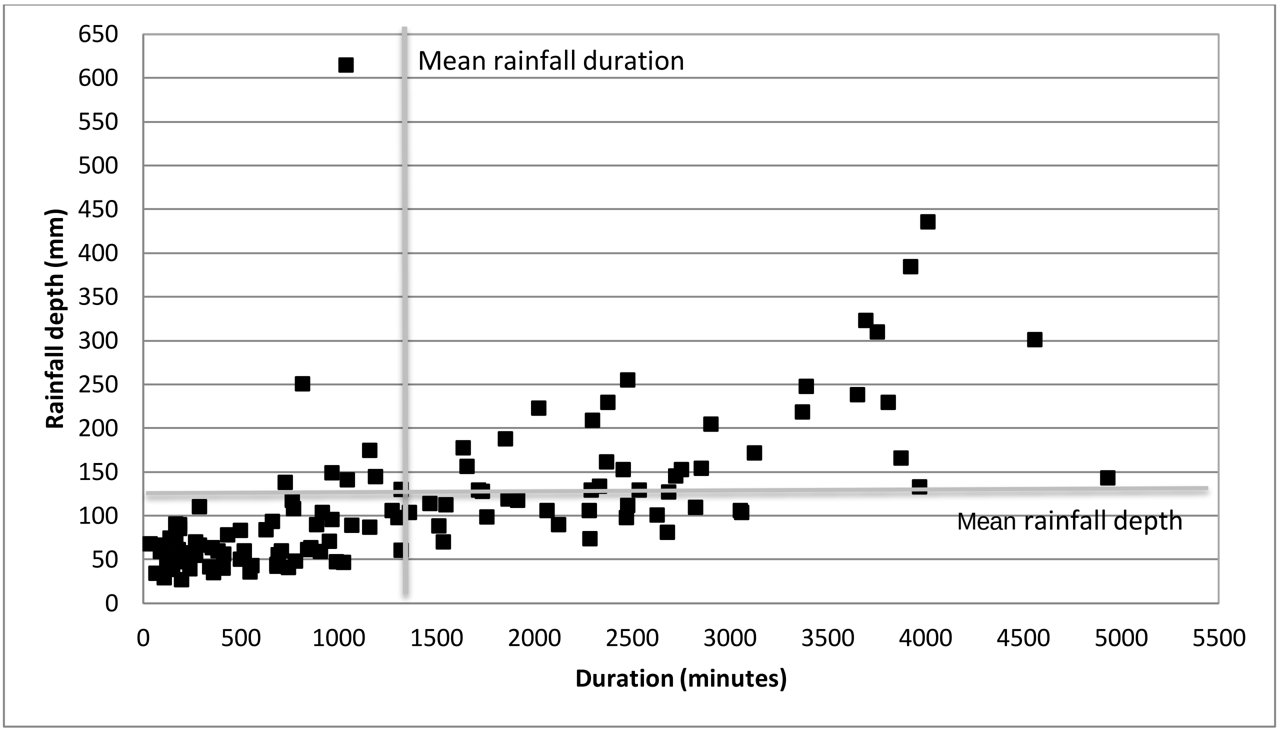


Figure 4-1: Mean rainfall depth and duration of the 120 erosive events analysed in this study

When considering the Total Kinetic Energy (KE) (Table 4-1) and Total Rainfall erosivity (EI_{30}) (Table 4-1) across all six automated weather stations, the 120 events received a total kinetic energy of 250329 (J m^{-2}) and a total rainfall erosivity of 11255814 (J mm m^{-2} h^{-1}). The coastal station of Beaux Songes (Table 4-3) has the lowest total KE 23192 (J m^{-2}) which accounts for only 9.2% of the total KE, and lowest total erosivity of 810306 (J mm m^{-2} h^{-1}), which represents only 7.2% of the total rainfall erosivity across all six automated weather stations.

Table 4-1: Total intra-storm attributes at the six automated weather stations

Automated weather stations	Total storm depth (mm)	Total storm duration (minutes)	Total kinetic energy (J m^{-2})	Total erosivity (J mm m^{-2} h^{-1})
Albion (12m.a.s.l)	1406.4	14868	25356	905812
Beaux Songes (225m.a.s.l)	1297.2	14004	23192	810306
Arnaud (576m.a.s.l)	3006.8	38022	51705	1827222
Monbois (590m.a.s.l)	2304.6	35808	40034	1439542
Grand Bassin (605m.a.s.l)	3222.2	47808	54007	1739853
Trou aux Cerfs (614m.a.s.l)	2808	23611	56035	4533079
Total	**14045.2**	**174121**	**250329**	**11255814**

The events at the Albion (Table 4-2) automated weather station account for 8% of the total rainfall erosivity and 10.1% of the total KE across all six stations. Although the automated weather station at Trou aux Cerfs receives noticeably fewer total erosive events than any of the other stations on the central plateau, the top twenty events at this weather station have the highest 'total kinetic energy content' generated 56035 (J m^{-2}), representing 22.4% of the total KE across all 6 six automated weather stations- with event no. 1 at Trou aux Cerfs contributing more than 26% of the total KE (Table 4-7).

At Albion, Beaux Songes and Grand Bassin (Table 4-6) the corresponding event no. 1 contributes at each station represents 11.9%, 11.5% and 11.7% respectively. The high altitude station of Trou aux Cerfs also has highest total erosivity 4533079 (J mm m^{-2} h^{-1}) (Table 4-1) of all six automated weather stations, and represents 40.3% of the total rainfall erosivity across all six stations. Event no. 1 at Trou aux Cerfs is responsible for 49% of the total rainfall erosivity at this automated weather station. This is more than double the rainfall erosivity received at any other station during their corresponding events no. 1. For example, at the low altitude station of Albion and the inland station of Monbois, the comparable event no. 1 (at each corresponding station) is responsible for only 8% of the rainfall erosivity at these stations. While, the rainfall erosivity received during the event no. 1 at the automated weather station of Beaux Songes is 19%.

The maximum six-minute rainfall intensity (I_6) of the events measured at the six automated weather stations ranged from 26 to 198mm/h. Highest maximum six-minute rainfall intensity (I_6) of 198 mm/h was measured at two automated weather stations, namely Trou aux Cerfs (Table 4-7) and Monbois (Table 4-5). The maximum (I_6) values measured were 116 mm/h at Albion (Table 4-2) and Beaux Songes (Table 4-3) and 102mm/h at Arnaud (Table 4-4). The lowest maximum six-minute rainfall intensity (I_6) of 26mm/h was measured at Grand Bassin (Table 4-6). The maximum 30-minute rainfall intensity (I_{30}) ranged from 13.2 to 152mm/h. The maximum I_{30} value was recorded at Trou aux Cerfs (the highest station).

Table 4-2: The top twenty erosive … 12m.a.s.l) from 2004 to 2008

Event number	Date and Time Start	Date and Time End	Storm Depth (mm)	Storm Duration (minutes)	Max Intensity (I_6) (mm/h)	Max Intensity (I_{30}) (mm/h)	Total Kinetic Energy ($J\ m^{-2}$)	Erosivity ($J\ mm\ m^{-2}\ h^{-1}$)	Synoptic circulation or Weather System
1	16/09/08 (17:18)	17/09/08 (20:30)	177.6	1638	42	24	3015	72350	U
2	04/03/05 (19:24)	05/03/05 (07:30)	117.4	762	88	46	2127	97852	U
3	03/03/06 (22:30)	05/03/06 (05:54)	119.0	1866	26	17	1857	31945	C
4	09/06/07 (10:18)	10/06/07 (02:18)	96.0	966	50	30	1667	50683	U
5	30/11/08 (10:24)	30/11/08 (13:12)	74.2	138	48	46	1599	73543	U
6	23/01/06 (22:18)	24/01/06 (06:24)	83.2	498	66	40	1584	63994	U
7	25/03/08 (13:24)	26/03/08 (10:54)	97.8	1302	30	20	1548	30954	C
8	08/03/04 (07:24)	08/03/04 (09:18)	59.0	90	116	92	1425	131136	U
9	22/03/05 (18:30)	24/03/05 (14:24)	81.0	2682	54	18	1245	22918	C
10	02/01/06 (03:06)	02/01/06 (08:24)	63.8	354	70	38	1178	44764	C
11	16/02/06 (17:18)	17/02/06 (07:54)	63.6	858	38	32	1111	35557	C
12	02/03/05 (14:12)	02/03/05 (17:30)	50.6	204	82	46	1049	48674	U
13	13/12/04 (18:48)	14/12/04 (03:24)	59.6	516	42	24	989	23746	U
14	20/03/05 (19:12)	21/03/05 (07:06)	55.6	690	26	16	906	14853	C
15	23/04/05 (11:30)	23/04/05 (12:30)	34.0	66	100	65	818	52979	U
16	22/02/08 (14:24)	23/02/08 (07:24)	46.6	1026	38	23	756	17239	C
17	14/05/08 (08:42)	14/05/08 (14:36)	34.8	360	80	50	727	36058	CF
18	22/10/07 (06:42)	22/10/07 (15:42)	36.0	546	92	38	673	25292	SB
19	12/01/04 (13:30)	12/01/04 (15:18)	29.4	108	46	28	581	16503	U
20	13/01/04 (13:24)	13/01/04 (16:42)	27.2	198	54	30	499	14769	U
TOTAL			1406.4	14868	**TOTAL**		25356	905812	
MEAN			70.3	743	**MEAN**		1268	45291	

WF= Windfields over Mauritius, C= Cyclonic Activity, ITCZ=Intertropical Convergence Zone, CF= Cold fronts, AC= Anticyclones, SB= Sea breezes, EW= Easterly Waves Perturbations in the Lower Troposphere, CM= Cloud Masses and Upper Level Lows, U= Weather system unknown. See Table 3-3.

Table 4-3: The top twenty erosive event attributes for Beaux Songes (225 m.a.s.l) from 2004 to 2008

Event number	Date and Time Start	Date and Time End	Storm Depth (mm)	Storm Duration (minutes)	Max Intensity (I_6) (mm/h)	Max Intensity (I_{30}) (mm/h)	Total Kinetic Energy (J m^{-2})	Erosivity (J mm m^{-2} h^{-1})	Synoptic circulation or Weather System
1	04/03/05 (19:24)	05/03/05 (07:24)	138.0	726	94	57	2673	151849	U
2	25/03/08 (13:24)	26/03/08 (11:06)	130.4	1320	50	39	2230	87417	C
3	23/01/06 (17:54)	24/01/06 (06:42)	108.2	768	60	36	1957	70450	U
4	16/02/06 (17:18)	17/02/06 (07:54)	89.8	888	58	43	1693	73130	C
5	03/03/06 (22:12)	04/03/06 (20:42)	103.6	1362	40	14	1634	22220	C
6	15/03/08 (03:30)	15/03/08 (06:42)	57.8	192	86	51	1240	63482	C
7	22/03/05 (18:42)	24/03/05 (08:42)	74.0	2286	30	14	1108	15063	C
8	01/02/04 (08:18)	01/02/04 (12:36)	54.8	270	54	36	1030	37506	C
9	09/06/07 (09:30)	09/06/07 (23:30)	61.6	840	32	16	988	15814	U
10	04/02/05 (11:24)	04/02/05 (14:42)	47.4	198	116	52	985	51215	C
11	12/01/04 (12:36)	12/01/04 (15:12)	48.4	150	64	34	968	33291	U
12	27/01/04 (08:24)	27/01/04 (10:30)	38.4	132	102	59	861	50622	C
13	04/03/04 (11:24)	05/03/04 (04:24)	47.2	990	62	23	799	18221	C
14	14/02/04 (07:24)	14/02/04 (11:12)	39.4	240	66	36	776	27951	U
15	15/02/05 (20:48)	16/02/05 (02:30)	41.4	342	42	29	750	21615	C
16	22/01/05 (15:06)	23/01/05 (02:24)	42.6	684	48	22	738	16236	C
17	22/10/07 (07:06)	22/10/07 (13:42)	40.2	408	80	28	719	20409	SB
18	20/03/05 19:42)	21/03/05 (07:12)	44.6	684	34	15	703	10960	C
19	19/09/05 07:24)	19/09/05 (19:36)	48.2	780	32	18	698	12839	U
20	22/02/08 (14:18)	23/02/08 (02:36)	41.2	744	42	16	642	10015	C
TOTAL			1297.2	14004	**TOTAL**		23192	810306	
MEAN			64.86	700	**MEAN**		1160	40515	

WF= Windfields over Mauritius, C= Cyclonic Activity, ITCZ=Intertropical Convergence Zone, CF= Cold fronts, AC= Anticyclones, SB= Sea breezes, EW= Easterly Waves Perturbations in the Lower Troposphere, CM= Cloud Masses and Upper Level Lows, U= Weather system unknown. See Table 3-3.

Table 4-4: The top twenty event attributes for Arnaud (576 m.a.s.l) from 2004 to 2008

Event number	Date and Time Start	Date and Time End	Storm Depth (mm)	Storm Duration (minutes)	Max Intensity (I_6) (mm/h)	Max Intensity (I_{30}) (mm/h)	Total Kinetic Energy ($J\ m^{-2}$)	Erosivity ($J\ mm\ m^{-2}\ h^{-1}$)	Synoptic circulation or Weather System
1	22/03/05 (08:48)	25/03/05 (04:06)	435.8	4014	68	24	7293	177954	C
2	02/03/06 (18:24)	05/03/06 (22:48)	301.2	4560	44	23	4808	111543	C
3	16/05/08 (04:30)	17/05/08 (21:42)	255.4	2478	84	53	4469	235963	CF
4	24/03/08 (23:36)	26/03/08 (15:36)	299.8	2376	70	42	4108	170877	C
5	18/03/05 (02:06)	19/03/05 (11:42)	223.0	2022	80	44	4020	178501	C
6	23/01/06 (16:12)	24/01/06 (09:30)	141.0	1044	56	25	2422	60059	U
7	30/04/04 (16:42)	02/05/04 (16:12)	154.2	2856	30	17	2338	39274	U
8	04/03/05 (15:00)	05/03/05 (19:54)	128.0	1734	82	45	2213	100005	U
9	01/01/04 (16:54)	03/01/04 (07:06)	129.4	2292	38	13	1994	26319	C
10	16/02/06 (13:42)	17/02/06 (04:48)	103.8	918	66	33	1966	65274	C
11	09/04/04 (08:30)	10/04/04 (10:12)	112.2	1548	74	40	1904	75401	U
12	28/11/08 (20:06)	01/12/08 (04:06)	109.4	2826	60	29	1767	50883	U
13	20/03/05 (20:36)	22/03/05 (06:52)	106.2	2064	58	32	1714	55540	C
14	26/02/04 (05:30)	26/02/04 (15:54)	84.0	630	82	54	1702	92596	C
15	31/01/04 (12:24)	01/02/04 (13:18)	88.2	1512	64	40	1561	63051	C
16	01/01/06 (11:18)	03/01/06 (04:18)	98.0	2472	56	19	1555	29858	C
17	20/03/04 (00:24)	21/03/04 (19:42)	86.6	1158	94	46	1529	70952	U
18	12/01/04 (10:36)	12/01/04 (15:00)	69.8	270	92	54	1474	79619	U
19	22/02/08 (13:00)	23/02/08 (06:36)	89.0	1068	40	19	1460	28026	C
20	16/03/08 (10:18)	16/03/08 (13:12)	61.6	180	102	82	1409	115529	C
TOTAL			3006.8	38022	**TOTAL**		51705	1827222	
MEAN			150.3	1901	**MEAN**		2585	91361	

WF= Windfields over Mauritius, C= Cyclonic Activity, ITCZ=Intertropical Convergence Zone, CF= Cold fronts, AC= Anticyclones, SB= Sea breezes, EW= Easterly Waves Perturbations in the Lower Troposphere, CM= Cloud Masses and Upper Level Lows, U= Weather system unknown. See Table 3-3.

Table 4-5: The top twenty erosive event attributes for Monbois (590m.a.s.l) from 2004 to 2008

Event number	Date and Time Start	Date and Time End	Storm Depth (mm)	Storm Duration (minutes)	Max Intensity (I_6) (mm/h)	Max Intensity (I_{30}) (mm/h)	Total Kinetic Energy (J m^{-2})	Erosivity (J mm m^{-2} h^{-1})	Synoptic circulation or Weather System
1	22/03/05 (13:48)	25/03/05 (04:18)	310.2	3756	36	22	4984	109648	C
2	16/02/06 (16:24)	17/02/06 (19:52)	156.2	1656	86	45	2943	131829	C
3	28/11/08 (13:12)	30/11/08 (11:30)	152.4	2754	70	45	2850	128822	U
4	04/03/06 (07:42)	05/03/06 (23:06)	161.2	2370	198	69	2827	195617	C
5	18/03/05 (00:42)	19/03/05 (17:30)	152.4	2454	76	37	2569	94544	C
6	23/01/06 (15:52)	24/01/06 (11:36)	144.8	1188	54	26	2484	64572	U
7	12/01/04 (10:18)	12/01/04 (15:00)	110.6	288	96	74	2364	173974	U
8	08/04/04 (16:30)	12/04/04 (03:06)	143.0	4932	48	24	2196	51833	U
9	01/05/04 (00:36)	02/05/04 (15:30)	133.4	2334	30	14	2014	28192	U
10	05/07/05 (22:42)	07/07/05 (06:36)	117.4	1914	26	20	1858	36416	U
11	04/03/05 (19:18)	06/03/05 12:30	112.0	2478	58	21	177	37679	U
12	04/03/04 (08:48)	05/03/04 (22:42)	105.6	2280	46	17	1623	27917	C
13	01/03/04 (08:48)	01/03/04 (11:30)	70.6	168	96	65	1620	105636	C
14	14/02/05 (07:00)	16/02/05 (02:42)	101.0	2628	36	16	1543	24693	C
15	31/01/04 (11:48)	01/02/04 (13:18)	70.2	1536	66	34	1202	40388	C
16	28/12/08 (09:52)	28/12/08 (11:48)	48.0	120	46	32	1187	37970	U
17	31/12/05 (14:24)	01/01/06 (05:54)	59.4	906	54	29	1014	29216	C
18	18/09/08 (08:06)	18/09/08 (17:18)	42.8	558	178	72	999	71899	U
19	27/03/04 (21:36)	28/03/04 (19:30)	60.8	1320	46	21	993	20649	U
20	29/02/04 (08:30)	29/02/04 (11:12)	52.6	168	58	28	988	28048	U
TOTAL			2304.6	35808	**TOTAL**		40034	1439542	
MEAN			115.23	1790	**MEAN**		2002	71977	

WF= Windfields over Mauritius, C= Cyclonic Activity, ITCZ=Intertropical Convergence Zone, CF= Cold fronts, AC= Anticyclones, SB= Sea breezes, EW= Easterly Waves Perturbations in the Lower Troposphere, CM= Cloud Masses and Upper Level Lows, U= Weather system unknown. See Table 3-3.

Table 4-6: The top twenty erosive event attributes for Grand Bassin (605m.a.s.l) from 2004 to 2008

Event number	Date and Time Start	Date and Time End	Storm Depth (mm)	Storm Duration (minutes)	Max Intensity (I_6) (mm/h)	Max Intensity (I_{30}) (mm/h)	Total Kinetic Energy (J m^{-2})	Erosivity (J mm m^{-2} h^{-1})	Synoptic circulation or Weather System
1	22/03/05 (09:24)	25/03/05 (02:42)	384.8	3924	52	31	6334	197612	C
2	18/03/05 (02:00)	20/03/05 (10:24)	247.6	3390	68	36	4138	147300	C
3	16/05/08 (07:00)	17/05/08 (20:48)	209.2	2298	120	52	3657	188688	CF
4	15/09/08 (18:30)	18/09/08 (10:00)	229.4	3810	28	14	3509	49126	U
5	24/03/08 (08:12)	26/03/08 (15:18)	218.4	3372	42	26	3479	90454	C
6	30/04/04 (15:30)	02/05/04 (15:48)	204.8	2904	38	14	3172	44415	U
7	05/07/05 (00:24)	07/07/05 (07:12)	187.6	1854	28	18	3056	53784	U
8	03/03/06 (19:24)	05/03/06 (22:42)	171.4	3126	42	22	2713	58605	C
9	23/01/06 (17:42)	24/01/06 (09:42)	148.8	966	86	39	2599	100833	U
10	09/04/04 (09:06)	11/04/04 (06:24)	145.2	2724	58	35	2539	89374	U
11	14/02/08 (11:42)	17/02/08 (04:12)	165.6	3876	34	16	2511	37165	C
12	14/03/08 (10:30)	15/03/08 (07:30)	106.2	1272	102	58	2188	127757	C
13	04/03/05 (15:12)	06/03/05 (11:48)	127.0	2688	118	82	2125	175135	U
14	01/01/04 (15:12)	03/01/04 (08:52)	129.4	2538	56	31	2099	64640	C
15	26/02/04 (06:12)	26/02/04 (17:30)	93.8	660	48	18	1974	34735	U
16	22/01/05 (09:58)	23/01/05 (15:12)	98.4	1758	54	26	1619	41443	C
17	29/11/08 (00:18)	01/12/08 (03:36)	105.6	3054	36	19	1601	30106	U
18	09/04/05 (15:30)	11/04/05 (18:30)	103.8	3060	26	19	1573	30202	C
19	08/01/05 (07:36)	08/01/05 (14:42)	78.4	432	74	46	1566	72679	U
20	16/03/08 (10:18)	16/03/08 (11:48)	66.8	102	122	68	1556	105802	C
TOTAL			3222.2	47808	TOTAL		54007	1739853	
MEAN			161.11	2390	MEAN		2700	86993	

WF= Windfields over Mauritius, C= Cyclonic Activity, ITCZ=Intertropical Convergence Zone, CF= Cold fronts, AC= Anticyclones, SB= Sea breezes, EW= Easterly Waves Perturbations in the Lower Troposphere, CM= Cloud Masses and Upper Level Lows, U= Weather system unknown. See Table 3-3.

Table 4-7: The top twenty erosive e

x Cerfs (614m.a.s.l) from 2004 to 2008

Event number	Date and Time Start	Date and Time End	Storm Depth (mm)	Storm Duration (minutes)	Max Intensity (I_6) (mm/h)	Max Intensity (I_{30}) (mm/h)	Total Kinetic Energy (J m^{-2})	Erosivity (J mm m^{-2} h^{-1})	Synoptic circulation or Weather System
1	28/05/06 (10:18)	29/05/06 (03:30)	615.0	1038	198	152	14738	2240158	U
2	26/05/06 (22:12)	27/05/06 (11:36)	250.6	816	198	138	5896	816062	U
3	22/03/05 (14:48)	25/03/05 (04:24)	322.8	3696	56	30	5362	158710	C
4	02/03/06 (17:30)	05/03/06 (06:18)	238.4	3645	34	20	3756	73618	C
5	23/01/06 (16:12)	24/01/06 (11:24)	175.0	1158	74	38	3165	121544	U
6	09/04/04 (09:06)	12/04/04 (04:24)	133.2	3972	50	28	2178	60980	U
7	25/01/04 (13:58)	25/01/04 (16:42)	90.4	168	118	78	2139	167729	C
8	04/03/04 (08:54)	05/03/04 (13:30)	129.0	1716	82	28	2076	57303	C
9	18/03/05 (04:54)	19/03/05 (05:18)	113.8	1464	92	42	2066	86770	C
10	02/03/04 (08:58)	02/03/04 (11:06)	90.0	186	102	53	1973	104178	C
11	03/01/06 (06:58)	03/01/06 (07:30)	68.0	36	198	133	1845	245782	C
12	29/02/04 (08:30)	29/02/04 (11:36)	85.2	186	102	53	1843	97301	U
13	01/01/04 (16:24)	03/01/04 (03:42)	89.6	2124	46	15	1342	19864	C
14	28/05/06 (01:24)	28/05/06 (06:06)	66.4	288	198	46	1328	61636	U
15	31/01/04 (20:42)	01/02/04 (12:36)	70.6	954	76	32	1294	41919	C
16	19/02/05 (07:54)	19/02/05 (14:42)	60.2	384	58	37	1153	42881	U
17	13/01/04 (09:00)	13/01/04 (15:48)	56.4	414	68	39	1069	41893	U
18	13/12/04 (18:06)	14/12/04 (05:42)	60.0	708	40	19	980	18816	U
19	13/04/04 (11:24)	13/04/04 (13:48)	43.0	150	98	52	921	48260	U
20	03/02/08 (14:00)	03/02/08 (22:00)	50.4	498	64	30	910	27676	C
TOTAL			2808	23611	**TOTAL**		56035	4533079	
MEAN			140.4	1181	**MEAN**		2802	226654	

WF= Windfields over Mauritius, C= Cyclonic Activity, ITCZ=Intertropical Convergence Zone, CF= Cold fronts, AC= Anticyclones, SB= Sea breezes, EW= Easterly Waves Perturbations in the Lower Troposphere, CM= Cloud Masses and Upper Level Lows, U= Weather system unknown. See Table 3-3.

4.2. Intra-storm distribution of rainfall depth

4.2.1. Storm rainfall depth and cumulative rainfall generated over time by the erosive events

Following the equation by van Dijk *et al*. (2002), the six-minute kinetic energy content (KE) of each individual event at each automated weather station was calculated and the cumulative kinetic energy as a percentage was plotted in (Figure 4 – 2). The top twenty events at the six automated weather stations exhibit a well-defined exponential distribution of cumulative kinetic energy of rainfall over time (storm duration). Events at Beaux Songes and Albion automated weather stations generate 90% of the total kinetic energy in the first 1500 minutes of the event. At the automated weather station of Arnaud 85% of the total cumulative kinetic energy is received within the first 2000 minutes of the event. The events at Trou aux Cerfs and Grand Bassin generate 90% of the total cumulative kinetic energy in the first 2500 minutes from the onset of the event. At the automated weather station of Monbois 85% of the total cumulative kinetic energy is received within the first 2500 minutes of the event. Subsequently, 93% of all the events analysed in this project receive 80% of the total cumulative kinetic energy within the first 2500 minutes of the event. The extremely long storm duration could be the caused by a long lag in the fourth quartile (Q4) of events.

Despite the 120 events all displaying clear variations in rainfall depth over time, all the stations received more than 80% of the cumulative kinetic energy content within the first 2500 minutes of the event. Therefore, the six-minute increment rainfall depth of each individual event measured at each station was plotted over the first 2500 minutes in order to analyse the intra-event temporal distribution of rainfall. At the low altitude station of Albion 75% of the cumulative rainfall received at this station occurs within the first 702 minutes from the onset of the event, with most of the events occurring at this station tapering out before reaching 1500 minutes with only three storms exceeding this time (Figure 4-3. A). Two of the three events that exceed the 1500 minutes are both associated with cyclonic activity in the vicinity of the island, namely Tropical Cyclone Diwa and Tropical Cyclone Hennie.

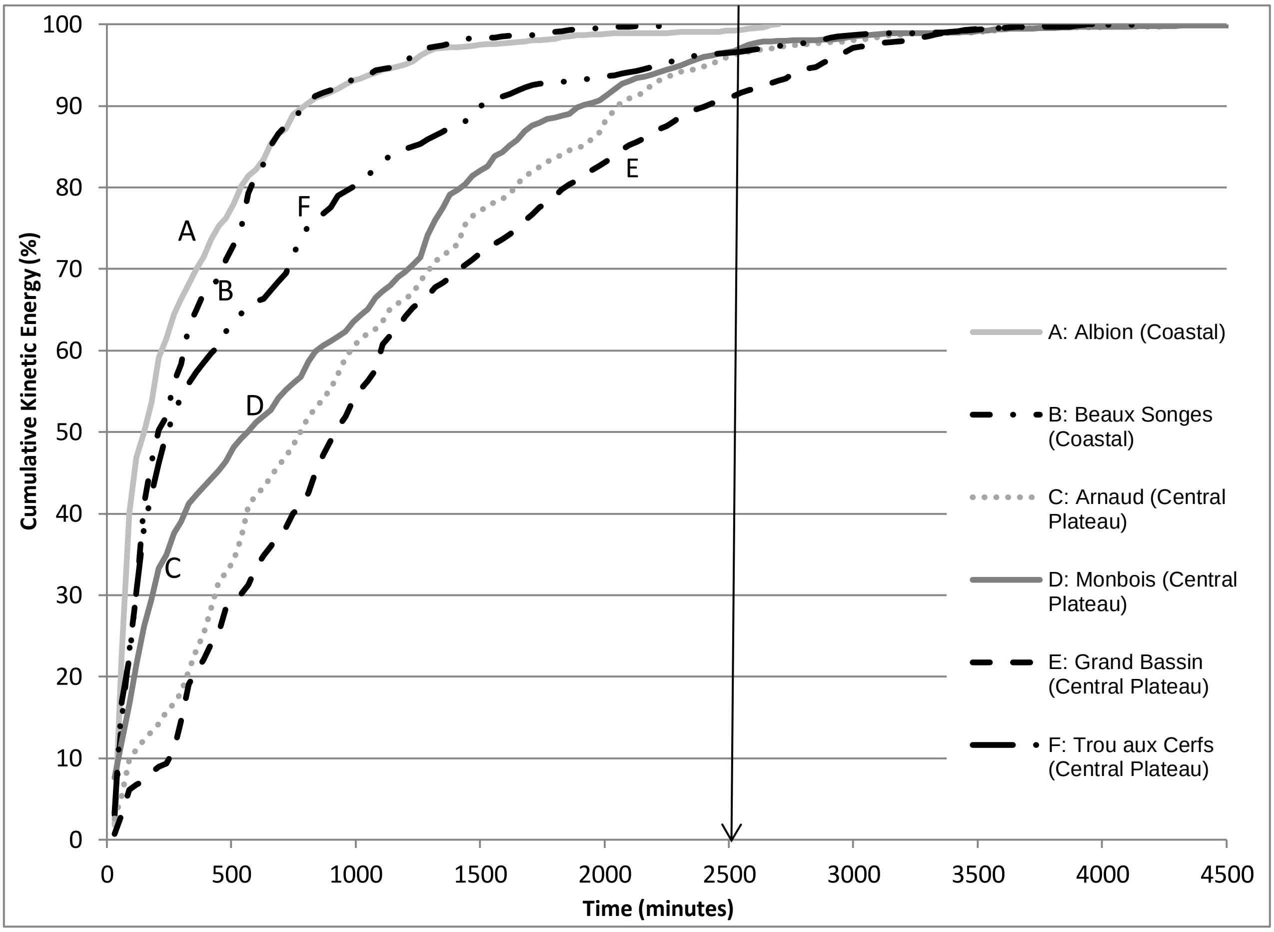


Figure 4-2: Cumulative kinetic energy generated over time by the erosive events at the respective automated weather stations on Mauritius

At the low altitude station of Beaux Songes 75% of the cumulative rainfall occurs within the first 600 minutes from the onset of the event. From Figure 4-3. B it is evident that most of the events taper out before 1500 minutes with only one event exceeding this duration. The events at automated weather station of Beaux Songes (event no. 7; Table 4-3) that exceeded 1500minutes were associated with rainfall received from Cyclone Hennie. At the inland automated weather station of Arnaud (Figure 4-4. C) and the high altitude station of Grand Bassin (Figure 4-5. E) 65% of the cumulative rainfall is received within the first 1704 and 1920 minutes respectively. While at the automated weather station of Monbois (Figure 4-4. D) and high altitude station of Trou aux Cerfs (Figure 4-5. F) 70% of the cumulative rainfall is received within the first 1548 and 984 minutes. The events at Trou aux Cerfs started tapering out after 1500 minutes. Evidently, visible tapering off of the events occur at most of the stations, excluding Grand Bassin, where despite longer events occurring, 80% of the cumulative rainfall is received within the first 2500 minutes from the onset of the event.

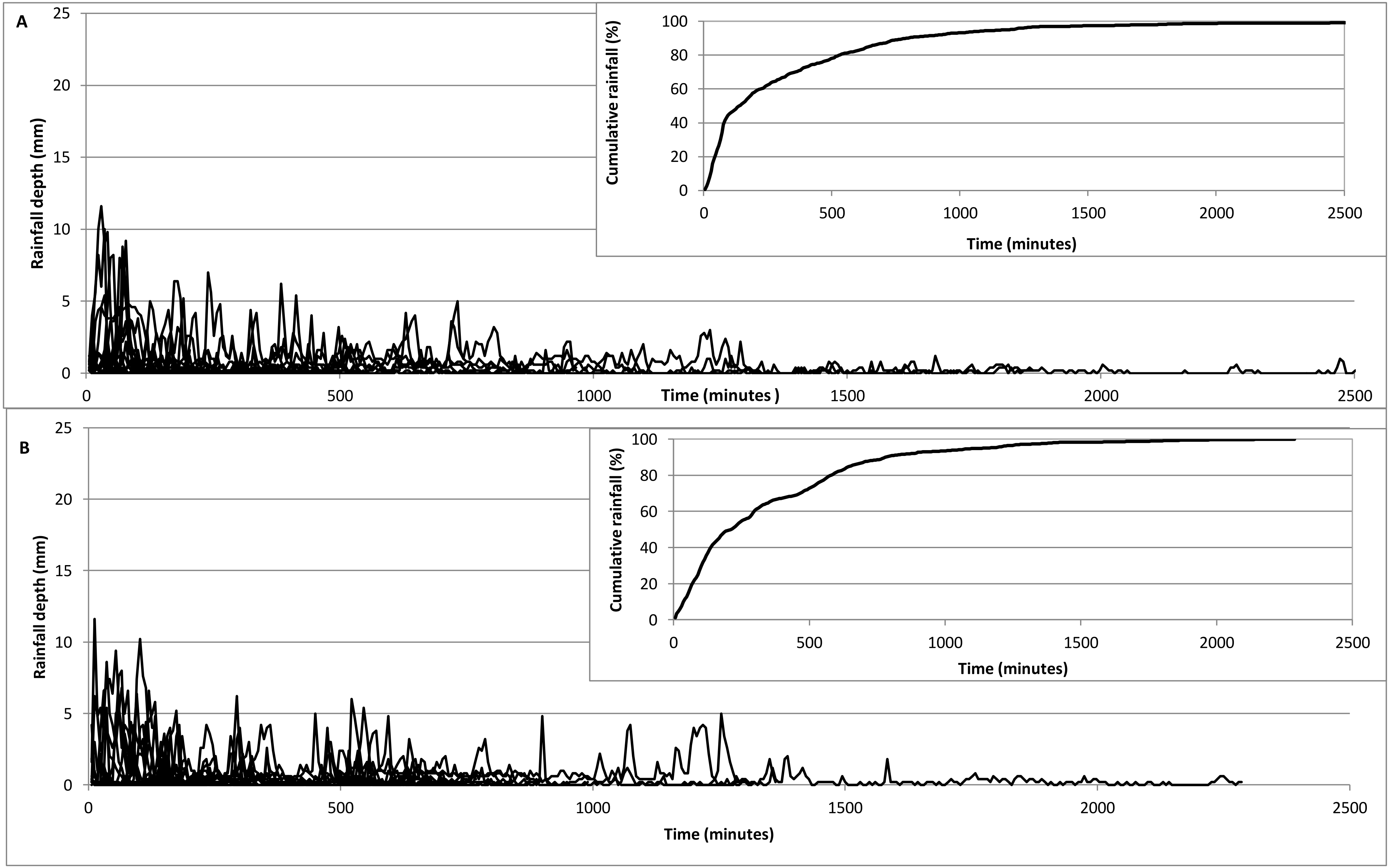
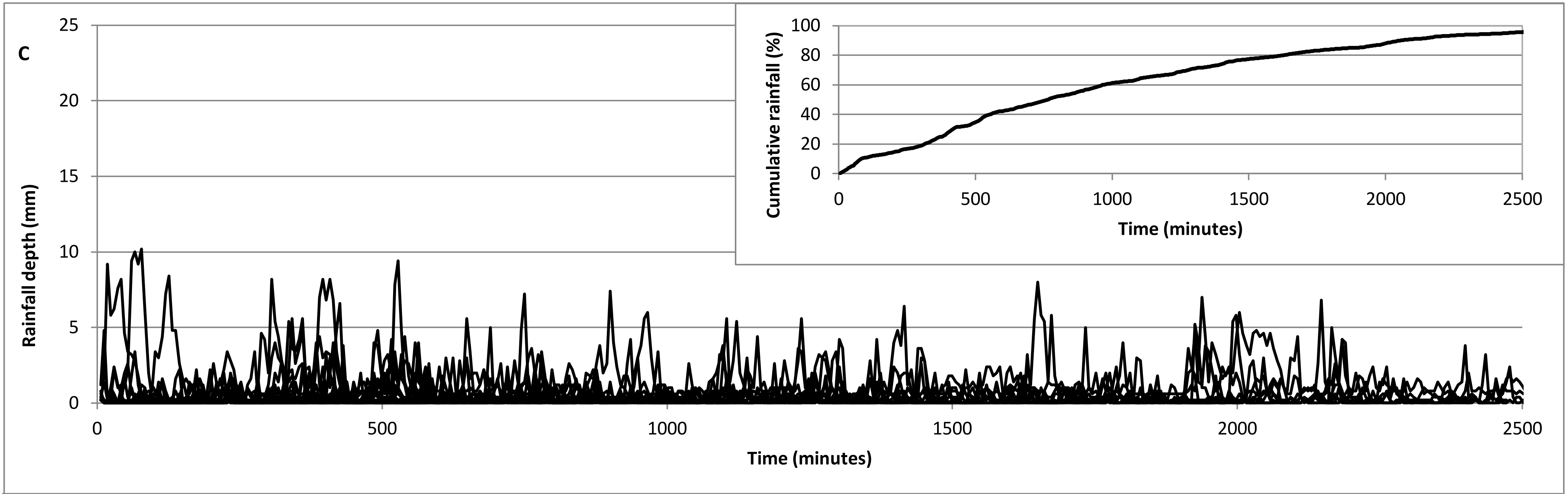


Figure 4-3: Rainfall depth and cumulative rainfall generated over time by the events measured at the respective stations on Mauritius: (A) Albion and (B) Beaux Songes



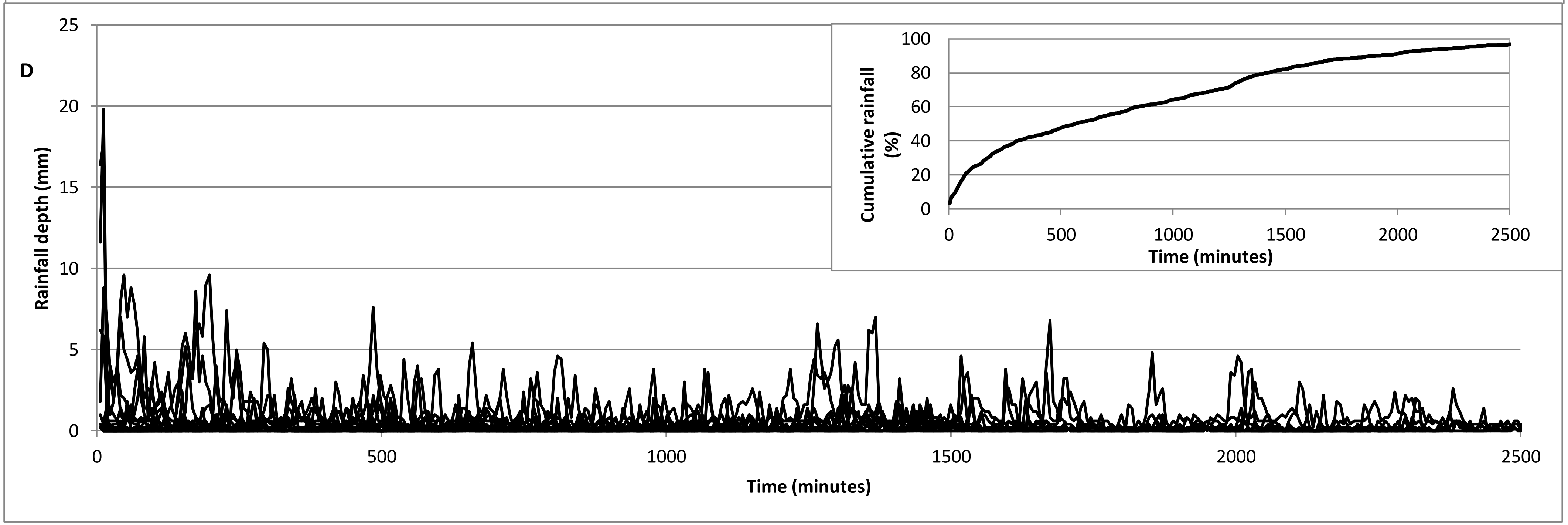


Figure 4-4: Rainfall depth and cumulative rainfall generated over time by the events measured at the respective stations on Mauritius: (C) Arnaud and (D) Monbois

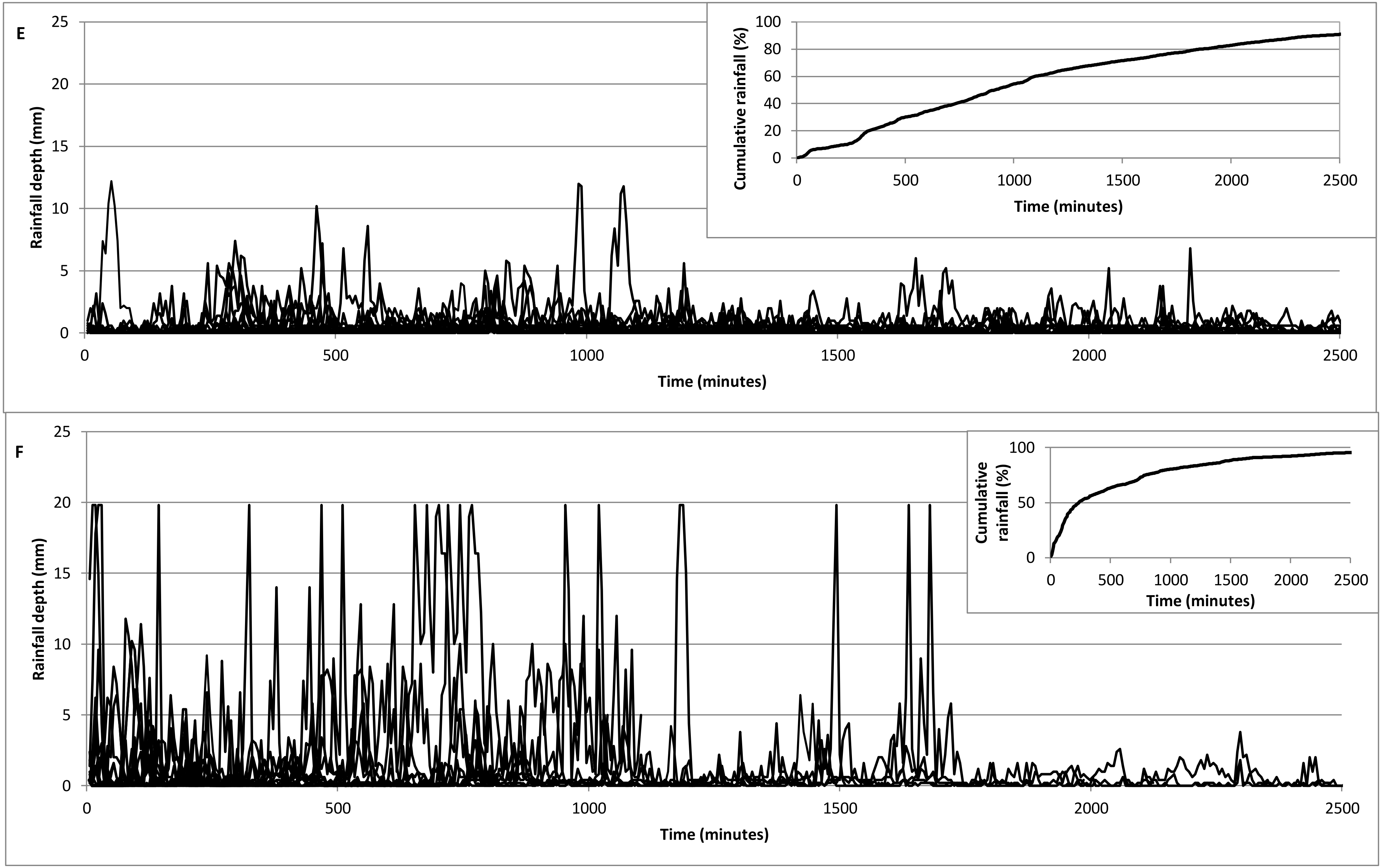


Figure 4-5: Rainfall depth and cumulative rainfall generated over time by the events measured at the respective stations on Mauritius: (E) Grand Bassin and (F) Trou aux Cerfs

4.2.2. Storm rainfall depth as a function of storm duration

To test the rainfall generation as a function of rainfall duration, the six-minute rainfall depth of each individual event was plotted as a percentage of rainfall duration and then each event was divided into quartiles, Q1 through Q4 (Figure 4-6). As anticipated the top twenty events at the six automated weather station indicate variability of rainfall over time, but at the low altitude stations (Albion and Beaux Songes) a high proportion of the events generate peak rainfall within the first (Q1) and second (Q2) quartiles or the first half (Q1 and Q2) of the event. At the low altitude stations of Albion (Figure 4 – 6. A) and Beaux Songes Figure 4 – 6. B), 70% and 65% of the rainfall is received during the first half (Q1 and Q2) of the event, whilst only 30% and 35% rainfall is received in the second half (Q3 and Q4) of the event.

The events at Arnaud (Figure 4 – 6. C) and Grand Bassin (Figure 4 – 6. E) are fairly evenly distributed, with 55% of the peak rainfall generated during the first half (Q1 and Q2) of the event and 45% generated during the second half (Q3 and Q4) of the event at both stations. At the Monbois automated weather station (Figure 4 – 6. D) a high proportion of the erosive events (65%) generated peak rainfall during the first half, which is similar to both low altitude stations, specifically Albion and Beaux Songes. The events experienced at the automated weather station at Trou aux Cerfs (Figure 4 – 6. F) receives the highest proportion of rainfall during the second (Q2) and third (Q3) quartiles with 75 % of the peak rainfall being generated during this period. Only 5% of the peak rainfall is generated during the first quartile (Q1), which is distinctly different from all the other stations. Hence, 80% of the peak rainfall is generated between the first (Q1) and the third (Q3) quartile and consequently only 20% is received during the fourth quartile (Q4). The weather station with the highest altitude Trou aux Cerfs thus has the highest variability between the timing of rainfall.

4.3. Intra-storm distribution of extreme and peak intensity

4.3.1. Timing of extreme (above 30mm/h) rainfall intensity generated by the erosive events

Utlising the modified definition of an erosive event by Stocking & Elwell (1976), ensures the applicability of the six-minute rainfall data collected and guarantees consistency with previous studies on Mauritius (see also Anderson, 2012; Mongwa, 2012; Nel *et al.,* 2012; 2013).

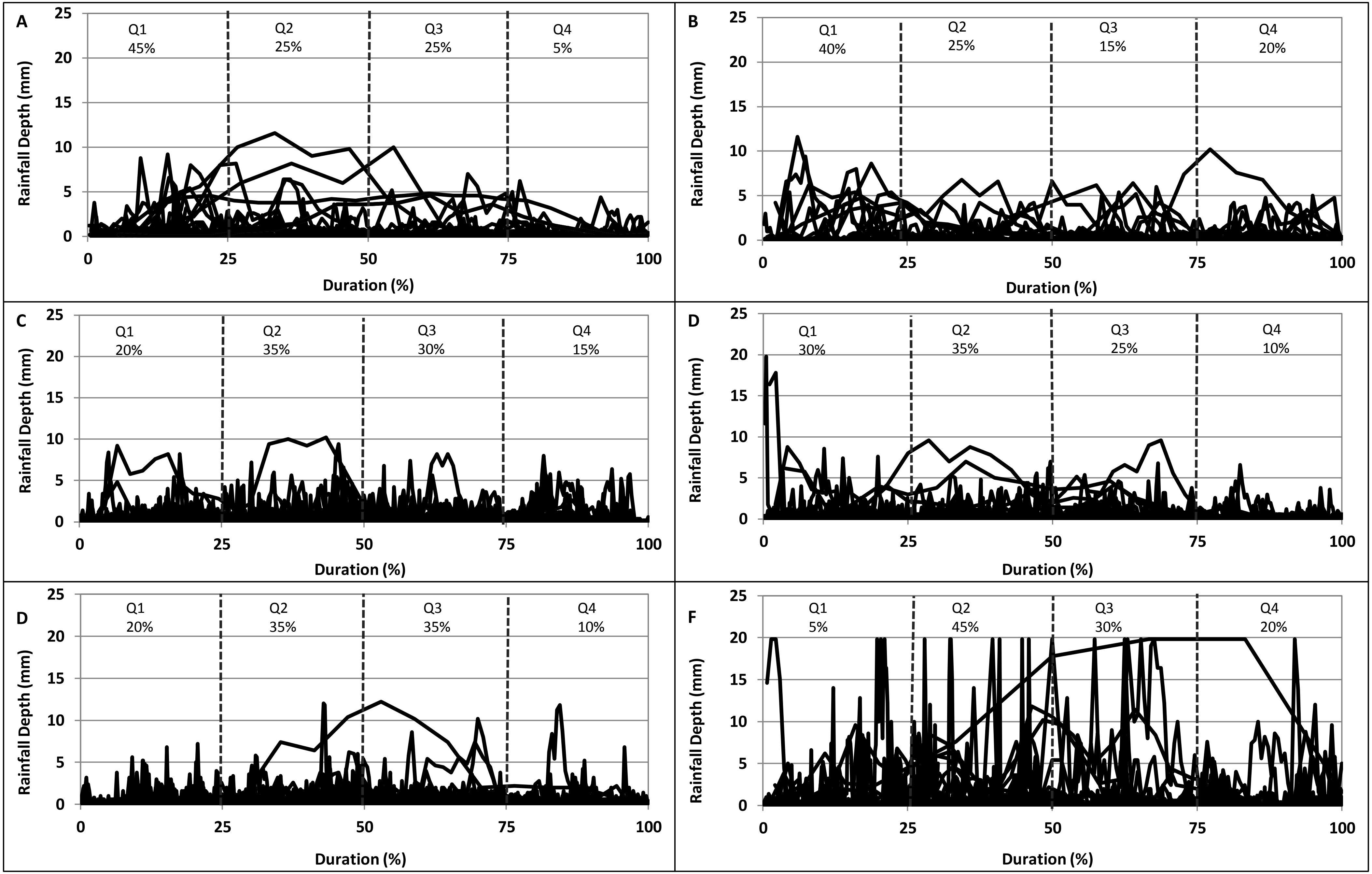


Figure 4-6: Rainfall depth as a function of event duration at the respective stations in Mauritius. (A) Albion; (B) Beaux Songes; (C) Arnaud; (D) Monbois; (E) Grand Bassin; (F) Trou aux Cerfs

To test at which stage during an event the rainfall intensity has the potential to exceed the infiltration rates and sebsequently become potentially erosive (using the defintion adapted from Stocking & Elwell (1976)), the intra-storms variations of six-minute intensity exceeding 30mm/h were considered. The timing of the extreme intensities are vital as it influences the type and particle size of the eroded materials.

Nearly all the 120 events (75%) measured at all six automated weather stations have intensities above 30mm/h during the first 500 minutes (Figure 4-7). The vast majority (81%) of the 120 events receive their peak rainfall intensities within the first 1500 minutes of the event. At the automated weather stations of Albion (Figure 4–7. A) and Beaux Songes (Figure 4–7. B), 83% and 75% respectively of the high rainfall intensities are received within the first 500 minutes of the event, with all (100%) of the high rainfall intensities being received within 1500 minutes. The events received at the inland automated weather station of Arnaud (Figure 4–7. C) display the most variability in the peak intensities, 65% of the extreme rainfall intensities are received within the first 1000 minutes. The events measured at the high-altitude automated weather station of Trou aux Cerfs (Figure 4–7. F) received 70% of the extreme rainfall intensities within the first 1000 minutes, some as high as 198mm/h, several of the extreme intensities were received as late as 3408 minutes from the onset of the event. The possibility of overlapping or ‘back-to-back’ storms could be considered.

At the inland automated weather stations of Monbois and Grand Bassin (Figure 4–7. E), 63% and 70% respectively, of the high rainfall intensities are received within the first 1500 minutes. Although the automated weather station at Monbois (Figure 4–7. D) and at Trou aux Cerfs (Figure 4-7 F) have a maximum intensity of 198mm/h, Trou aux Cerfs received delayed peaks in intensity during the storm duration. These peaks are noticeably later in the event duration than the extreme rainfall intensities received at any of the other stations. Both low altitude stations of Albion and Beaux Songes have a maximum extreme intensity of 116mm/h and Grand Bassin has a maximum intensity of 118mm/h. The automated weather station of Arnaud receives the lowest maximum rainfall intensity of 102mm/h across all six of the automated weather stations. Particularly high extreme intensities are mostly confined to the first 1500 minutes of the events at all the stations, though some events receive peak intensities well after the first 1500 minutes. Arnaud, Monbois, Grand Bassin and Trou aux Cerfs all receive peak rainfall intensities well after the first 500 minutes, with intensities peaking as late as 2000 minutes after the onset of the events. This is distinctly different at the low altitude stations, Albion and Beaux Songes, which receive all their peak intensities during the first 1500 minutes. The peak in extreme intensities occurring late in the event, such as at the high altitude stations, could have a significant impact on the potential rainfall erosivity experienced at these stations.

4.3.2. Extreme rainfall intensity (above 30mm/h) as a function of storm duration

When considering the distribution of the high intensity rainfall as a function of rainfall duration, just over half (57%) of the 120 events have their high intensities within the first (Q1) and second (Q2) quartile of rainfall duration (Figure 4-8). At both Albion (Figure 4-8. A) and Beaux Songes (Figure 4–8. B) 40% and 45% of the events respectively, received their rainfall intensities during the first quartile (Q1) and 68% and 65% of the peak intensity are received during the first half of the event (Q1 and Q2). At Albion only 4% of the peak intensities occur during the fourth quartile (Q4) whilst Beaux Songes receives only 10% of the peak intensities during the third quartile (Q3). At the automated weather stations of Albion and Beaux Songes only 32% and 35%, respectively, of the peak intensities occur during the second half of the event (Q3 and Q4). The inland automated weathers of Arnaud (Figure 4–8. C) and Monbois (Figure 4–8. D) display a similar pattern, with 60% and 61%, respectively, occurring during the first half of the event (Q1 and (Q2).

The automated weather station at Grand Bassin displays the least amount of variability of extreme rainfall intensity distribution, with 53% being received during the first half (Q1 and Q2) and 48% during second half (Q3 and Q4) of the event (Figure 4–8. E). Trou aux Cerfs (Figure 4–8. F) displays a similar pattern to the other automated weather stations, where the majority (65%) of the peak intensity are received during the first half (Q1 and Q2) of the event, and only 35% being received during the second half (Q3 and Q4). However, automated weather station at Trou aux Cerfs is the only rainfall station that receives extreme high rainfall intensities (198mm/h) during the third and fourth quartiles (Q3 and Q4). This is noteworthy as it does not take place at any other automated weather stations, where the extreme high rainfall intensities are typically confined to the first (Q1) and second (Q2) quartiles. These peak intensities occurring so late into the event could have major implications for the erosivity at this automated weather station.

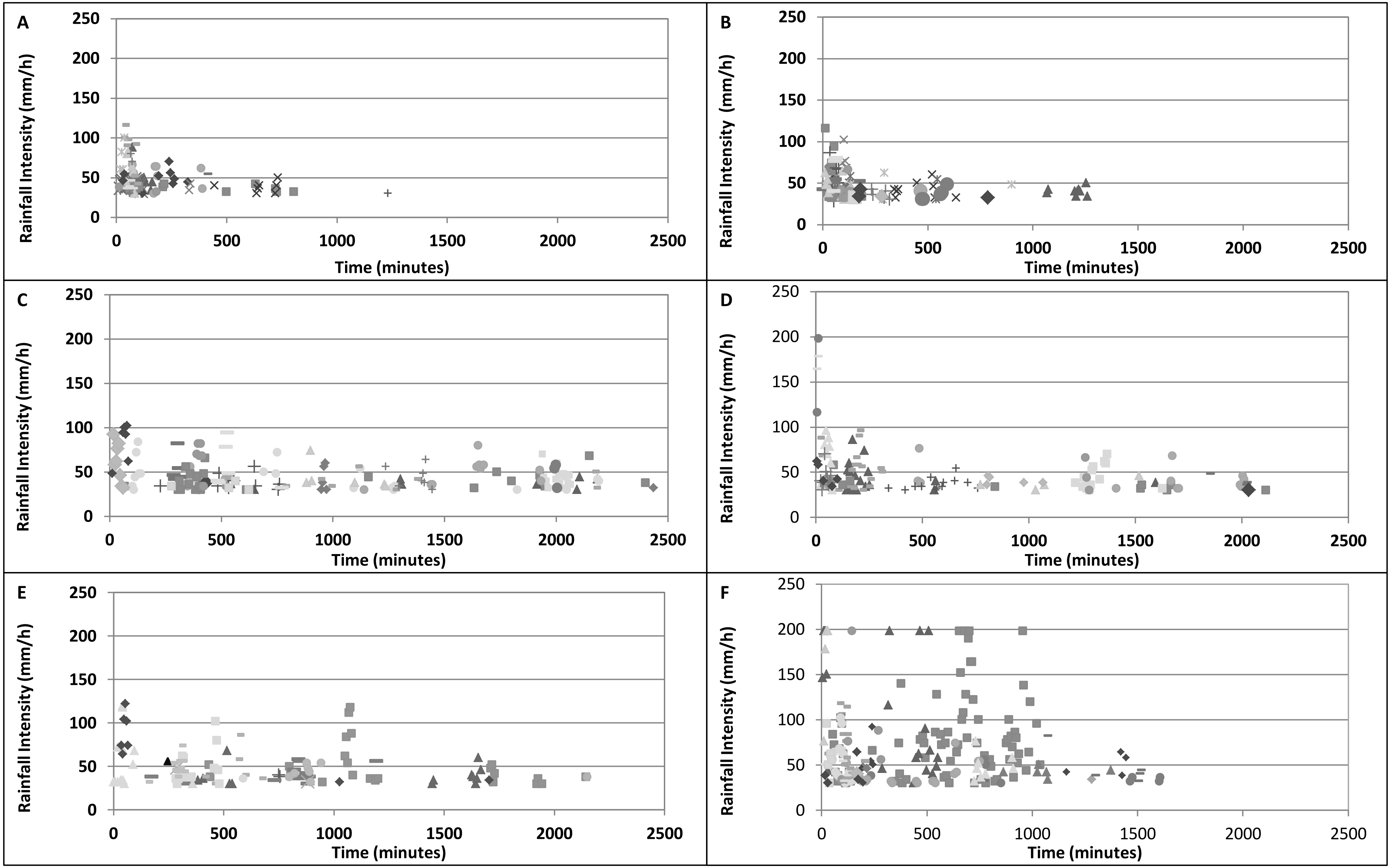


Figure 4-7: Timing of extreme rainfall intensity (above 30mm/h) generated by the erosive events at the respective stations (each individual event is presented by a different symbol). (A) Albion;(B) Beaux Songes; (C) Arnaud; (D) Monbois; (E) Grand Bassin; (F) Trou aux Cerfs

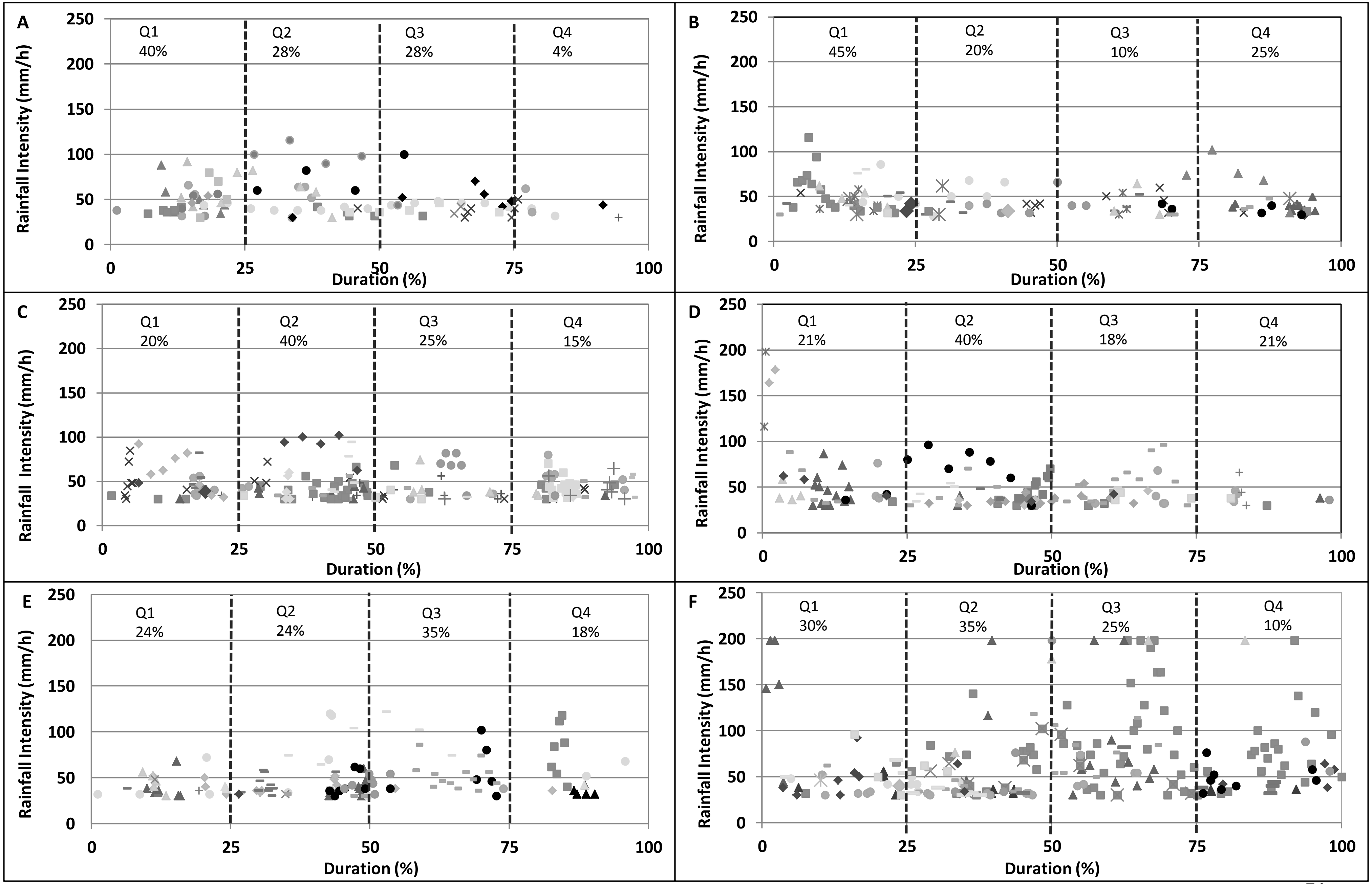


Figure 4-8: Timing of extreme rainfall intensity (above 30mm/h) as a function of rainfall duration at the respective stations (each individual event is presented by a different symbol). (A) Albion; (B) Beaux Songes; (C) Arnaud; (D) Monbois (E) Grand Bassin; (F)Trou aux Cerfs

4.4. Climatic drivers and temporal analysis of erosive events

The eight weather systems prevailing over Mauritius as identified by Fowdur *et al.* (2014) (see Table 3-3) were each given representative symbols which were applied to the 120 events. These symbols were utilised in an attempt to classify the events into the appropriate weather systems from synoptic data available from the Mauritius Meteorological Services Monthly Bulletins of Climatological Summaries, Mauritius Meteorological Services website (MMS, 2014a) as well as the Météo-France Réunion (Météo-France, 2015) website. Although the lack of synoptic data at the event scale was a limitation to organising the events into the appropriate weather systems from the available data, an attempt has been made to classify the events accordingly.

More than half 63 (53%) of the total events analysed for this project are related to cyclonic activity within the vicinity of the island. Only 5 (4%) of the total events are related to non-cyclonic events, and have been identified as frontal mesoscale rainfall caused by cold fronts (MMS, 2008). Due to the lack of available synoptic data, 53 (44%) of the total events have unknown weather systems. During the study period, a few tropical cyclones were within the vicinity of the island. Upon considering the dates that each of the 120 events occurred, a number of dates coincide with rainfall caused by cyclonic activity occurring around the island. Numerous cyclonic events occurred concurrently at all six stations. The most important dates during which concurrent events occurred include; 20-26 March 2005 and 02-04 March 2006.

The period from 22 to 26 March 2005 is remarkable as it coincides with cyclone Hennie that was classed as a Severe Tropical Depression (MMS, 2014c). Noticeable pre-cyclonic rainfall also occurred at all six automated weather stations from 18 to 21 March 2005 (Météo-France., 2015). Hence, cyclone Hennie represents rainfall from multiple events at all of the automated weather stations. As a result cyclone Hennie represents at least two of the events at each of the six automated weather stations. While the rainfall from events associated with Cyclone Hennie occur on the same day, the events rank differently at each station based on the ranking of the total kinetic energy content generated of the respective event. At the inland station of Arnaud, rainfall from cyclone Hennie corresponds to three of top twenty events. At the coastal stations of Albion and Beaux Songes rainfall from cyclone Hennie is event no. 9 and event no. 7 respectively. The rainfall depth, duration and erosivity for the event recorded at the Albion station is much higher than the rainfall depth, duration and erosivity at Beaux Songes. Rainfall from cyclone Hennie is represented by event no. 1 at Arnaud, Monbois and Grand Bassin. Despite the station at Grand Bassin has the highest erosivity of these three stations, the station at Arnaud has the highest storm duration, depth and Total Kinetic energy. Even though rainfall from event no. 3 at Trou aux Cerfs represents cyclone Hennie it has higher rainfall erosivity than the rainfall from the event at Monbois, where cyclonic Hennie is no. 1.

The start time of rainfall from Cyclone Hennie is also variable. Rainfall is first recorded at Arnaud at (08:48) on the 22 March 2005, then 36 minutes later at Grand Bassin, followed by Monbois a further 4 hours and 24 minutes later, then 1 hour later it is recorded at Trou aux Cerfs, then a further 3 hours and 42 minutes later at Albion. Finally the rainfall from the event commences at Beaux Songes 12 minutes after Albion. Rainfall from this cyclonic event ends on the 24 March 2005 at both low altitude stations but continues until the 25 March 2005 at all the other automated weather stations.

Another important period is 02 March 2006 to 04 March 2006 which coincides with Cyclone Diwa (MMS, 2014c). Even though the rainfall from Diwa represents an event at all six stations, the events rank differently (due to kinetic energy content). Cyclone Diwa represents event no. 3 at Albion, whilst it is event no. 4 at both Monbois and Trou aux Cerfs and at Beaux Songes it corresponds to event no. 5. At Arnaud it is event no. 2 and event no. 8 at the Grand Bassin rainfall station. The rainfall received from Cyclone Diwa started a day earlier at Arnaud and Trou aux Cerfs than at the four other automated weather stations. The rainfall from the events at Arnaud and Trou aux Cerfs commenced within an hour of each other, 18:24 at Arnaud and 17:24 at Trou aux Cerfs. Four of the six events associated with rainfall from Cyclone Diwa extended one day past the date on which the tropical cyclone officially ended. The event at Beaux Songes is the shortest, and only occurs from 03 March 2006 (22:12) to 04 March 2006 (20:42).

Even though the two concurrent events discussed above represent cyclonic events some of the other concurrent events coincide with non-cyclonic rainfall, namely cold fronts, sea breezes induced rainfall and thunderstorms. Frontal mesoscale rainfall was caused by two cold fronts crossing the island on the 16 and 19 of May 2008 (MMS, 2008). These two cold fronts were followed by easterly waves causing a very unstable atmosphere (MMS, 2008). These cold fronts caused heavy rain and thunderstorms across the entire island (MMS, 2008). Despite, this cold front bringing widespread rainfall to the island- it is only recorded as erosive events at the automated weather stations at Arnaud and Grand Bassin. Though frontal mesoscale rainfall from this cold front represents event no. 3 at both Arnaud and Grand Bassin, the erosivity of this event is noticeably higher at Arnaud than it is at Grand Bassin. Pre-cold frontal uplift was recorded on the 14 May 2008 at the coastal station of Albion (event no. 17) (MMS, 2008).

Another noteworthy event occurred at Albion on the 8 March 2004 (Nel *et al.*, 2012). This is represented by event no. 8. During the 90 minute rainfall event, 59 mm of rainfall was received and no rainfall was recorded at any of the other rainfall stations. Hence, it is assumed that it was non-cyclonic in nature and was potentially due to a localised convective rainfall event associated with thunderstorms at a storm scale.

The seasonal distribution of the erosive events is noteworthy. Mauritius has two predominant annual weather seasons; a warm, wet summer from November to April and a cool dry winter from May to October (Padya, 1989). Therefore, the seasonal distribution of the 120 events was done according to this classification. Events occurring during the summer months account for 102 (85%) of all 120 events, while those occurring during the winter months only account for 18 (15%). The total rainfall depth (mm) received from all 120 events was 14045.2 mm, and 81% was received during the summer months and 19% was received during the winter months of May to October. Granted the automated weather station at Albion had the highest number of events during the winter months (20%), this winter rainfall only accounted for 24% of the rainfall received at this station. Rainfall received at Arnaud during the summer months is 92% of the total rainfall received at this station. At Monbois, 87% of the rainfall received at this station was during the summer months. Trou aux Cerfs (the station with the highest altitude) received 67% of the rainfall during the summer months and 33% during the winter months. Event no. 1 and 2 at Trou aux Cerfs occur during the winter months. This event at Trou aux Cerfs (event no.1) is responsible for 26% of the total KE and 49% of the rainfall erosivity received at this station, hence this event has the potential to be deemed as highly erosive. It is highly likely that cold fronts were responsible for these events as the passage of cold fronts throughout the winter months is generally associated with an increase in convective activity and subsequent rainfall over Mauritius, particularly in areas with distinct orographic characteristics (Padya, 1989) such as those surrounding the automated weather station at Trou aux Cerfs. The annual distribution of the events are substantial, 108 (90%) of 120 of the events occur during the first half of the year from January to June, with January to March receiving the vast majority of the events (87 of 108 events). In contrast, only 12 of the 120 events occurred during the second half of the year.

In summary, Chapter 4 has presented the results of the objectives set out following the methodology discussed in the previous chapter. The most important findings and observations have been highlighted and will be discussed in the next chapter, Chapter 5. Although, all the events exhibited temporal variability in rainfall depth and rainfall intensity, some common intra-storm characteristics are present amongst all the events. In all cases, the influence of the orography on the spatial and temporal variation of the events is apparent. Events were not restricted to tropical cyclones, but also included other weather systems such as cold fronts, sea breezes induced rainfall and thunderstorms. The intra-storm attributes of the events have potential implications on soil erosion risk. These will be discussed in depth in the following chapter.

Chapter 5 : Discussion

The tropical environment of Mauritius is attributed to its size, location, topography, local island-scale weather systems and maritime climate. This consequently allowed the intra-storm investigation of erosive events (based on the 'total kinetic energy generated') to be contextualised within a tropical island environment. Six automated weather stations provided the opportunity to investigate how elevation can influence the intra-storm attributes of rainfall parameters. Although no other weather station data were available at the time of the study, the automated weather stations utilised for this project represent rainfall totals at two geographical extremes of the island (low and high totals). Considering the results from the previous chapter, this chapter discusses the identification of the erosive events from the data provided by the Mauritius Meteorological Services (MMS), followed by the role of Mauritius' physiography on spatial and temporal differences to the within-storm distribution of rainfall depth, extreme rainfall intensity and cumulative kinetic energies. Then the influence of elevation, associated with orographic lifting, has on the erosive events at the geographical extremes of the island will be discussed. The chapter concludes in a discussion of the potential implications of the erosive events on soil erosion risk.

5.1. Identification of the erosive events

Only one other study (Nel, 2007) has identified and analysed intra-storm attributes of rainfall parameters. The current study has attempted to analysis double the number of erosive events utilised in the initial study by Nel (2007) as well as increased the time period (duration) in order to provide a greater intra-storm analysis in an attempt to include more weather event types. A climatological analysis of the erosive events, not done by Nel (2007), was also undertaken in this study. An attempt was made to classify the erosive events into the appropriate synoptic weather systems. However, the absence of synoptic descriptions of the daily weather patterns and the lack of synoptic data at the event scale was a limitation to organising the events. However, some assumptions were made using the information available from the Mauritius Meteorological Services Monthly Bulletins of Climatological Summaries, Mauritius Meteorological Services website (MMS, 2014a) as well as the Météo-France Réunion (Météo-France, 2015) website.

While a few months of the data acquired from the MMS were missing or incomplete, the synchronicity of the data allowed for the direct inter-station comparisons. Subsequently, the events utilised in this intra-storm analysis may possibly not have been the actual top twenty events at each automated weather station, but were the top measured events at each station. These events were also not defined in the context of extreme events, they were simply taken as the twenty events with the highest total kinetic energy producing events from an erosivity perspective at the six automated weather stations.

5.2. Spatial and temporal variations of erosive events

Temporal and spatial variability of erosive events and the associated rainfall erosivity is important in tropical areas, as rainfall erosivity is affected by storm type and varies with topography and altitude (Salako, 2007). On Mauritius, spatial and temporal variability is evident in the characteristics of the erosive rainfall recorded at the stations. Although temporal variability with regard to rainfall depth is demonstrated by the 120 events, a common characteristic amongst all the events is that more than 80% of the rainfall generated is within the first 2500 minutes of the event. Therefore, visible tapering off of the storm duration occurs after 2500 minutes at the majority of the stations analysed for this project. However, the events at Grand Bassin are the exception, where despite noticeably longer storms occurring, 80% of the cumulative rainfall is received within the first 2500 minutes from the onset on the event. The location of this rainfall station, on the southern, leeward side on the island could have a significant impact on the duration of the erosive events.

Mauritius experiences two distinct seasons, a rainy summer season from November to April, and drier winter season from May to October (Padya, 1989; Nigel & Rughooputh; 2010a; Nel *et al.*, 2012; Staub *et al.,* 2014). The seasonality is predominately due to the migration of the Inter Tropical Convergence Zone (ITCZ) (Fowdur *et al*., 2014). The ITCZ is closest to Mauritius from January to March, subsequently warm season depressions affect the island, resulting in high rainfall and markedly more erosive events. This is evident from the 120 events, with 73% of the events occurring from January to March during the southward migration of the ITCZ towards the subtropical latitudes and the occurrence of tropical cyclones (Staub *et al*., 2014). During the winter months, the ITCZ is located north of the equator causing anticyclonic conditions with the interruption of the occasional cold front that are associated with an increase in convective activity over the island (Staub *et al*., 2014). While only 15% of the 120 events occurred during the winter, large percentages of winter rainfall events on Mauritius have been deemed as erosive and is rainfall associated with non-tropical cyclones that posed substantial soil erosion risk (Nigel & Rughooputh, 2010b; Nel *et al*., 2012).

At the inland automated weather stations of Arnaud and Monbois, 92% and 87% respectively, of the rainfall associated with the events is received during the summer months when the erosion risk is most significant. At the automated weather station of Trou aux Cerfs, 67% of the erosive rainfall is received during the summer months, and 33% during the winter months, which is similar to findings made by Anderson (2012); Mongwa (2012) and Nel *et al.* (2012). Therefore the seasonal distribution of erosive rainfall received at this station is better than at the other automated weather stations, indicating that this station receives more erosive rainfall during winter than any other station. Event no. 1 and no. 2 at Trou aux Cerfs are assumed to be cold fronts. The passage of cold fronts throughout the winter months is generally associated with an increase in convective activity and subsequent rainfall over Mauritius, particularly in areas with distinct orographic characteristics (Padya, 1989) such as those surrounding the automated weather station at Trou aux Cerfs. Event no. 1 at Trou aux Cerfs is responsible for 49% of the rainfall erosivity received and accounts for the highest total rainfall depth received from the 120 events. Thus, these two non-tropical cyclonic events pose huge erosional risks at this station. Elevation is responsible for Trou aux Cerfs receiving fewer total events than the other stations located on the central interior (Anderson, 2012; Nel *et al*., 2012).

Mauritius, similar to other tropical islands, has a noticeable spatial difference in rainfall across the island (Bender *et al.,* 1985; Barcelo *et al.*, 1997; Yen & Chen, 2000; Fowdur *et al.*, 2006). Flatter, lower coastal areas generally remain drier than the central plateau throughout the year, except in January and February when the mean annual rainfall is high even on the west coast, or the leeward side of the island due to the southeasterly tradewinds (Staub *et al.,* 2014). Rainfall variability of the erosive events is comparable to the mean annual rainfall which varies longitudinally across the island from 1400 mm in the eastern coastal lowlands, to 4000 mm on the uplands and 800 mm along the western coastal lowlands (Rughooputh, 1997; Dhurmea *et al.*, 2006; WRU, 2007). This spatial differentiation is evident in the characteristics of the erosive rainfall at the stations, with a noticeable increase in all intra-storm variables measured at the coastal versus the interior stations (Nel *et al.*, 2012). Rainfall received from the events at the west coast station (Albion and Beaux Songes) is noticeably less than the erosive rainfall of the uplands station (Arnaud, Monbois, Grand Bassin and Trou aux Cerfs).

5.3. The influence of elevation on the erosive events at the respective stations

Orography is the influence of mountain topography on subaerial conditions and the most striking orographic effect is on the distribution of rainfall across an area (Terry & Wotling, 2011). Places characterised by complex topography, such as Mauritius, typically receive rainstorms because topographic forms drawing out atmospheric moisture through orographic precipitation mechanisms (Barstad & Smith, 2004). The best known relationship of the orographic effect- rainfall increases with elevation (Prudhomme & Reed, 1998). Mauritius' rainfall gradient is due the orographic effects of the South Easterly trade winds interacting with the south-eastern mountain range and the central uplands (Fowdur *et al.*, 2006). Therefore, distribution of rainfall is highly dependent on an island's topography (Hoyos *et al.,* 2005; Dhurmea *et al.,* 2009; Senapathi *et al*., 2010). However, the results from this project contradict the general relationship that rainfall increases with elevation and better align themselves with findings made by Hoyos *et al*. (2005), who found that in the tropical mountainous areas of the Colombian Andes, seasonal rainfall increases to a certain elevation then decreases. Even though the change in elevation on Mauritius is less than the change in elevation noted by Hoyos *et al.* (2005), the events at Trou aux Cerfs (614m.a.s.l; the station with the highest altitude), had a lower total rainfall depth than the other stations on the elevated central plateau, namely Arnaud (576m.a.s.l), Monbois (590m.a.s.l) and Grand Bassin (605m.a.s.l). Hence, the importance of elevation, surrounding geographic features and microclimates on the rainfall distribution and characteristics that an area experiences.

Owing to variations in diurnal exposure, elevation and distance from the sea, a succession of island scale climatic regions or microclimates exist (Nigel & Rughooputh, 2010a). Twenty seven microclimates have been identified by Padya (1989), despite the small size of the island. The substantial variations in the microclimatic characteristics of Mauritius are derived from the climate (Rughooputh, 1997). Subsequently, the geographic features and microclimates of the landscape surrounding of the weather stations influence the rainfall distribution, erosivity and rainfall intensity of the erosive events. Even with both Albion and Beaux Songes being situated on the west coast, Albion (12 m.a.s.l) receives more rainfall than Beaux Songes (225 m.a.s.l) thus highlighting the influence which the rain-shadow and surrounding geographic features has on Beaux Songes and the influence the Indian ocean potentially has on rainfall received at Albion.

The westward or leeward orientation of the orographic barrier is also important when associating rainfall and elevation (Staub *et al*., 2014). The diverse microclimates on the island could be used to explain and interpret the intra-storm differences between the stations on the interior of the island. Despite the automated weather stations of Arnaud, Monbois, Grand Bassin and Trou aux Cerfs are all located on the elevated interior, the distinction should be made to exactly where on the elevated interior each station is found. Arnaud and Trou aux Cerfs stations are located within the same microclimatic zone on the leeward side of the central plateau and the Monbois station is located on the westward side of the central plateau. The southern and east coasts of Mauritius received higher rainfall than the west and north coast due to the prevailing southeasterly trade winds (Fowdur *et al*., 2014; Staub *et al*., 2014).

As the Grand Bassin station is located on the boundary between the central plateau and the south uplands, it is speculated that the uplands located near this station could affect the development of erosive events, and in turn affect the local climate around the station (Anderson, 2012). Influences of the southeasterly trade winds could be more apparent at Grand Bassin due to the geographic features and microclimate of the landscape surrounding the weather station. The unique location of Grand Bassin is responsible for this station receiving the highest rainfall depth of all six stations (Anderson, 2012). Thus results indicate that the intra-storm attributes of rainfall events are strongly dependent on the geographic features within the immediate surroundings of the weather stations, and distance between weather stations did not always lead to predictable differences in intra-storm attributes

Rainfall intensity and erosivity increases with elevation; with the station at Trou aux Cerfs recording the both the highest maximum intensity (I_{30}) and the highest rainfall erosivity. This is dissimilar to the Nel *et al*. (2007) study in the Drakensberg that covered an altitudinal range (1060m to 3165 m.a.s.l), where the lower altitude stations recorded the higher maximum intensities and erosivities than those at higher altitudes. Differences between the temperate (Drakensberg) and tropical (Mauritius) could be attributed to the differences in dominant rainfall generating mechanisms occurring in each region and altitudinal range (ΔH), influencing the amount of precipitation received as well as the intensity and kinetic energy of the rainfall. The main rainfall generating mechanism in most tropical region are predominately convection and cyclonic, and as a result the tropics receive more rain at higher intensities than the temperate regions whose rainfall is dominated by mid-latitude cyclones and consequently larger EI_{30} values are observed in the tropics (Hoyos *et al.,* 2005). Since, the erosive power of the precipitation is accounted for by the rainfall-erosivity factor R, the individual stations all experience different erosivity because of the combined effect of magnitude, duration and intensity of each rainfall event (Bonilla & Vidal, 2011). Hence, if all other parameters are kept constant, soil loss is directly proportional to the rainfall erosivity (Wang *et al*., 2002) Trou aux Cerfs would consequently have the highest rates of potential soil loss.

Regardless of knowing that rainfall erosivity of an event is influenced by the intra-storm distribution of rainfall intensity, it is only recently that such variability has been incorporated into soil-erosion modelling (Parsons & Stone, 2006). Rainfall intensity is regarded as a fundamental control of interrill runoff and erosion because rainfall intensity can have an effect on the size distribution of the detached sediment as well as the total amount of detached sediment (Parsons & Stone, 2006). Since runoff is inversely related to infiltration the effect of rainfall intensity on runoff can be understood through its effects on infiltration (Parsons & Stone, 2006). Timing of the peak rainfall depth and peak extreme intensity is paramount to the infiltration as well as the potential runoff and erosion experienced at each station.

Although the events display variability in both rainfall depth and rainfall intensity, similarities in the timing of the peaks are present. In general, the peak rainfall depth corresponds almost directly to the peak rainfall intensities experienced. Peak rainfall depth and peak rainfall intensities are received during the first half of the event at both low altitude stations (Albion and Beaux Songes) as well as Monbois on the windward side of the central plateau. At the Grand Bassin and Arnaud automated weather stations the peak rainfall is more variable, but it still corresponds to the peak intensities occurring during the first half of the event. The automated weather station at Trou aux Cerfs is the exception, where the peak rainfall and intensities are received during the middle part (Q2 and Q3) of the event. Events peaking towards the end of the event could have detrimental effects on peak runoff rates, potential soil loss and the overall erosivity. Elevation might be responsible for the majority of the events at Trou aux Cerfs having their peak rainfalls and intensity during the second half of the event. It should be emphasised that despite this, the erosive events show high temporal variability with no event showing constant intensity over time. The timing of the peak rainfall depth and peak intensities as well as the specific storm pattern have important implications for the amount of soil loss and the size of the particle being eroded. Rainfall intensity is a key measure of rainfall erosivity, for example a region with higher rainfall intensities could have more or similar erosivity when related with a region with higher rainfall amount and more frequent rainfall (Salako, 2008).

Erosive events peaking in intensity towards the end in conjunction with varying-intensity events have the highest peak runoff rates and soil loss (Nel, 2007). The highest potential soil erosion risk is anticipated to occur at Trou aux Cerfs as this station received the most consistently high rainfall intensity of any station. Parsons & Stone (2006) emphasise that events with higher rainfall intensity, are responsible for higher percentages of coarser particles and a higher clay content being found in the eroded sediment because of the breakdown of the cohesion between the particles. Under natural rainfall conditions the peak sediment transportation coincides with the peaks in rainfall intensities (Moore, 1979). Consequently, the erosivity of the erosive rainfall in Mauritius is strongly influenced by both the timing of peak intensity and the specific event pattern.

A similar intra-storm study conducted in the Drakensberg by Nel (2007) found 70% of the erosive events measured have intensities above the 25mm/h during the first 100minutes of event duration and all the stations receive a high proportion of peak rainfall intensity within the first half of the event, then the erosivity of erosive rainfall in the Drakensberg could be moderated by the within-storm distribution of rainfall intensity. The Drakensberg study shows that despite common tendencies of rainfall event structure between events and between stations can be distinguished, the within-storm distribution indicated that no two events are precisely similar and no two stations in this region show similar distribution of event patterns. The study by Nel (2007) implies that the structure of erosive rain is both site and event specific, and due to the many spatial disparities exist for intra-storm rainfall distribution which exist between the small number of stations measure in this study, it is not possible to extrapolate the study by Nel (2007) for the Drakensberg region as a whole. However, the events experienced on Mauritius share some common characteristics between events and stations. The intra-storm analysis suggests despite the spatial differentiation in the structure and nature of the erosive rainfall, generalisations can be made regarding the potential erosion experienced in the coastal and interior regions of the island.

5.4. The potential implication of the erosive events on soil erosion risk

Soil erosion risk, like rainfall, on Mauritius varies seasonally (Le Roux, 2005; Nigel & Rughooputh, 2010b). Considerable soil erosion risk in summer is as a result of tropical cyclones, thunderstorms and orographically-induced rainfall (Le Roux, 2005; Seerutten *et al.*, 2007). Just over half (52%) of the 120 events are related to cyclonic activity and posed high erosion risk, as between 48% and 68% of the soil erosion on the island is associated with cyclonic activity (Seerutten *et al.*, 2007). Furthermore, the erosion risk maps by Nigel & Rughooputh (2010b) show that all land cover and cultivation types on Mauritius are at risk of severe erosion, particularly during intense cyclonic events during January and February. While the events support these notions, it also highlights the importance of considering non-tropical cyclones which were also shown to pose substantial erosion risk.

The greatest risk of soil erosion on Mauritius typically occurs from December to April each year, and is linked to the severe tropical cyclones and accompanying torrential rainfall experienced during this period (Nigel & Rughooputh, 2010b; Nigel, 2011). Furthermore, the lack of vegetation in December results in this month posing the highest erosion hazard (Nigel & Rughooputh, 2010b). The humid and super-humid climates of the central interior (Arnaud, Monbois, Grand Bassin and Trou aux Cerfs) are inclined to experience greater erosion than the sub-humid coastal regions of the island (Albion and Beaux Songes) (Nigel, 2011). Soil erosion risk then decreases to moderate levels during March to April and is very low during May to October (Nigel, 2011).

Erosion risk patterns closely, and inversely, follow patterns of vegetation cover on the island. Vegetation cover is at its greatest during March, following on from the peak rainfall depth received during February, and consequently provides the most protection from erosion during this time. As rainfall decreases from April to November so does the vegetation cover, causing an increase in the erosion hazard of rainfall (Nigel & Rughooputh, 2010b). Consequently, the potential soil erosion risk is highest during the earliest part of the wet season (December) when the majority of the rainfall occurs and vegetation cover is at its lowest and does not yet provide adequate protection to the soil (Morgan, 2005; Nigel & Rughooputh, 2010b). The erosive events in this study follow the same seasonal rainfall pattern, thus exacerbating the soil erosion when the erosion risk is at its highest.

On Mauritius, areas with flat terrain and lowly erodible soils, like those found at Albion, have low erosion susceptibility (Nigel, 2011). Furthermore, areas with undulating terrain, similar to the terrain at Beaux Songes, exhibit moderate erosion susceptibility. Mountainous areas and valley sides, comparable to the terrain at Arnaud, Monbois, Grand Bassin and Trou aux Cerfs have very high levels of erosion susceptibility. The central elevated plateau, the mountain environment and the southern and eastern regions also have the highest soil risk (Nigel & Rughooputh, 2010). Additionally these regions also correspond to the areas with the highest annual rainfall. However, the land cover in the mountainous regions and valley sides provides some protection against soil erosion, especially due to the existence of forests and other natural dense vegetation (Nigel, 2011).

Natural vegetation cover is also strongly influenced by orographic effects, which promote high levels of variability in rainfall, and result in stark differences in natural vegetation between the wet windward and the drier leeward sides of the island (Terry & Wotling, 2011). The sparse shrub-like natural vegetation in conjunction with the extensive sugarcane cultivation in the drier, leeward, west coast region could result in the soils here being more vulnerable to erosion than in the central region of the island which has denser vegetation, known to cope with a higher rainfall intensity and therefore be more resistant to erosion by direct rainfall (Le Roux, 2005).

On the contrary, the extensive sugarcane cultivation on the west coast could aid in decreasing soil erosion, as the soil under the sugarcane is not disturbed during harvest and a dense protective cover is provided within less than two months after regrowth or planting (Le Roux *et al.,* 2005). However, good land management is vital as the potential for soil erosion increases substantially when the sugarcane's canopy cover decreases during harvests (Kremer, 2000). The importance of vegetation cover for reducing the erosion susceptibility of soils is further emphasized by the high erosivity values and erosion susceptibility of the upper catchment areas. These regions have erosivity values four to five times higher than coastal areas and results in a much higher erosion risk, particularly on any poorly vegetated, steep slopes (Le Roux, 2005) and vegetation therefore plays a critical role in reducing the erosion susceptibility of the soils and erosion risk in the mountainous areas on the central plateau.

Daily, monthly or annual rainfall totals are used as an indication of rainfall erosivity in all soil risk models and assessments on Mauritius (Kremer, 2000; Le Roux *et al.,* 2005; Nigel & Rughooputh, 2010a, b). But previous studies (Le Roux, 2005; Anderson, 2012; Mongwa, 2012) have shown that the erosive events generate a large amount of the erosivity and therefore simply using the annual or monthly rainfall measurements could potentially underestimate the erosion risk at an island scale. Therefore, in order to increase the effectiveness of soil risk assessments in a tropical maritime environment, such as Mauritius, the temporal time scale of the data used should be adjusted to adapt with the storm to synoptic scale systems that dominate the risk for soil erosion (Mongwa, 2012).

There is general consensus that dramatic changes in the hydrological cycle stemming from global climatic changes will cause more erosive events in the future (Nearing *et al.,* 2004). While this is an important consideration warranting further attention, the limited duration (5 years) of the data used in this study prevented such long-term predictions regarding the intra-storm attributes of erosive events from being undertaken. Findings from Senapathi *et al*. (2010) do however indicate that rainfall frequency, at an island scale, is expected to increase and subsequently alter the temporal distribution and intensity of the rainfall and culminate in potentially increasing the erosivity of Mauritius (MMS, 2014a). Future increases in rainfall intensity could therefore be associated with higher erosivity values across all stations on the island (Anderson, 2012). Increased rainfall frequency and erosivity is particularly relevant from a meteorological and an agricultural perspective, as climate change will certainly have implications for the agricultural practices and ecological systems in Mauritius (Senapathi *et al*., 2010). The effects of climate change on the intra-storm attributes of erosive rainfall on Mauritius should therefore be investigated in future work as it potentially poses substantial changes to soil erosion risk. Soil erosion risk assessments and modelling will become critical to understanding the current soil erosion risks as well as future trends in establishing suitable and dynamic soil conservation management plans and strategies.

Chapter 5 presented a discussion based on the results that were found in Chapter 4. The importance of the geographic location of the stations and climatic zones of the differences between the intra-storms attributes experienced in different regions was addressed. Additionally, the orographic influence of the elevated central plateau on rainfall and erosivity was highlighted. Seasonality of the erosive events and vegetation cover was found to pose a substantial threat to soil erosion risk. The project concludes in the following chapter by highlighting the most significant findings made during this study.

Chapter 6 : Conclusion

The tropical volcanic island of Mauritius has a distinct elevated central plateau which rises more than 550 m.a.s.l and interacts with the island's predominantly tropical weather systems and south-easterly trade winds (Fowdur *et al.,* 2014; Staub *et al.,* 2014). This study made use of two weather stations on the west coast (Albion and Beaux Songes) and four stations on the Central Plateau (Arnaud and Trou aux Cerfs on the leeward side, Monbois on the windward side and Grand Bassin on the southern side) that provided high resolution rainfall data which enabled the first intra-storm analysis on the island. Although previous studies have been undertaken on storm kinetic energy, erosivity and soil erosion risk of rainfall in Mauritius (Le Roux, 2005; Nigel & Rughooputh, 2010a, b; Nel *et al*., 2012; 2013), very little is known regarding the intra-storm attributes and general climatology of rainfall parameters in tropical island environments. This project therefore aimed to present findings on the intra-storm attributes and climatological characteristics of erosive events at two physiographic extremes on Mauritius: the west coast and the elevated central plateau. The within-storm distribution of rainfall depth, extreme rainfall intensity, cumulative kinetic energies and general climatological characteristics of the dry west coast were compared to those of the higher altitude stations situated in the central region which received the highest rainfall. A number of conclusions are presented on the intra-storm attributes of the erosive events on a tropical island with an elevated central plateau:

6.1. Seasonality and spatial distribution of the erosive events

Rainfall seasonality on Mauritius is predominately owing to the migration of the Inter Tropical Convergence Zone (ITCZ) (Fowdur *et al*., 2014), which results in noticeably higher rainfall and more erosive events during the summer months when the ITCZ is closest to the island (Fowdur *et al*., 2014; Staub *et al.,* 2014). Although this study found that only a small number of events occurred during the winter months, a large proportion of these have been deemed erosive and were associated with non-tropical cyclonic events (Nel *et al.,* 2012). The events were, therefore, not restricted to tropical cyclones and this study has highlighted the need to consider other weather systems such as frontal mesoscale rainfall from cold fronts (MMS, 2008) which also posed substantial soil erosion risk.

Mauritius, like other tropical islands, shows noticeable spatial variation in rainfall (Bender *et al.,* 1985; Barcelo *et al.*, 1997; Yen & Chen, 2000; Fowdur *et al.*, 2006) which is also evident when considering the intra-storm characteristics of erosive events at the automated weather stations across the island. This study found a noticeable increase in all intra-storm variables measured at the coastal weather stations compared to those in the interior. The amount of rainfall during events at the west coast stations (Albion and Beaux Songes) was noticeably less compared to that of uplands stations (e.g. Arnaud, Monbois, Grand Bassin and Trou aux Cerfs). Rainfall intensity and erosivity increased with elevation and spatial differences in erosivity were related to the total number of erosive events along with the frequency of these events at each station. Differences in erosivity between the coast and the elevated interior are not only related to absolute rainfall depth, but also the nature of the events.

6.2. Elevation and the erosive events

Elevation is a key factor influencing the intra-storm attributes of the erosive events on Mauritius. This study confirmed findings from other studies which highlight the importance of the elevated interior as a topographical feature primarily responsible for the high rainfall gradient present across the island (Anderson, 2012; Mongwa, 2012; Nel *et al.,* 2012). Differences in the occurrence of erosive events across the island were documented by Anderson (2012); Mongwa (2012); Nel *et al.* (2012) which reinforced the idea of a 'rain-shadow' effect created by the interaction between the elevated central interior and the south-easterly tradewinds with other local weather systems (Fowdur *et al.,* 2014; Staub *et al.,* 2014). Definite regions were apparent across the island which displayed marked differences in rainfall intensity, intra-storm attributes, erosivity and total kinetic content. The west coast region experienced lower rainfall depth, intensity, erosivity and total kinetic content compared to the elevated central plateau region. This again highlights the influence of the elevated interior on the general rainfall characteristics of the events.

The analysis of intra-storm attributes revealed that the assumption of a positive association between rainfall and altitude is inadequate, as mean rainfall depth and kinetic energy content produced by the events measured during this study did not simply increase with increasing altitude. Rainfall received from the events at the automated weather stations indicated that rainfall increased with elevation up to a point and then decreases. This study has demonstrated that the spatial distribution of rainfall amount, intensity and erosivity stems from complex interactions between the elevation, geographic features (i.e. the remnants of the shield volcano and central plateau) and microclimates of the landscapes surrounding the weather stations, and that simply considering the distance between automated weather stations does not always lead to predictable differences in intra-storm attributes.

While the erosive events display variability in both rainfall depth and rainfall intensity, similarities in the timing of the peaks are present. Peak rainfall depth almost always corresponded to the peak rainfall intensities experienced, with the exception of Trou aux Cerfs where the events tended to peak towards the end. Such behaviour could have an increasing effect on peak runoff rates, potential soil loss and the overall erosivity of the storms. Events generally showed high temporal variability as no event had a constant intensity over time. The timing of the peak rainfall depth and peak intensities as well as the individual event characteristics are all vital to consider and may perhaps have important implications for the amount of soil loss and potential soil erosion experienced at any given location on the island.

6.3. Potential erosion risk of the erosive events

Soil erosion risk on Mauritius varies seasonally (Le Roux, 2005; Nigel & Rughooputh, 2010b). The potential for soil erosion is greatest during the earliest part of the wet season when the majority of the erosive events occur and vegetation cover does not yet provide sufficient protection to the soil (Morgan, 2005; Nigel & Rughooputh, 2010b). Erosive rainfall in combination with the amount, density and type of vegetation cover is therefore considered to be responsible for determining the potential erosion risk over the entire island. Natural vegetation on the western side of the island is sparse, shrub-like and grassy, which could potentially make the soil more vulnerable to erosion from erosive rainfall. Conversely, areas in the interior are considered less vulnerable to the effect of erosive rainfall, as natural vegetation is denser and therefore provides greater protection to the soil during these erosive events (Le Roux, 2005). However, the extensive sugarcane cultivation on the west coast decreases potential soil erosion risk. Good land management is essential in this regard as potential soil erosion increases greatly when the canopy cover of sugarcane decreases during harvests (Kremer, 2000).

An area's terrain and the erodibility of the soils greatly influence its erosion susceptibility. Flat and undulating terrain, such as found at the west coast stations of Albion and Beaux Songes, has a lower erosion susceptibility than mountainous areas and valley sides, such as that around the stations on the elevated central plateau (Arnaud, Monbois, Grand Bassin and Trou aux Cerfs). Despite the dense natural vegetation of the central plateau acting to protect the soils against erosion, this region is actually considered to be most at risk. This is as a result of the steep terrain and soil type causing a high level of erosion susceptibility in addition to the large amount of erosive rainfall and high rainfall erosivity received (Nigel, 2011). The intra-storm distribution of rainfall in this area also worsens the situation as the rainfall generated from the erosive events has the ability to generate high peak runoff rates in the latter parts of the storms thereby enhancing the amount of soil loss experienced.

Despite the longstanding recognition that the rainfall erosivity of an event is influenced by the intra-storm distribution of rainfall intensity, such variables have only recently been incorporated into soil-erosion modelling (Parsons & Stone, 2006). Daily, monthly or annual rainfall totals are frequently used as an indication of rainfall erosivity in all soil risk models and assessments on Mauritius (Kremer, 2000; Le Roux *et al.,* 2005; Nigel & Rughooputh, 2010a, b). But previous studies (Le Roux, 2005; Anderson, 2012; Mongwa, 2012) have shown that event scale rainfall generate a large amount of the erosivity experienced and therefore simply using annual or monthly rainfall measurements may underestimate the erosion risk at an island scale. Therefore, in order to increase the effectiveness of soil risk assessments in tropical maritime environments, such as Mauritius, the temporal scale of the data used should be adjusted to adapt with the storm (event scale) to synoptic scale systems that dominate the risk for soil erosion (Mongwa, 2012). The highest possible resolution of rainfall data should also be utilised to ensure more accurate soil risk assessments and greatly assist Mauritian authorities in defining and prioritising key areas for soil conservation measures, promote better land use management, agricultural practices and conservation planning to maximise the limited land resources on the island.

Erosion risk models and assessments generally assume that erosive rain falls at a constant intensity yet the intra-storm analysis of this study demonstrates that constant intensity erosive events are non-existent on Mauritius and presumably not in any other tropical island environment. This project has therefore shown that intra-storm rainfall characteristics have important implications for soil erosion risk, especially in the elevated central plateau of Mauritius, and that a certain complexity is evident regarding the characteristics of the erosive events measured at specific stations.

6.4. Research needs and recommendations

Although the erosive events on Mauritius share common characteristics between events and stations, the within-storm distribution indicated that no two events are identical and no two stations show comparable rainfall event pattern distributions. However, the intra-storm analysis of the erosive events suggests despite the spatial differentiation in the structure and nature of the erosive rainfall generalisations can be made regarding the potential erosion experienced in the coastal and interior regions of the island. Furthermore, the inclusion of more automated weather stations is warranted as this will provide a better representation of rainfall characteristics across the island. Researchers are encouraged to determine the possible erosional relationships between different event structures and synoptic conditions on the island. Should more data become available at the sufficient synoptic scale, it is suggested that erosive events with similar synoptic conditions are grouped and the intra-storm attributes associated of each synoptic condition be established. This will aid greatly in determining the potential erosional impact associated with each synoptic condition relative to its intra-storm attributes and provide further the accuracy in erosion risk assessments on the island of Mauritius. Lastly, the findings from this study are directly applicable to the well-known and frequently applied (R)USLE model. However, the results, specifically the within-storm distribution of rainfall depth, extreme rainfall intensity and general climatological characteristics of the erosive events, found in this study also have the potential to improve not only the future (R)USLE erosion models, but also other more sophisticated non-(R)USLE modelling efforts, including modelling the sediment yield similar the advanced event-based models described by van Rompaey *et al*. (2005) including the WEPP (Nearing *et al.* 1989), LISEM (De Roo, 1996), EUROSEM (Morgan *et al.*, 1998), EROSION-3D (Schmidt *et al.*, 1999). Spatially-distributed sediment delivery models that assess the sediment yield usually have higher data demands, especially with regards to rainfall and the description thereof to ensure the accurate estimations of sediment yield.

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