

**DEVELOPING RAINFALL EROSIVITY EQUATIONS FOR USE IN  
TANZANIA WITH LIMITED RAINFALL INTENSITY DATA**

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**A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN LAND  
USE PLANNING AND MANAGEMENT OF SOKOINE UNIVERSITY OF  
AGRICULTURE. MOROGORO, TANZANIA.**

**2013**

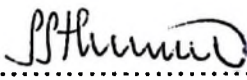
## ABSTRACT

Soil erosion by water is a growing problem in Tanzania particularly in semi-arid areas and on the mountain steep slopes. The potential for soil erosion is based on many factors. One of the factors limiting erosion control in the country is the availability of rainfall erosivity information. The study focused on developing rainfall erosivity equations for use in Tanzania using limited available rainfall intensity data. The rainfall intensity charts from 13 selected rain gauge stations were used to calculate the daily, monthly and annual rainfall erosivity ( $EI_{30}$ ) values. The calculated annual  $EI_{30}$  ranged from 570 (MJ-mm/ha-h-y) to 10 568 (MJ-mm/ha-h-y) which are typical rainfall erosivity values in the tropics. The linear, logarithmic and power equations relating the calculated annual rainfall erosivity to annual rainfall volume and Fournier index were developed for each of the 13 selected rain gauge stations. An equation relating rainfall erosivity to annual rainfall volume for all the 13 rainfall gauge stations showed to be the most accurate based on coefficient of determination ( $R^2$ ) and the standard error of estimate. The Linear equation which had an  $R^2$  value of 0.95 and standard error of estimate equal to 505.85, resulting from combined data sets for all stations showed to be the best and was thus recommended to be used for calculating rainfall erosivity in Tanzania. The recommended equation was used to calculate  $R$ - values of 278 rain gauge stations and for developing rainfall erosivity map for Tanzania. The ARC VIEW GIS using Inverse Distance Weighted (IDW) interpolation method was used to develop the Iso- erodent map of Tanzania. The predicted average long term annual rainfall erosivity ranged from about 1 140 MJ-mm/ha-h-y to 12 118 MJ-mm/ha-h-y. The highest rainfall erosivity values were

for the areas receiving highest amount of rainfall volumes including some parts of the Lake Victoria, Uluguru Mountain, part of northern and southern highlands and Zanzibar islands. The Central semi-arid areas and part of the northern highlands of the country having low annual rainfall volumes have low rainfall erosivity.

**DECLARATION**

I, MOH'D MMANGA OMAR do declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.


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## ACKNOWLEDGEMENTS

A number of people have directly or indirectly contributed towards the successful completion of this dissertation. I would like to express my deepest and sincere appreciation to my supervisor Prof. M. K. Mulengera of the Department of Agricultural Engineering and Land Planning for his great support and guidance in the whole period of my research work. I wish to thank the Tanzania Meteorological Agency (TMA) and their staff for allowing me to have full time access during data extraction. I wish also to have special thanks to Mr. J. Ndunguru and C. Malekele of TMA for their great support during data collection and analysis. I wish also to express my sincere thanks to the Tanzania Commission for Science and Technology (COSTECH) for awarding me a sponsorship for the postgraduate studies at Sokoine University of Agriculture.

I am very grateful to the staff of the Department of Agricultural Engineering and Land Planning (DAELP), especial Prof. C.V. Silayo, Head of the Department of Agricultural Engineering and Land Planning, Prof. D. N. Kimaro, Dr. S. Baanda, Prof. A. K. Tarimo, the MSc. Programme Co-ordinator and my colleague postgraduate students, for their advice and consultation during the whole period of my MSc. Programme. Also thanks to Dr. K. Ludovic and Mr. Y. Matembo for assisting me in Arc view GIS spatial analysis and preparation of the rainfall Iso-erodent map of Tanzania.

I would also extend my appreciation and thanks to my employer the Ministry of Agriculture, Food security and Cooperative for granting me the study level.

Deserving special thanks is my family, particularly my mother Mrs. F.S. Omar and brother Mr. O. Ali for supporting me spiritually and morally during the long study period. I also wish to express my heartfelt appreciation to my expected wife Rauhiya for her encouragement during the whole period of my study.

## **DEDICATION**

This work is dedicated to my dear mother, Mrs. F. S. Omar, who laid the foundation of my education.

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## LIST OF ABBREVIATIONS AND SYMBOLS

$\sigma$	Standard error of estimate
$\sigma^2$	Variance
El <sub>30</sub>	Storm erosivity/Annual rainfall erosivity
F	Modified Fournier Index
GIS	Geographic Information System
I <sub>30</sub>	Max thirty minute's intensity of rainfall storm
IDW	Inverse Distance Weighted
IIED	International Institute for Environment and Development London
IRA	Institute of Resource Assessment University of Dar es salaam Tanzania
P	Mean annual rainfall
p <sub>j</sub>	Mean rainfall for month j
R	Rainfall erosivity factor
R <sup>2</sup>	Coefficient of determination
RUSLE	Revised Universal Soil Loss Equation
TMA	Tanzania Meteorological Agency
USLE	Universal Soil Loss Equation

## CHAPTER ONE

### 1.0. INTRODUCTION

#### 1.1. Background Information

The Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978), is the most frequently used empirical model for predicting the average soil loss rate from agricultural land. Renard *et al.* (1997) came up with the Revised Universal Soil Loss Equation (RUSLE) by introducing improved means of computing the soil erosion factors. Soil erosion is a serious problem worldwide, with inestimable economic and environmental impacts because of its extent, magnitude, rate, and complex processes (Lal and Elliot, 1994). Rainfall erosivity factor (R) is one of the most important parameter of USLE or RUSLE models. It is among the natural factors affecting soil erosion, and unlike some other natural factors, such as relief or soil characteristics, it is not amenable to human modification. Among the major factors controlling soil erosion, such as vegetation cover and soil erodibility, rainfall erosivity is the most important since it is difficult to predict and control by humans. Information on the extent of soil erosion is vital to many professionals such as civil and construction engineers for the design and construction of buildings, roads, dams and utility lines, urban and forest managers for the assessment of erosion hazards and even agriculturists and soil scientists engaged in the preservation of soil loss through soil conservation strategies (Obi and Salako, 1995; Sonneveld and Nearing, 2003).

Wischmeier and Smith (1978) described rainfall erosivity as an interaction between kinetic energy of raindrops and soil surface. This interaction may result to a greater

or lower degree of detachment and down slope transport of soil particles according to the amount of energy and intensity of rain by considering the same type of soil, topographic conditions, soil cover and management. Hudson (1963) and Wischmeier and Smith (1958) showed a relationship between rain drop size and the kinetic energy. Accurate estimation of rainfall erosivity requires long term and continuous rainfall intensity data (Wischmeier and Smith (1978). Soil erosion is closely related to rainfall partly through detaching power of the raindrops hitting the soil surface and partly through the contribution of rain to runoff (Morgan, 1986).

However, such data rarely demonstrate good spatial and temporal coverage. The characteristics of the rainfall that affect soil erosion include rainfall amount, intensity, distribution, energy load and its seasonality and variability (Flanagan *et al.*, 1988).

According to Moore (1979) rainfall erosivity in East Africa, the intensity and kinetic energy parameters showed the highest erosivity hazards to be in Uganda, the Lake Victoria, part of the Kenya Highland and the Coast of southwestern of Tanzania. The lowest of the erosivity hazard occurred in the drier areas of Kenya and Tanzania. Due to the lack of accurate information of rainfall erosivity in Tanzania, this study used the limited rainfall intensity records and widely available rainfall records (i.e. daily, monthly and annual volume) to develop rainfall erosivity equations that can be used in different agro-ecological zones. The developed equations are useful tools in planning and designing soil and water conservation methods for maintaining land quality and improved land productivity for the present and future generations.

## **1.2. Problem statement and justification**

Soil erosion is a critical problem in many developing countries including Tanzania. It is a major threat for crop production. Pimentel *et al.* (1995) showed that about 12 million hectares of the agricultural land are destroyed and abandoned each year due to the soil erosion caused by poor agricultural practices. The soil erosion prediction basically requires information on rainfall erosivity. However, rainfall erosivity database in Tanzania is still limited. Therefore, the estimation of soil loss in Tanzania is limited by availability of rainfall erosivity information and lack of appropriate rainfall erosivity model.

The mostly used soil loss predicting model is the Universal Soil Loss Equation (USLE) or its revised version (RUSLE) (Wischmeier and Smith 1978, Renard and Freimund 1994). Therefore, this study developed equations for computing rainfall erosivity using limited available rainfall intensity data in Tanzania. Moore (1979), developed USLE/RUSLE rainfall erosivity equations based on kinetic energy for use in East Africa but the developed equations are not accurate enough for some of the agro ecological zones of Tanzania because the equations used few meteorological rainfall record stations which do not represent all agro ecological zones. The developed rainfall erosivity equations are based on the data from rainfall gauge stations in Kenya, which explain the limited accuracy when applied in Tanzania. Also Nyenza (1995) developed rainfall erosivity equations for different climatic zones of Tanzania but the developed equations do not give the USLE erosivity factor and they lack necessary information which can enable modification to give appropriate erosivity factor of the USLE/RUSLE equations. Therefore, there is a

need for developing better rainfall erosivity equations for accurate prediction of soil erosion in Tanzania.

### **1.3. Objectives**

#### **1.3.1. Overall objective**

To develop the rainfall erosivity equations for USLE for use in Tanzania with limited rainfall intensity data

#### **1.3.2. Specific objectives**

- i. To use available rainfall intensity charts of Tanzania to calculate USLE's rainfall erosivity factor
- ii. To use computed rainfall erosivity values to develop models relating the erosivity to widely available rainfall records (i.e. daily, monthly and annual rainfall volume)
- iii. To develop rainfall erosivity map of Tanzania

## CHAPTER TWO

### 2.0. LITERATURE REVIEW

#### 2.1. Soil Erosion

Soil erosion is a process in which earth materials are detached and transported across a given surface (Nyakatawa *et al.*, 2001). It is regarded as the major and most widespread kind of soil degradation and as such, affects significantly the sustainable agricultural land use (Nyakatawa *et al.*, 2001). Soil erosion has become a major environmental threat due to the growth of the world's population, and is one of the main consequences of projected land use and climate change scenarios (Gobin *et al.*, 2004). Soil degradation is recognized as a serious environmental threat in Sub-Saharan Africa (Rose *et al.*, 1994); not only due to a highly vulnerable soil-climate-ecosystem, but also because of extremely vulnerable agricultural society depending on soil quality as a fundamental base for its livelihood. Soil erosion is one of the most common and wide spread forms of soil degradation and is closely related to processes of nutrient depletion and desertification in semi-arid environments (Cobo *et al.*, 2010).

Soil erosion in Tanzania has been documented since the arrival of European explorers in the 19<sup>th</sup> century (Rapp, 1975). It is a wide spread problem facing agricultural sector in Tanzania. This problem is dominant in many regions but is most severe in Central semi – arid regions (Rapp, 1975). Soil erosion decreases agricultural productivity and leads to loss of soil nutrients, declining crop yields and reduced water availability (Renard *et al.*, 1997). Moreover, soil moved by erosion

carries nutrients, pesticides and other harmful farm chemicals into rivers, streams, and ground water resources (Nyakatawa *et al.*, 2001). The magnitude of soil erosion is well documented in the northern slope of Uluguru Mountain (Kimaro *et al.*, 2008). The soil loss prediction in Tanzania is limited by rainfall erosivity data which is one of the most important factors used in modeling soil loss. The USLE/ RUSLE (Wischmeier and Smith, 1978; Renard and Freimund 1994) are the most widely used soil loss predicting models in Tanzania. The advantage of USLE or RUSLE models in the soil loss prediction is that, they have been widely used and tested over many years and the validity and limitations of models are already known (Renard *et al.*, 1997). The limitation of the models is that they have mainly been developed using data from the Midwest of the USA, and therefore significant adjustments are required to the algorithms used to derive the key factors before the models can be applied to other areas (Renard *et al.*, 1997).

The relationship between the amount of rainfall and the amount of soil erosion depend on its annual distribution. However, erosion is worse in regions with alternating dry and wet seasons as soil moisture and cover of vegetation is not continuously maintained (Webster and Wilson, 1980). According to Lee (1980) heavy rains in the wet season with high soil moisture content retards the level of infiltration, makes it difficult for soil air to escape and leave no room for additional water, ending in increasing runoff and soil erosion.

Laws and Parsons (1943) found that soil loss by splash, overland flow and rill erosion are closely related to R-factor ( $EI_{30}$ ) of the USLE, which is the product of the kinetic energy and maximum 30-minute rainfall intensity.

The use of USLE/RUSLE models for predicting soil erosion in Tanzania is limited because not all the factors of the equations are directly applicable to Tanzania conditions (Mulengera, 1996). A major limiting factor to those models in Tanzania is rainfall erosivity factor which varies from one agro ecological zone to another.

## **2.2. Rainfall erosivity factor (R)**

Wischmeier and Smith (1978) described rainfall erosivity as an interaction between kinetic energy of raindrops and soil surface and the interaction may result to a greater or lower degree of detachment and downslope transport of soil particles according to the amount of energy and intensity of rain by considering the same type of soil, topographic conditions, soil cover and management. Lal (1995) defined rainfall erosivity as the aggressiveness of the rain to cause soil erosion. Wischmeier and Smith (1958) concluded that the best predictor of soil losses is the parameter combining kinetic energy and maximum 30 minutes intensity. Hudson (1971) reported that the kinetic energy of the rainfall with intensity greater than 25 mm/h was strongly correlated with soil erosion. Also Moore (1979) developed rainfall erosivity equations for East Africa using the Kinetic energy of the rainfall with intensity greater than 25 mm/h. The kinetic energy equations like those developed by Wischmeier and Smith (1978), Kinnel (1981) and Brown and Foster (1987) are more

widely used for estimation of storm energy using rainfall intensity recorded from rainfall intensity charts.

For this study the storm kinetic energy was computed using the equation developed by Kinnel (1981). Rainfall erosivity was estimated by combining kinetic energy and maximum 30 minutes intensity as recommended by (Wischmeier and Smith, 1958).

Due to lack of availability of long-term continuous rainfall intensity records of at least 20 years, some researchers have related the  $EI_{30}$  index with widely available rainfall data (daily rainfall volumes, monthly rainfall volumes and annual rainfall volumes) (Lal and Elliot, 1994; Moore, 1979). Other researchers have found good relationships between the rainfall erosivity and the Fournier index (Coutinho and Tomas, 1994; Cohen, *et al.*, 2005). For example Arnoldus (1980) used this technique for the estimation of rainfall erosivity in some regions of USA and Africa. Coutinho and Tomas, (1994), used Fournier index for the estimation of rainfall erosivity for three different locations in the southern parts of Portugal.

At many sites worldwide the rainfall erosivity factor ( R) has been shown to be highly correlated with soil loss (Van der Knijff *et al.*, 2000; Shi *et al.*, 2004; Hoyos *et al.*, 2005; Curse *et al.*, 2006; Onori *et al.*, 2006; Dominguez-Romero *et al.*, 2007). Several approaches used so far for estimation of rainfall erosivity have shown that the rainfall erosivity models differ from region to region. Therefore, no single accurate model has been developed so far for estimation of rainfall erosivity for different agro ecological zones in Tanzania.

Many researchers developed rainfall erosivity models in the forms of either linear equation, logarithmic or power equations. For example Moore (1979) developed rainfall erosivity in the form of Linear equation while Gregor and Matjaz (2004) developed rainfall erosivity in the form of power equation. Also Shamshad *et al.* (2008) working in Malaysia develop erosivity equation in the form of power equation. Event rainfall erosivity values are usually well fitted to the event precipitation amount by an exponential relationship (Richardson *et al.*, 1983). Renard and Freimund (1994) used both mean annual precipitation and the modified Fournier index to estimate the R-factor. Pauwelyn *et al.* (1988) developed multi linear regression equation for calculating monthly rainfall erosivity in Zambia.

The regression analysis was carried out and a linear, logarithmic and power equation was tested and therefore, the appropriate model for use in different agro ecological zones of Tanzania was developed.

## CHAPTER THREE

### 3.0. MATERIALS AND METHODS

#### 3.1. Description of the Study Area

Tanzania is located in the Eastern Part of Africa between latitude 1<sup>0</sup>S and 12<sup>0</sup>S and longitude 30<sup>0</sup>E and 41<sup>0</sup>E and cover about 77millions hectares. Except for the coastal belt, most of the country is part of the central African plateau at altitude ranging from between 1000 to1500 meters above sea level, characterized by gently sloping plains and plateaus broken by scattered hills and low-lying wetlands. Other parts of the country are covered by Mountains which include Eastern Arc Mountains and Mount Kilimanjaro located in the Northern part of Tanzania whose highest peak is at about 5950 m above mean sea level (the highest in Africa) (Kauzuni *et al.*, 1993). The country also has the famous Great Lakes which include Lake Tanganyika, whose bed is at 358 m below sea level, Lake Victoria, Lake Nyasa, Lake Manyara and Lake Rukwa (URT, 2006a). The country can be roughly divided into four main climatic zones namely: Lowland Coastal Zone, the Highlands Zone, the Plateau Zone, and the Semi-arid Zone (URT, 2006a).

The climate of Tanzania varies from place to place in accordance with geographical location, altitude; relief and vegetation cover (URT, 2006b). The altitude plays a large role in determining rainfall pattern, with higher elevations receiving more precipitation and only about half of the country receives more than 762 mm annually (Mwandosya *et al.*, 1998). Over most of Tanzania, the rains begin between mid-

October and early December and continue until May to early June (Mhita, 1990). The unimodal areas normally the rain is from November to April, the areas experiences the unimodal rainfall regime include Dodoma, Kigoma, Lindi, Mbeya, Mtwara, Rukwa, Singida, Songea and Tabora. For bimodal areas the rainfall starts in October to December as short rain and March to May as a long rain, the areas under bimodal rainfall regime include Arusha, Dar es salaam, Kilimanjaro, Kagera Morogoro, Mwanza, Musoma, Shinyanga and Zanzibar (Mhita, 1990). The mean annual rainfall varies from 500 millimeters to over 2 500 millimeters depending on altitude and latitude. However, recently, rainfall pattern has become much unpredictable with some areas/zones receiving extremely minimum and maximum rainfall per year (URT, 2006b).

### **3.2. Materials**

The rainfall intensity charts for 13 meteorological stations from the Tanzania Meteorological Agency (TMA) headquarter in Dar es Salaam were used for the rainfall intensity data extraction. The annual rainfall volumes for 278 Tanzania rainfall gauge stations recorded by the former East Africa Directorate of Meteorology headquarter in Nairobi and the TMA were used in this research.

### **3.3. Methods**

#### **3.3.1. Data collection**

The rainfall intensity data were extracted from rainfall intensity charts of the selected stations obtained from the Tanzania Meteorological Agency (TMA) headquarters in Dar-es-salaam. The meteorological stations that were used are Musoma, Bukoba, Shinyanga, Kigoma, Singida, Hombolo, Morogoro, Julius Nyerere Airport, Naliendele, Songea, Kilimanjaro (KIA), Lyamungo and Mbeya. The stations have automatic rain gauges and rainfall intensity charts and almost cover all homogenous climatic zones of Tanzania. The location of the stations and their mean annual rainfalls are as summarized in Table 1. The 10 years rainfall record period was used for most of the selected stations. This was caused by the limited availability of complete or continuous annual rainfall intensity charts in some years' records. For some of the years and some stations the rainfall intensity data of one month or more were missing and this limited the use of longer period with continuous rainfall intensity charts for all the selected stations for calculating rainfall erosivity.

**Table 1: General information for 13 rain gauge stations**

Stations	Location			Year analysed	Mean annual rainfall (mm)
	Latitude	Longitude	Altitude		
	(S)	(E)	(m)		
Bukoba	1°20' S	31°49' E	1143	10	1 955.4
Dar es salaam	6°50' S	39°12' E	53	10	1 121.4
Hombolo	5°54' S	35°57' E	640	10	592.61
Kilimanjaro(KIA)	3° 25' S	37° 4' E	896	10	529.6
Kigoma	4°53' S	29°40' E	840	10	988.9
Lyamungo	3°14' S	37°15' E	1250	10	1 526.2
Morogoro	6°50' S	37°39' E	526	10	838.1
Musoma	1°30' S	33°48' E	1147	10	889.4
Mbeya	8°56' S	33°28' E	1758	10	955.3
Naliendele	10°22' S	40°10' E	120	10	1 180.3
Shinyanga	3°39' S	33°25' E	1000	5	851.3
Singida	4°48' S	34°43' E	1307	6	674.6
Songea	10°40' S	35°35' E	1036	10	1 114.1

### 3.3.2 Calculation of rainfall erosivity

The kinetic energy was calculated using the equation developed by Kinnel (1981). Storm kinetic energy was determined by the summation of kinetic energy values time's segments' rainfall storm volumes. The kinetic energy of a storm depends on the intensities of rainfall and the amount of precipitation that is associated with such

the intensities of rainfall and the amount of precipitation that is associated with such intensities. Storm erosivity was then determined by multiplication of computed storm kinetic energy with maximum 30 minutes intensity as recommended by (Wischmeier and Smith, 1958).

#### **3.3.2.1. Daily rainfall erosivity**

The storm intensity corresponding with their storm volumes and the maximum thirty minute intensity extracted from rainfall chart were used to compute  $EI_{30}$  using equation developed by Kinnel (1981). The erosivities calculated from rainfall storm events that took place in a single day were summed to obtain the daily erosivity ( $EI_{30}$ ) values.

#### **3.3.2.2. Monthly rainfall erosivity**

Monthly  $EI_{30}$  values were then computed by summing up  $EI_{30}$  values of the daily storms that occurred during the month (Foster *et al.*, 1981).

#### **3.3.2.3. Annual rainfall erosivity**

The annual rainfall erosivity factor (R) values which were the summation of all computed  $EI_{30}$  values over a year (Renard *et al.*, 1997) were compiled for the 13 selected stations.

#### **3.3.3. Rainfall erosivity models development**

The study used monthly and annual rainfall volumes and Fournier index values for the 13 stations to establish the relationship with erosivity values. The most suitable

and accurate models were recommended for the estimation of rainfall erosivity values for the other station of agro ecological zones. Two regression approaches were used as explained below:

o

1. The first approach involved development of regression models (Linear, Logarithmic and Power equation) using annual erosivity values ( $EI_{30}$ ) and annual rainfall volumes.
2. The second approach involved development of regression models between erosivity values ( $EI_{30}$ ) and modified Fournier index. The modified Fournier index was calculated using mean monthly rainfall. According to (Renard and Freimund, 1994) the modified Fournier index is expressed as

$$F = \frac{\sum_{j=1}^{12} p_j^2}{P} \dots\dots\dots (1)$$

Where, F is the modified Fournier index,  $p_j$  is the mean rainfall (mm) for month j and P is the annual rainfall (mm).

The regression was done by using SPSS software package. The three forms of equations were statistically tested to identify which form is the best to represent different climatic zones in estimating rainfall erosivity according to the data analyzed. Accuracy of the equations was assessed using the coefficient of determination ( $R^2$ ) and standard error of estimate (Moore, 1979). The comparison of

the equations was carried out based on the coefficient of determination ( $R^2$ ) and error analysis (Shamshad *et al.*, 2008).

#### **3.3.4. Development of spatial erosivity models**

Based on annual rainfall volumes and Fournier index the regression equations were developed for each selected station. Similar models developed for each of the meteorological stations values were used to identify which stations could be combined in developing spatial erosivity models. The different features such as geographical location, distribution of rainfall, starting and ending of the rain seasons and rainfall amounts were used for grouping the areas into zones. The similarities of the constant values of the model developed for each meteorological station also were used as indicators for grouping together the models (i.e Linear, Logarithmic and Power regression). Finally the data for all stations were grouped together and tested for single model combining all the agro ecological zones of the country.

#### **3.3.5. Development of rainfall erosivity map**

The primary and secondary data of rainfall volume were used for the development of rainfall erosivity map. The secondary data of rainfall volume from former East Africa Directorate of Meteorology headquarter in Nairobi and the TMA were used for this purpose. The annual rainfall erosivity model chosen to represent all agro ecological zones in Tanzania and the annual rainfall volumes of all available rainfall gauge stations were used to calculate long term annual rainfall erosivity (R) values. Also annual rainfall distribution map of Tanzania was developed using the long term annual rainfall volumes for 278 rain gauge stations. The Atlas map by (Kalunda *et*

*al.*, 2009) was used to check the generated annual rainfall map based on the gauge rainfall records. The rainfall erosivity values were then used to prepare rainfall erosivity map for the entire country. The ARC VIEW GIS software using Inverse Distance Weighted (IDW) interpolation method was used to develop the annual rainfall volume and annual rainfall erosivity maps (Shamshad *et al.*, 2008, Silva, 2001). The Inverse Distance Weighted (IDW) interpolation method is the method in which the interpolation is done by averaging the nearby weighted parameters values being mapped.

## CHAPTER FOUR

### 4.0. RESULTS AND DISCUSSION

#### 4.1. Agro-ecological Rainfall Characteristics

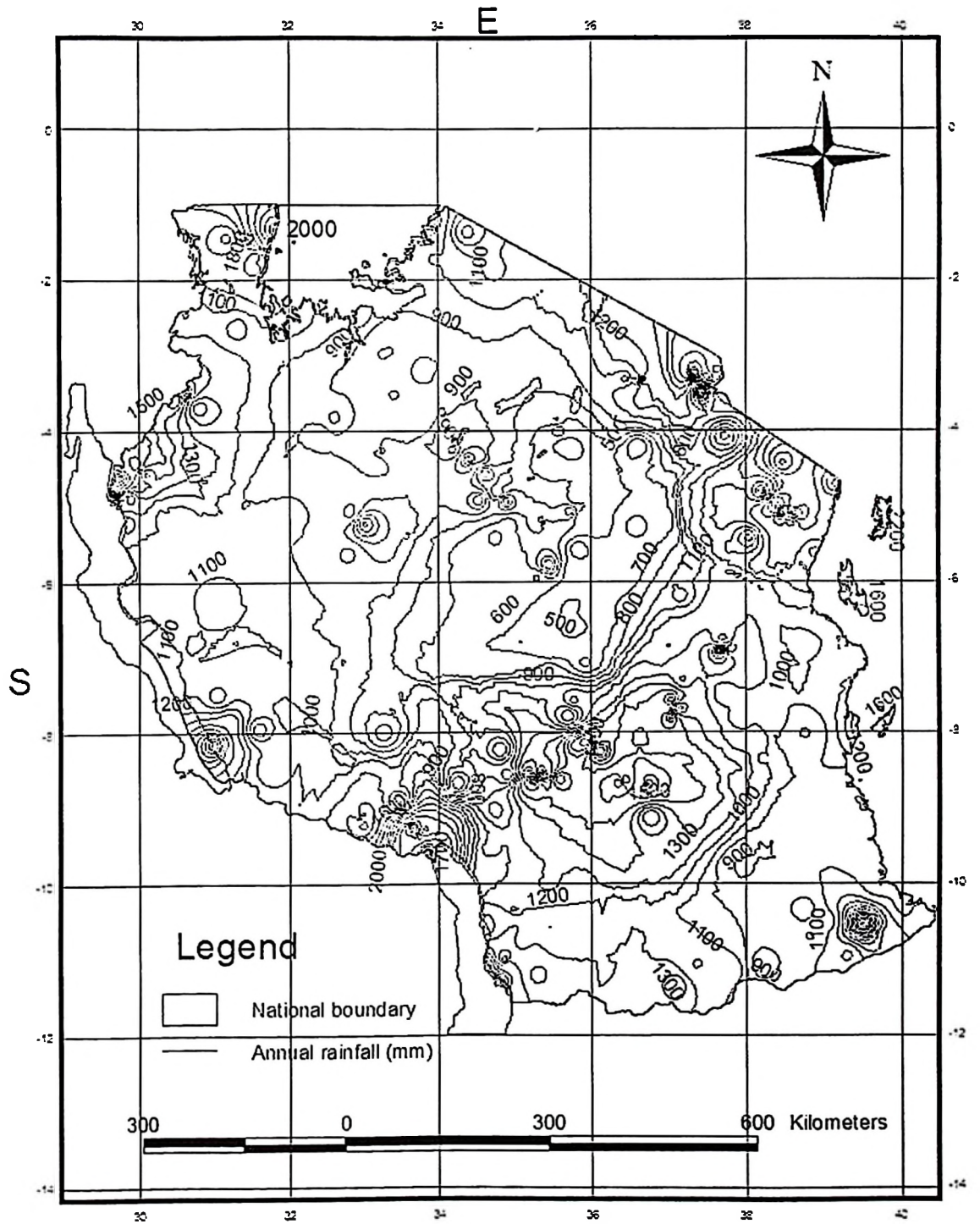
##### 4.1.1. Mean monthly rainfall volume

The long term mean monthly rainfall volumes for the 13 rain gauge stations are shown in Appendix 1 (Fig. 4 to 16). The histogram plots (i.e. Fig. 6, 10, 13, 15 and 16 for Hombolo, Mbeya, Naliendele, Singida and Songea respectively) show that the stations experience unimodal rainfall pattern. The unimodal rainfall stations depict one long rainy season which begins in October and ends in May with dry and cold spell between June and October. The monthly rainfall histograms show to have one peak between January and December but they show variations in duration of the rain seasons and dry seasons. The rainy seasons range from 6 to 7 months and the dry seasons range from 5 to 6 months. The annual rainfalls in unimodal stations ranged from about 430 mm to about 1 400 mm (Table 4, Appendix 2). The histograms for the gauge stations with bimodal rainfall pattern (i.e. Fig. 4, 5, 7, 8, 9, 11, 12 and 14 for Bukoba, Dar es salaam, Kigoma, Kilimanjaro, Lyamungo, Morogoro Musoma and Shinyanga respectively) depict short rains (*Vuli*) from October to January with monthly peak between November and December and long rains (called *Masika*) from March to May with monthly peak in April. Rain seasons range from 6 to 7 months and the dry seasons range from 4 to 5 months. The annual rainfall ranged from about 260 mm to about 2 530 mm (Table 4, Appendix 2). However the rainfall and the dry periods vary, depending on altitude and geographical location of the rain gauge stations.

#### **4.1.2. Annual rainfall distribution map in Tanzania**

The annual rainfall distribution map was developed using long term rainfall volumes for 278 rain gauge stations distributed all over Tanzania. The mean annual rainfall varies from 500 mm to over 2 500 mm depending on altitude and latitude (URT, 2006b). The annual rainfall distribution is shown in Fig.2. The areas receiving high rainfall volumes include Lake Victoria areas, coastal zone, Usangu Plains and the highlands which include Rungwe Mountain, the Usambara Mountains, Kilimanjaro and Meru mountains areas. The central part of Tanzania to large extent is semi-arid receiving rainfall less than 600mm (Fig. 1).

The 278 rain gauge stations represent an average of one gauge station per 276 978 hectares or 6769.8 kilometer square. This is low rain gauge stations distribution density providing rough rainfall distribution map for some areas. Thus, some of the localized areas receiving varying rainfall amounts were not represented by the used gauge stations. For example the Uluguru Mountains known to have rainfall over 2 500 mm were represented by only one rain gauge station and the western high lands with rainfall over 1 200 mm per year were not represented by adequate gauge stations. Also large parts of south west areas and central areas were not well represented by rain gauges information. Thus, the accuracy of the map is subjective in such areas. These inconsistencies have implications on the developed Iso-erodent map of Tanzania.



**Figure 1: Rainfall distribution in Tanzania**

## **4.2. Rainfall Erosivity Models**

### **4.2.1. Annual rainfall volumes and erosivity values**

The annual rainfall values and the rainfall erosivity of the 13 rain gauge stations are shown in Appendix 2 (Table 4). The lowest annual rainfall erosivity that was calculated is 570 (MJ-mm/ha-h-y) for Kilimanjaro (1975) and the highest is 10 568 (MJ-mm/ha-h-y) for Bukoba meteorological station for (1994).

The rainfall intensity records for the 13 selected gauge stations showed that the rainfall intensity in Tanzania varies from one agro-ecological zone to another and is mainly related to rainfall amount with the exception for some areas. The areas receiving high amount of rainfall volumes showed to have higher rainfall intensity and also the areas receiving low amount of rainfall showed to have low rainfall intensity. Most of rain storms intensity records for the selected rain gauge stations ranged from 50 mm/h to 100 mm/h. Few stations recorded quite few rainfall intensities greater than the above range. In Lake Zone the highest rainfall intensity was 240 mm/h at Bukoba rain gauge station. In northern highland the highest intensity of 180 mm/h was recorded at Lyamungo station. For the case of coastal areas the highest rainfall intensity of 130 mm/h was recorded at Dar es Salaam station. In the southern highland the highest intensity of 150 mm/h was recorded at Mbeya station. In central areas the highest rainfall intensity of 133 mm/h was recorded at Hombolo station. The lowest rainfall intensity was recorded at Kilimanjaro (KIA) station in which less than 30 mm/h was observed. At Morogoro station the highest rainfall intensity of 98 mm/h was recorded. However, it is important to note that higher intensity records are rare thus, had long term rainfall

intensity records been available all the stations may have shown more or less equal amounts of the highest intensity records.

Larger amount of rainfall volumes with higher intensities fall in a short period of time and are characterized by high rainfall erosivity. On the other hand smaller rainfall volumes with low rainfall intensities fall in longer durations and are generally characterized by low erosivity. There is a strong positive relationship between annual rainfall erosivity and annual rainfall volume. The results show that the higher the annual rainfall, the higher the rainfall erosivity and vice versa. Similar results were shown by Moore (1979), who found that most hazardous areas in terms of rainfall erosivity are in Uganda, the Lake Victoria areas, the high lands of Kenya and parts of the coast which normally receive higher volumes of rainfall. The lowest erosivity hazard was found to be in the dry part of Kenya and Tanzania. Using example of Dar es salaam station as a coastal area the calculated average annual rainfall erosivity (Table 4, Appendix 2) equals to 4 551 (MJ-mm/ha-h-y). According to Moore (1979), the rainfall erosivity for Dar es salaam station is equal to 4 073 (MJ-mm/ha-h-y) using long term annual rainfall volumes. The rainfall erosivity values obtained from this research are nearly similar to that obtained by Moore (1979).

#### **4.2.2. Rainfall erosivity models for individual rainfall stations**

The regression models relating rainfall erosivity and annual rainfall volumes for the selected 13 rain gauge stations in Tanzania are shown in Appendix 3 (Table 5). All the equations show that the annual rainfall erosivity ( $EI_{30}$ ) values were statistically

correlated to annual rainfall at 95% confidence interval. There is a slight difference for a coefficient of determination ( $R^2$ ) between the models for particular rain gauge stations. For the liner models the coefficient of determination ( $R^2$ ) ranged from 0.83 for Hombolo station to 0.96 for Mbeya and Shinyanga Stations. In case of the logarithmic models the  $R^2$  varied from 0.86 for Hombolo station to 0.98 for Shinyanga station and for the power regression models the  $R^2$  values ranged from 0.84 for Hombolo station to 0.97 for Mbeya station. Renard and Freimund (1994) came up with power equations relating both annual rainfall volume and Fournier index to rainfall erosivity with coefficient of determination ( $R^2$ ) equal to 0.81. Pauwelyn *et al.*, (1988) in Zambia developed multi linear regression equation relating rainfall erosivity to average total monthly rainfall, average number of days per month with a rainfall of at least 10 mm, average number of days with a rainfall of at least 100 mm per month and the maximum daily rainfall per month with a coefficient of determination  $R^2$  equal to 0.98 and standard error equal to 9.3.

The regression models relating rainfall erosivity and Fournier index are shown in Appendix III (Table 6). There is higher variation for the coefficient of determination ( $R^2$ ) for the selected rain gauge stations. For the liner models the coefficient of determination ( $R^2$ ) ranged from 0.36 for Kilimanjaro station to 0.95 for Shinyanga Station. In case of the logarithmic models the  $R^2$  varied from 0.34 for Kilimanjaro station to 0.93 for Shinyanga station and for the power regression models the  $R^2$  values ranged from 0.28 for Kilimanjaro station to 0.95 for Shinyanga station. The coefficient of determination ( $R^2$ ) of the two stations (i.e Kilimanjaro (KIA) and Morogoro) are very low and the lowest. This is caused by the occurrence of low

rainfall intensity values for the used 10 years discontinuous rainfall intensity data that made effect on high variation R-factor. The rainfall intensities of less than 30 mm/h were recorded at Kilimanjaro. Also at Morogoro station the rainfall intensities of less than 60 mm/h occurred frequently. Kilimanjaro station seems to experience long dry season and low annual rainfall volumes ranging from 260 mm to 700 mm while for Morogoro station the annual rainfall ranges from 600 mm to 1100 mm. The findings of the other researchers based on Fournier models show the high coefficient of determination ( $R^2$ ). The typical example is Shamshad, *et al.* (2008) in Peninsular Malaysia who came up with a coefficient of determination  $R^2$  of 0.81. Renard and Freimund (1994) in USA came up with power equations with coefficient of determination ( $R^2$ ) equal to 0.81 for Fournier index based model.

#### **4.2.3. The rainfall erosivity models for Tanzania agro-ecological zones**

The models relating rainfall erosivity to rainfall volumes and Fournier index for individual station and for all the 13 stations show that there is significant difference in the accuracy of predicting rainfall erosivity. The combined erosivity models relating rainfall erosivity with annual annual rainfall volumes and Fournier index for all the 13 stations are shown in Table 2 and 3 respectively.

**Table 2: Combined erosivity models based on rainfall volume**

Regression models		$R^2$	St. Error( $\sigma$ )
Linear	$R = 4.8877Ar - 791.03$	0.95	505.85
Logarithmic	$R = -29158.367 + 4879.613 \log Ar$	0.89	755.04
Power	$R = 0.3715Ar^{1.341}$	0.91	688.38

Where,  $R$  = Annual rainfall erosivity(MJ-mm/ha-h-y),  $Ar$  = Annual rainfall volumes(mm)

**Table 3: Combined erosivity models based on Fournier index**

Regression models		$R^2$	St. Error( $\sigma$ )
Linear	$R = 22.920Fi + 62.391$	0.66	1306.909
Logarithmic	$R = -18911.288 + 4524.458 \log Fi$	0.70	1238.232
Power	$R = 6.659Fi^{1.230}$	0.70	1285.36

Where,  $R$  = Annual rainfall erosivity (MJ-mm/ha-h-y),  $Fi$  = Fournier index (mm)

The regression models in Table 2 show a high correlation between the annual rainfall erosivity and the rainfall volume with high coefficient of determination ( $R^2$ ) and low standard error of estimate compared to the models based on Fournier index as shown in Table 3. This indicates that the equations for estimating annual rainfall erosivity ( $R$ ) using rainfall volumes have higher accuracy. When standard error and the  $R^2$  are high, the accuracy of the model is lower relative to the case when  $R^2$  is high and standard error is low. Thus, the linear equation in Table 2, which has lower standard error of estimate and higher  $R^2$  than that for logarithmic and power equations show to be the most accurate. The standard error and the  $R^2$  values for the linear model are

with in the range of the values estimated by other researchers in different part of the world but with different models. Yu and Rosewell (1995) found the power function relationship between annual rainfall and erosivity (R) to be the best model for southeast Australia with coefficient of determination ( $R^2$ ) of 0.91. Renard and Freimund (1994) came up with power equation with coefficient of determination equal to 0.81 for estimating annual erosivity factor for continental United State using both annual rainfall volume and Fournier index. Shamshad, *et al.*, (2008) in Peninsular Malaysia developed power erosivity model based on Fournier index with coefficient of determination of 0.81. Gregor and Matjaz (2004) established power equation with a coefficient of determination  $R^2$  of 0.869 for estimating annual R-factor using annual rainfall volume in Southwest of Slovenia.

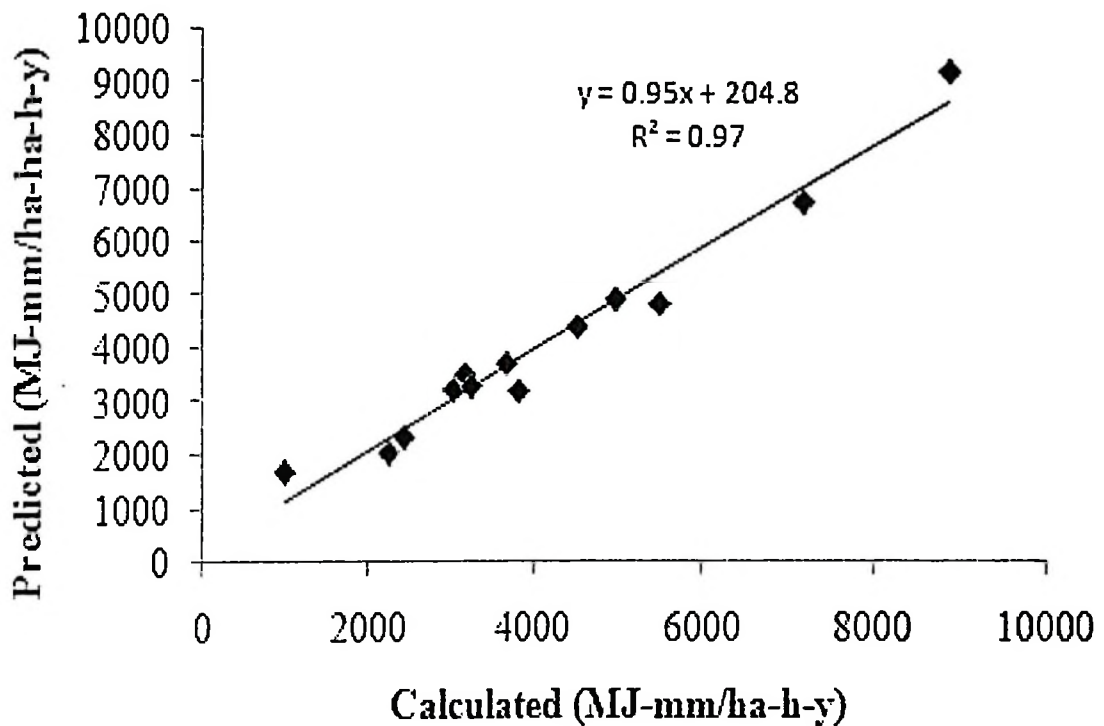
Although all the developed models are statistically accurate for estimating rainfall erosivity using annual rainfall volumes or Fournier index (Tables 2 and 3), the linear equation relating annual rainfall erosivity to rainfall volume is the best. The equation is:

$$R = 4.8877Ar - 791.03 \dots\dots\dots (2)$$

Where, R = Annual rainfall erosivity (MJ-mm/ha-h-y). Ar = Annual rainfall volumes (mm).

The coefficient of determination ( $R^2$ ) and variance ( $\sigma$ ) for the equation are 0.95 and 505.85 respectively. The relationship between calculated R-factors and the corresponding predicted R-factors for Tanzania using Eq. 2 is shown in the scatter plot, Fig 2. The diagram shows to fit accurately used erosivity values although the

regression line does not meet the  $x - y$  zero point intersection and has a slope not equal to unity.



**Figure 2: The relationship between average calculated and the predicted R-factor for 13 rain gauge stations**

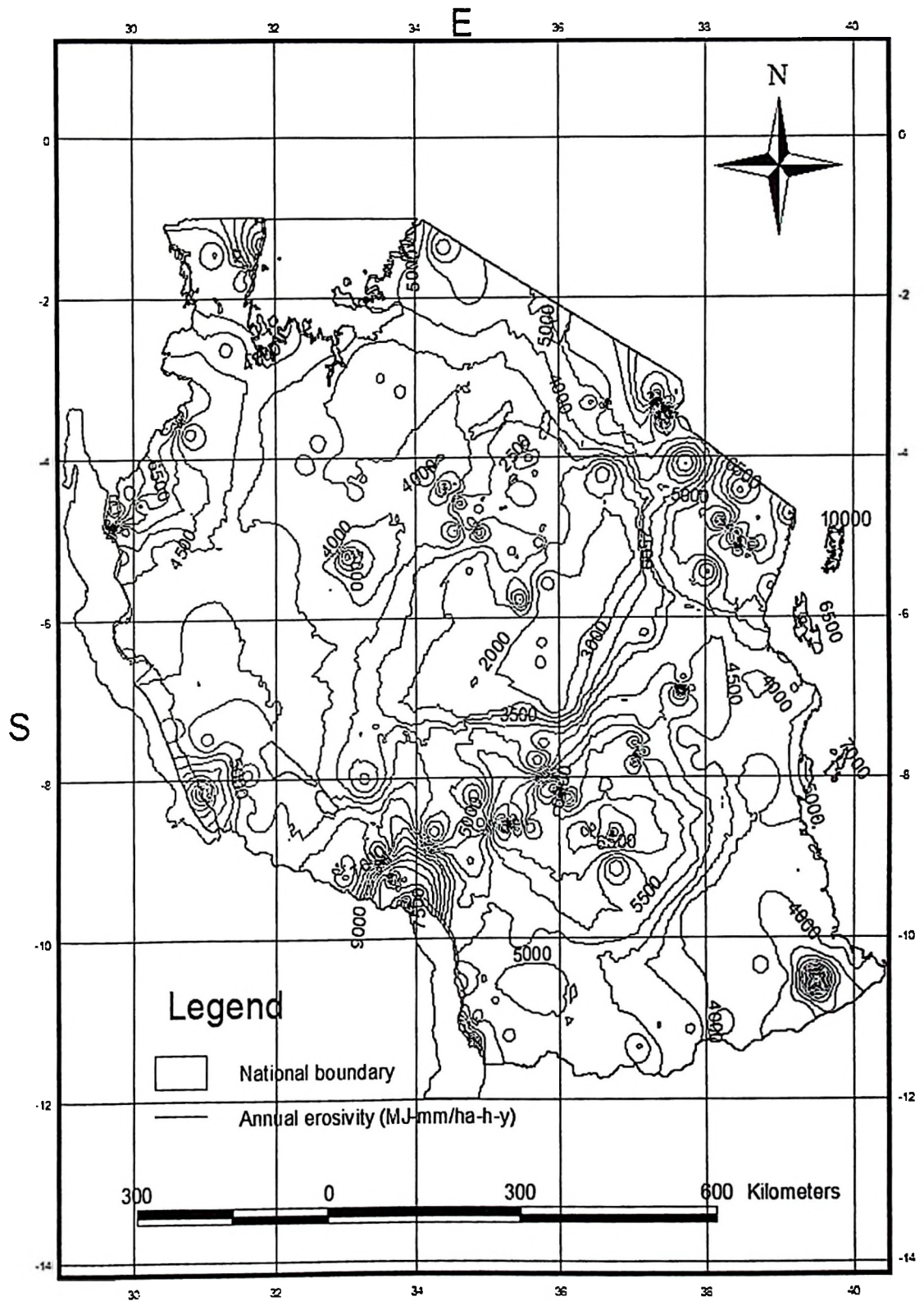
The differences for some of the values as appeared in the graph between the calculated and predicted R- factor values were caused by the variation between storm intensity and rainfall volumes. The storm intensity depends directly on rainfall volume falling in a particular time interval; high storm intensity occurs when large volume of water falls in short time interval. The small storm intensity occurs when little rainfall volume falls in large time interval. For some of the stations, particular years experienced high rainfall volume falling in a large time interval which corresponds to small storm intensity and small rainfall erosivity. However, the model

is quite accurate enough for use to estimate rainfall erosivity in different agro ecological zones.

Regarding the coefficient of determination ( $R^2$ ) and the standard error of estimate Equation 2 is the most accurate for estimation of rainfall erosivity in all agro ecological zones of Tanzania compared to Moore's (1979) equations which are less accurate due to the higher standard error of estimate values ( $\sigma$ ) and lower coefficients of determinations ( $R^2$ ).

#### **4.3. Spatial Erosivity Map**

Using Eq. 2, long term rainfall erosivity values for the 278 rain gauge stations were computed and Iso-erodent map generated using the calculated values of rainfall erosivity and Arc View GIS software using IDW interpolation method (Fig. 3). The full detail of the rain gauge stations locations and their corresponding erosivity values are shown in Appendix 4 (Table 7).



**Figure 3: Iso-erodent map of Tanzania**

The rainfall erosivity values are high in areas which receive high annual rainfall volumes including some part of the Lake Victoria areas, coastal zone, Usangu Plains, Usambara Mountains and parts of northern highlands. The least rainfall erosivity values are found in the central parts and northern lowland of Tanzania. These parts have got long dry seasons and their annual rainfall ranges from 250 mm to 600 mm. The rainfall erosivity in Tanzania as shown in Table 7 ranged from 1 140 MJ-mm/ha-h-y to 12 118 MJ-mm/ha-h-y. The higher range of the rainfall erosivity values in Tanzania is caused by the wider range of annual rainfall volumes. Figure 1 and 3 show that the distribution of annual rainfall erosivity corresponds directly to rainfall volume. The map of rainfall erosivity (Fig. 3) shows that about 60% of a country is characterized by annual rainfall erosivity higher than 3 000 MJ-mm/ha-h-y.

The erosivity values calculated in this research are within range of the value computed by the researchers (Yu and Rosewell, 1995; Renard and Freimund, 1994; Shamshad *et al.*, 2008 and Gregor and Matjaz, 2004) at different geographical locations. The rainfall erosivity values estimated using Moore's (1979) equations for different parts of Tanzania for all ecological zones range from 680 MJ- mm/ha-h-y to 10 994 MJ- mm/ ha-h-y. Wischmeier and Smith (1978) showed that mean annual values of rainfall erosivity index R in the USA ranged between 340 and 9 500 MJ-mm/ha-h-y. In India, the rainfall erosivity index R (after Central Soil and Water Conservation Research and Training Institute, 1977, cited by Morgan, 1986) ranged from 2 000 to 21 800 MJ- mm/ ha-h-y. For the map of France the mean annual values of rainfall erosivity index R (after Pihan, 1979, cited by Morgan, 1986) ranged from 500 to 3 500 MJ- mm/ ha-h-y and R index in South Africa (Smithen and

Schulze, 1982, cited by Morgan, 1986) range from 851 to 8 510 MJ-mm/ha-h-y. The mean annual values of rainfall erosivity index R in West Africa (after Roose, 1977, cited by Morgan, 1986) ranged from 1 700 to 34 500 MJ- mm/ ha-h-y. Shamshad *et al.*, (2008) found that the annual rainfall erosivity factor (R) for Peninsular Malaysia region ranged between 9 000 and 14 000 MJ-mm/ha-h-y. In West Africa the research made by Ufoegbune *et al.*, (2001), found that the rainfall erosivity for Ogun river basin in Nigeria ranged from 5 756 MJ- mm/ha-h-y to 19 583 MJ- mm/ ha-h-y. Silva (2001) found that the annual rainfall erosivity values in Brazil ranged from 3 116 to 20 035 (MJ-mm/ha- h-y). All the rainfall erosivity values determined by these researchers have shown that high rainfall areas have high rainfall erosivity values regardless of geographical locations. However, tropical areas with high intensity rain show to have higher rainfall erosivity for similar rainfall volume in Mediterranean countries (Angulo-Martinez *et al.*, 2009).

## CHAPTER FIVE

### 5.0. CONCLUSIONS AND RECOMMENDATIONS

#### 5.1. Conclusions

Soil erosion prediction basically requires accurate rainfall erosivity models for estimating rainfall erosivity factor R of the widely and commonly used USLE or RUSLE soil erosion prediction model. The study was able to develop rainfall erosivity model for use in USLE or RUSLE equation in all agro-ecological zones of Tanzania based on widely and easily available annual rainfall records. The appropriate procedures were used to extract storm intensity, storm volumes and the maximum thirty minute intensity using rainfall intensity charts for 13 rain gauge stations obtained from the TMA Headquarter in Dar es salaam and  $EI_{30}$  values were calculated and used in two modeling approaches. The first approach used rainfall volumes, and the second approach used Fournier index.

The results of this study demonstrate that linear equation relating rainfall erosivity to annual rainfall volume to be the best for estimating rainfall erosivity in Tanzania. The annual rainfall volumes from 278 rain gauge stations were used to calculate rainfall erosivity values which were used to develop Iso-Eroder map of Tanzania. The rainfall erosivity is high in areas having high annual rainfall volume including some part of the Lake Victoria areas, coastal zone and Usangu plain, Usambara Mountains and part of northern highlands. The central semi-arid areas and northern lowland parts of the country having low annual rainfall volumes are characterized by low annual rainfall erosivity. The long term rainfall erosivity ranged from 1 140 MJ-

mm/ha-h-y to 12 118 MJ- mm/ha-h-y. The Iso-Erodent map was generated using limited rain gauge stations due to the limited availability of continuous long term rainfall data and uneven location of rainfall gauge stations. Thus, some areas in the map were represented by low rain gauge density which limited the accuracy of the generated map in some localities. Therefore, in such localities the use of developed linear equation for accurate estimation of rainfall erosivity values for land use planning and soil and water conservation development is of great importance.

Rainfall erosivity is of great importance for soil erosion assessment, and has important implications for sustainable agricultural production and land use planning. Thus, the developed rainfall erosivity equation is a useful tool in planning and designing soil and water conservation methods for maintaining land quality and improved land productivity for the present and future generations in Tanzania.

## **5.2. Recommendations**

Due to the limited availability of continuous rainfall intensity data records for a long period of time, the estimation of rainfall erosivity value (R) based on the annual rainfall volumes is of significant and of great importance. The annual rainfall volumes records are common and most readily available for many meteorological stations in Tanzania. Also due to low rain gauge density in some areas, there is a need of installing more rain gauge stations in areas for more accurate prediction of rainfall erosivity in all agro ecological zones.

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## APPENDICES

Appendix 1: Mean monthly rainfall (mm) trend for 13 selected stations

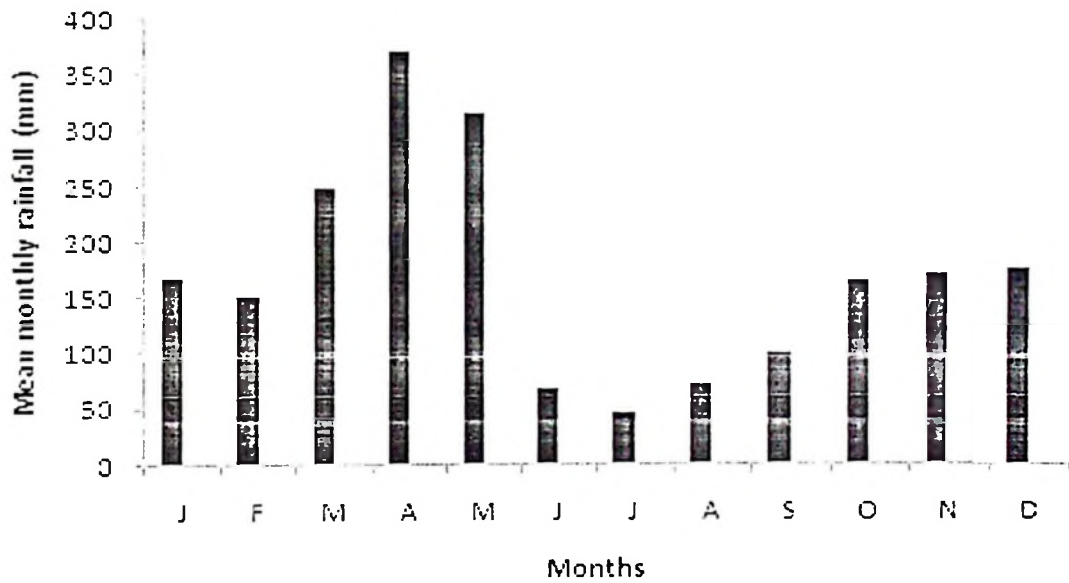


Figure 4: Mean monthly rainfall for Bukoba

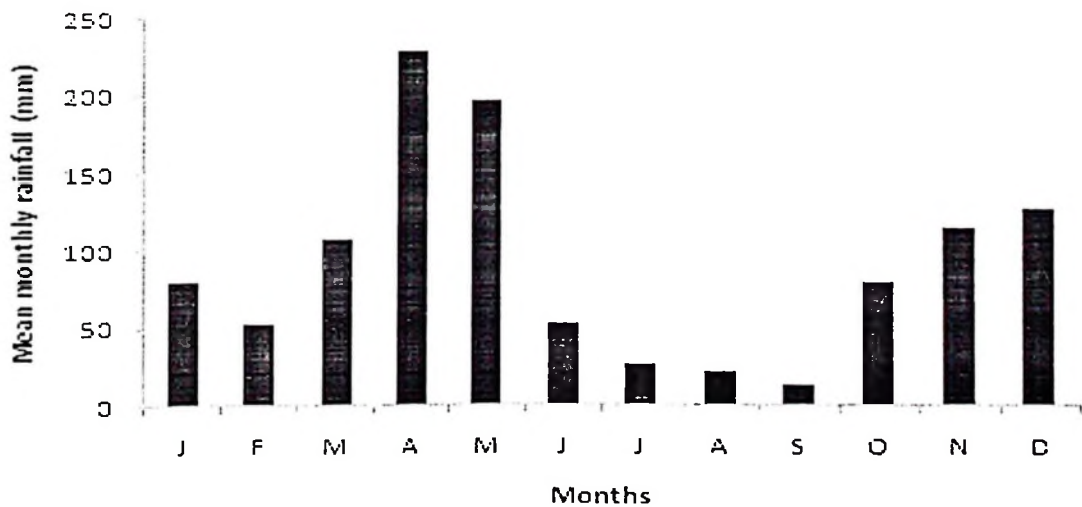


Figure 5: Mean monthly rainfall for Dar es salaam

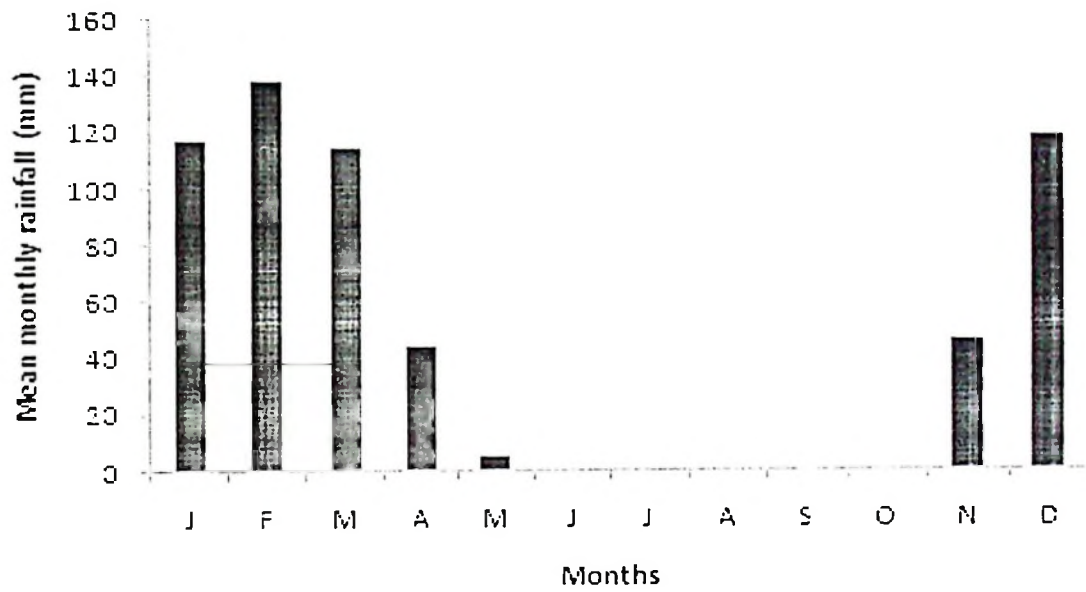


Figure 6: Mean monthly rainfall for Hombolo

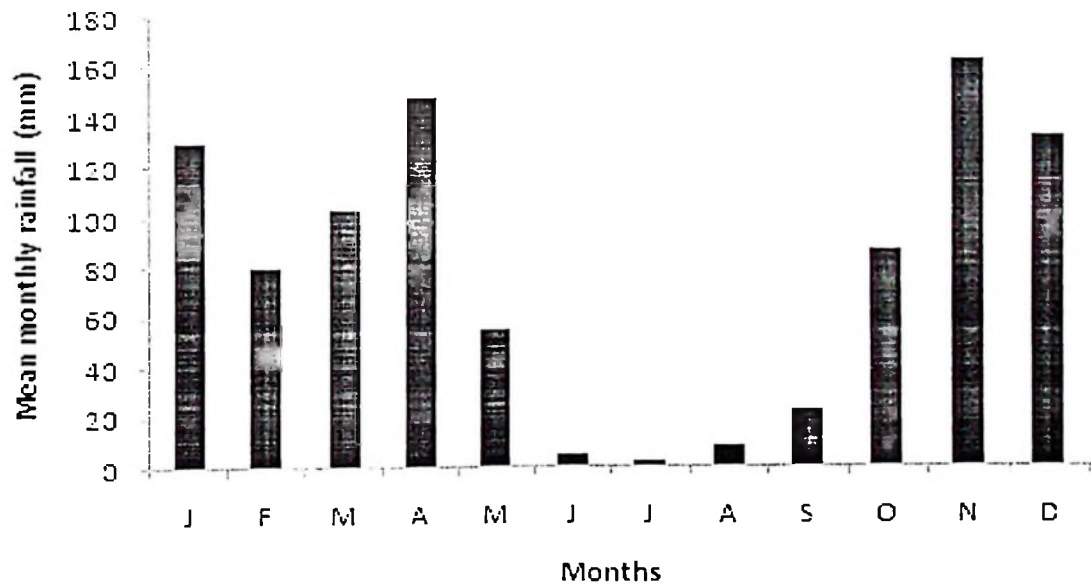


Figure 7: Mean monthly rainfall for Kigoma

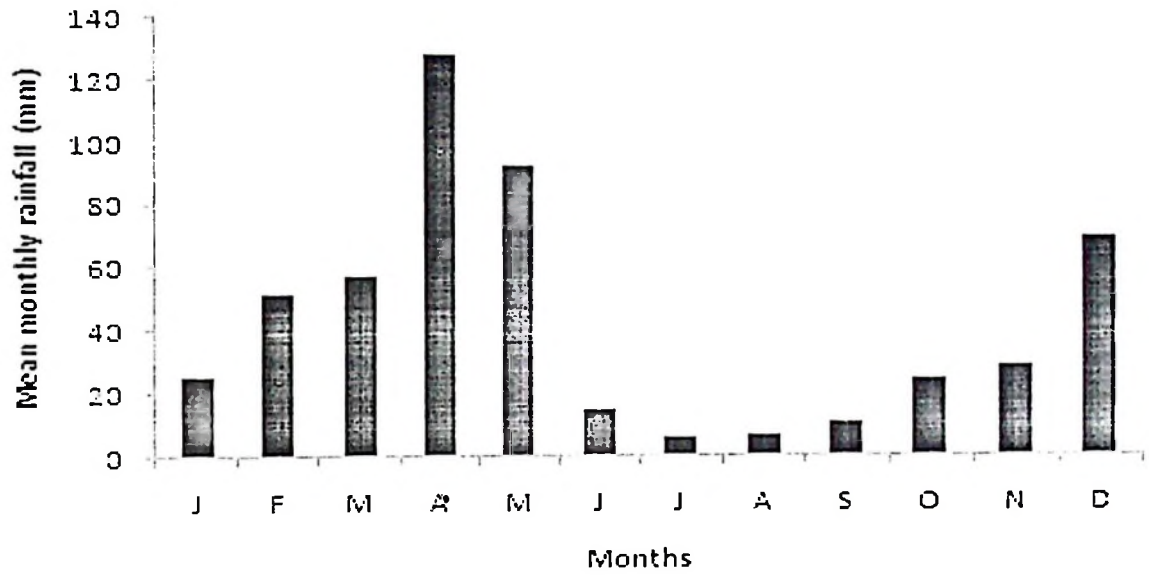


Figure 8: Mean monthly rainfall for Kilimanjaro

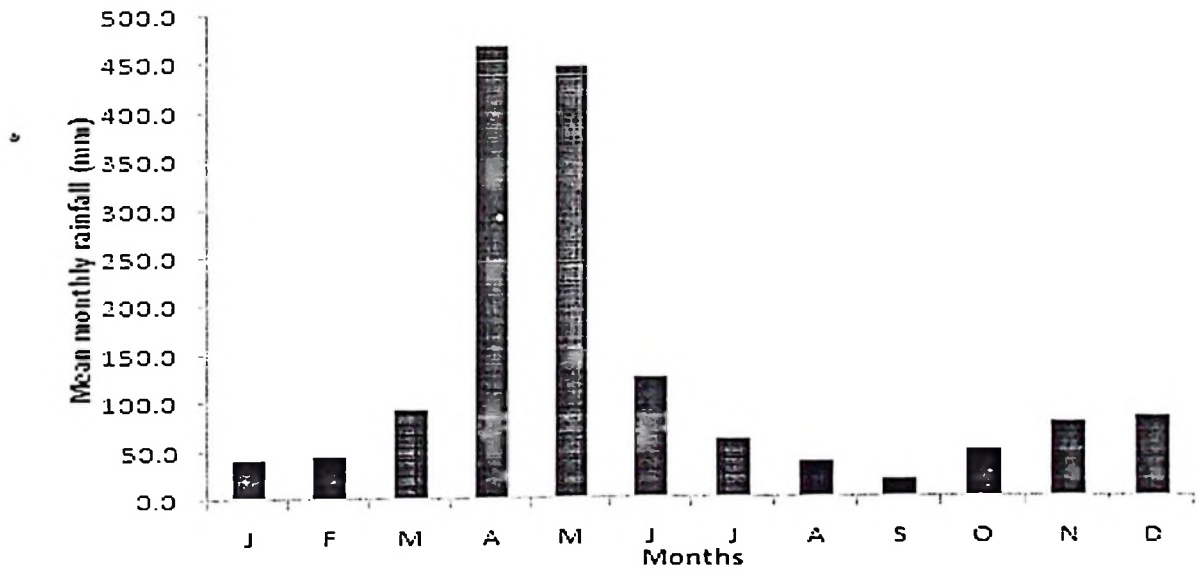


Figure 9: Mean monthly rainfall for Lyamungo

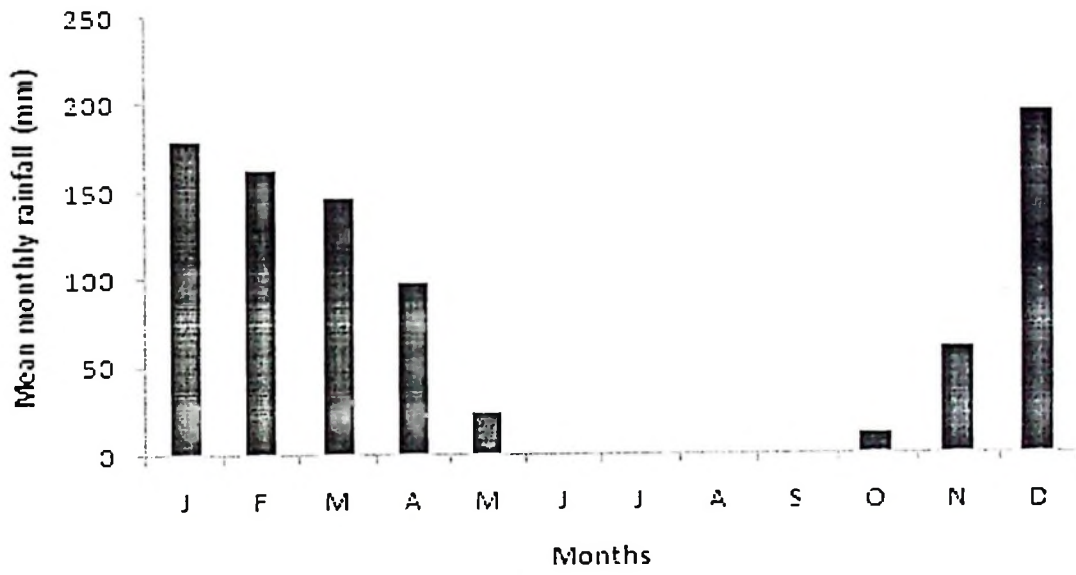


Figure 10: Mean monthly rainfall for Mbeya

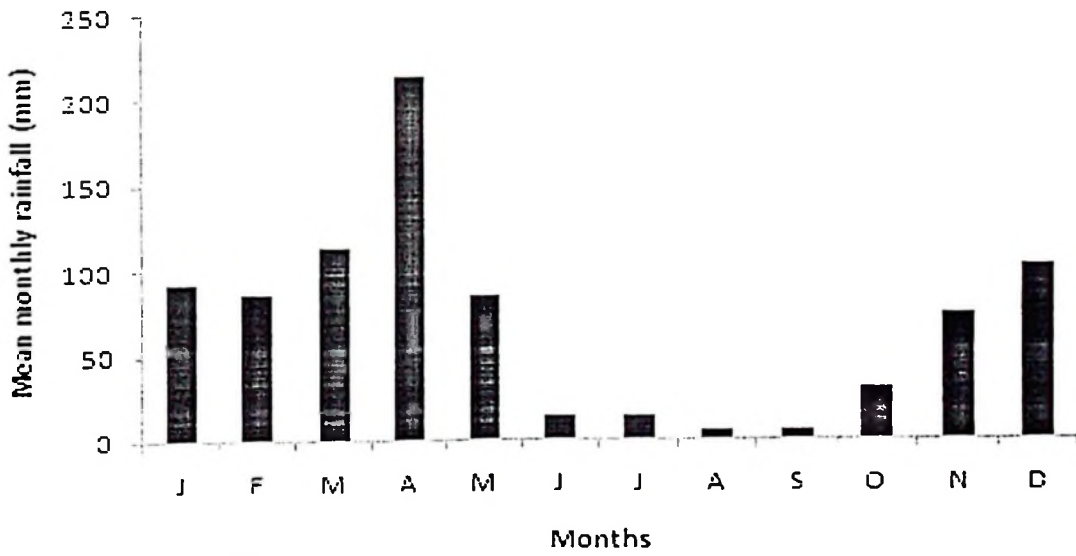


Figure 11: Mean monthly rainfall for Morogoro

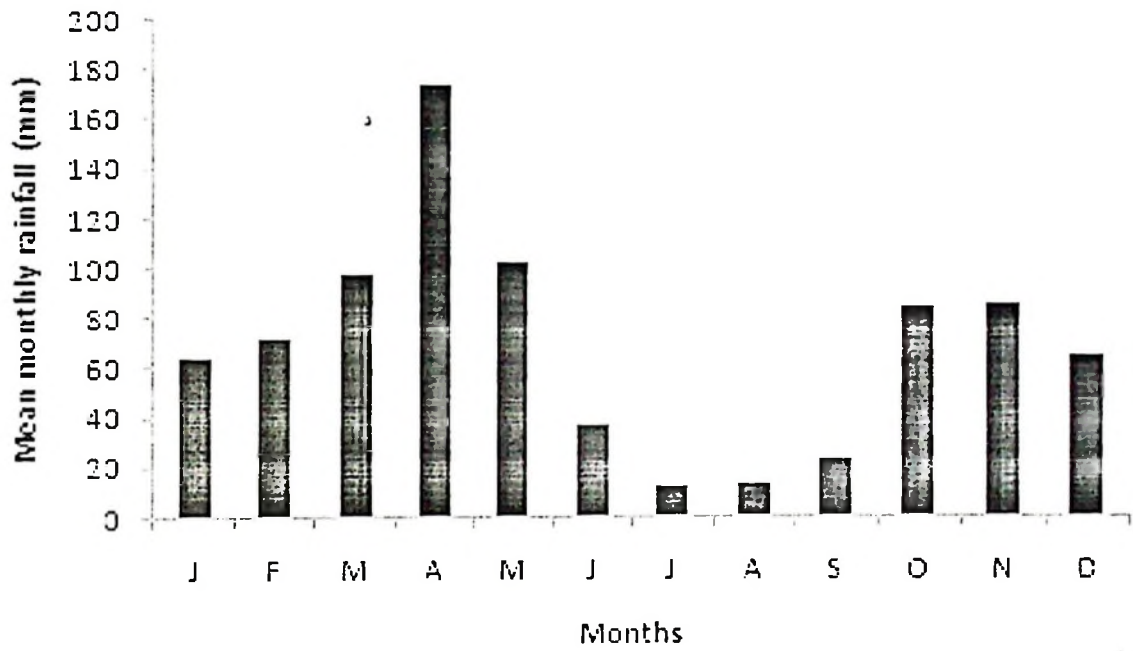


Figure 12: Mean monthly rainfall for Musoma

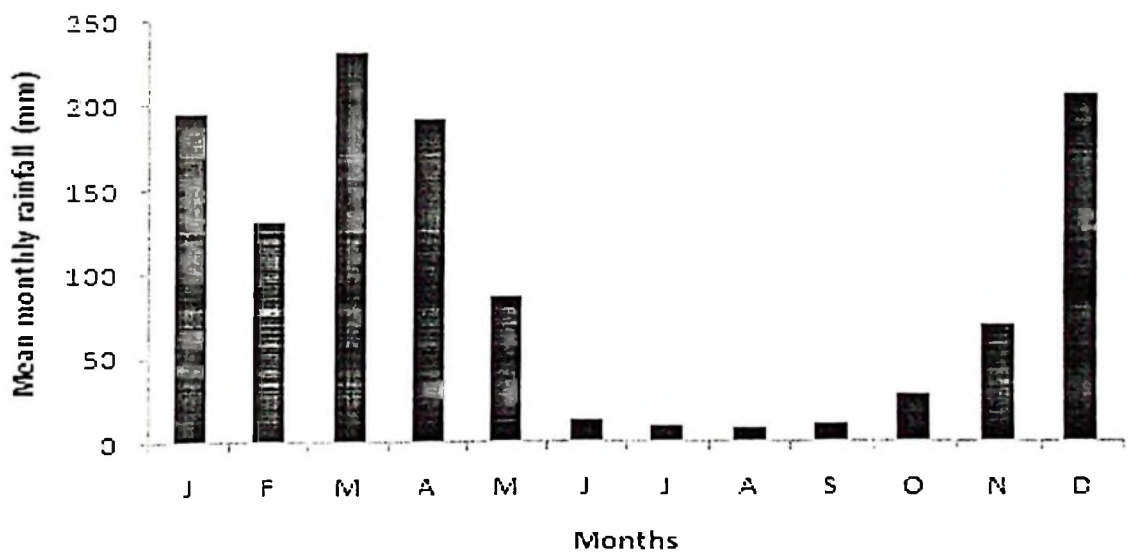


Figure 13: Mean monthly rainfall for Naliendele

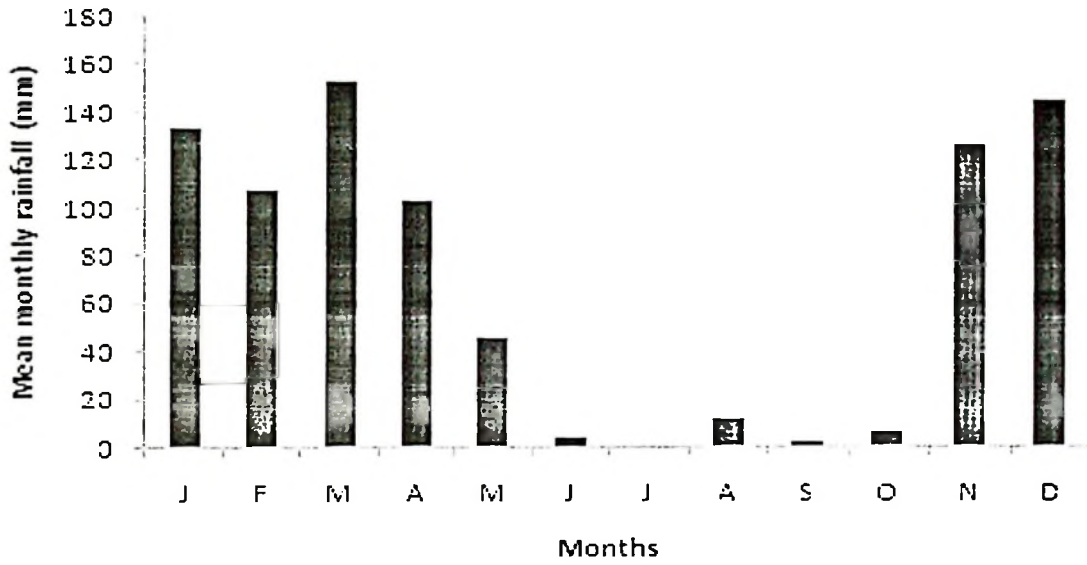


Figure 14: Mean monthly rainfall for Shinyanga

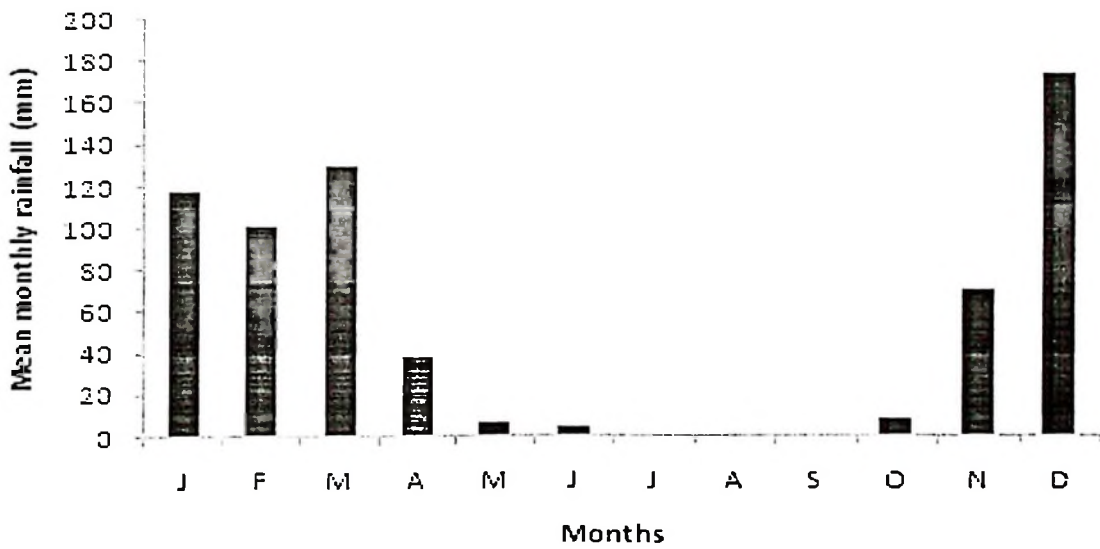


Figure 15: Mean monthly rainfall for Singida

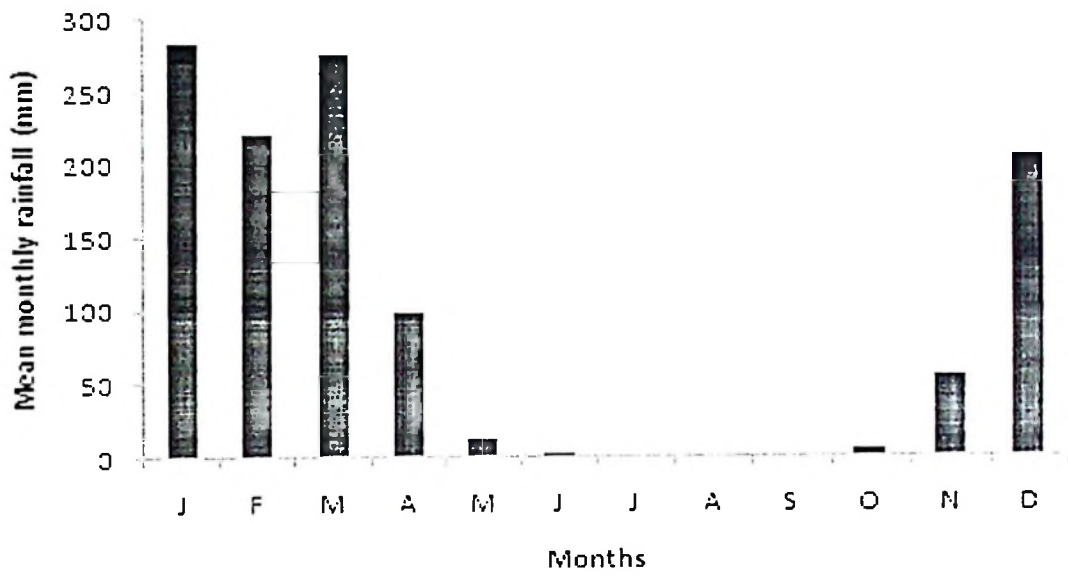


Figure 16: Mean monthly rainfall for Songea

## Appendix 2: Annual Rainfall Volumes and Erosivity Values

**Table 4: The rainfall volumes and erosivity values for 13 selected stations in Tanzania**

Stations	Year	Annual rainfall volume(mm)	Annual Rainfall Erosivity(MJ-mm/ha-h-y)
Bukoba	1985	2 298.1	9 490.4
	1986	2 240.1	9 390.7
	1987	1 835.8	7 918.6
	1988	2 091.5	9 563.7
	1989	1 904.5	8 644.4
	1990	1 795.8	7 174.7
	1991	2 100.4	9 353.1
	1993	1 811.5	7 970.9
	1994	2 525.7	10 567.9
	1995	1 910.9	8 467.3
	Dar es salaam	1982	1 400.2
1983		1 035.7	4 941.4
1985		9 19.1	3 163.3
1987		701.6	2 732.7
1988		934.2	3 584.6
1989		1 188.5	4 872.2
1990		1 127.5	4 649.6
1992		1 124.8	4 946.3
1993		1 141.3	4 786.6
1997		1 358	5 800.1
Hombolo	1981	571.9	2 012.8
	1983	429.8	1 378.3
	1984	460.9	1 468.4
	1986	572.2	1 819.3
	1987	599.5	2 457.4
	2002	608.1	2 431.4
	2007	846.1	3 298.7
	2008	608	2 802.3
	2009	612.3	2 456.7
	2010	546.6	2 246.8

Table 4 cont.....

Stations	Year	Annual rainfall volume(mm)	Annual Rainfall Erosivity(MJ-mm/ha-h-y)
Kilimanjaro (KIA)	1974	303.8	643.8
	1975	258.4	569.6
	1976	728.9	1 356.9
	1983	335.7	760
	1985	548.1	963.4
	1997	883.9	1 647.8
	2002	788.3	1 492.4
	2003	343.8	574.9
	2004	520.4	1 108.5
	2005	422.4	875.8
Kigoma	1975	809.8	3 038.3
	1977	1 052.3	3 936.1
	1982	1 151.4	4 728.6
	1983	835.3	3 045.8
	1986	1 124	4 528.6
	1987	797.5	2 952.6
	1989	993.5	4 208.6
	1992	913.5	3 856.9
	1993	781.1	2 867.6
	2010	841.8	3 578.3
Lyamungo	1981	1 336.5	5 673.8
	1982	1 714.5	8 091.3
	1983	1 389.8	6 167.4
	1984	1 776.4	7 867.4
	1985	1 345.8	6 437.8
	1986	1 761.6	8 739.9
	1987	924.2	4 185.0
	1988	1 423.1	7 120.5
	1989	1 671.5	8 103.8
	1990	2 124.7	9 372.8

Table 4 cont....

Stations	Year	Annual rainfall volume(mm)	Annual Rainfall Erosivity(MJ-mm/ha-h-y)
Mbeya	1971	960.6	3 535.9
	1974	790.5	2 560.8
	1976	863.2	3 012.2
	1977	840.6	2 909.7
	1981	609.0	1 763.6
	1984	1 072.2	4 236.3
	1985	971.9	3 673.4
	2006	1 030.1	3 967.3
	2007	840.4	3 090.4
	2008	893.0	2 864.6
Morogoro	1982	845.7	3 876.8
	1984	994.7	4 587.9
	1985	663.4	2 783.9
	1989	1 004.4	4 849.4
	1990	1 007.5	5 004.8
	1991	745.2	3 389.3
	1992	692.4	2 804.7
	1993	798.9	3 478.9
	1996	759.2	3 823.2
	2010	754.4	3 657.7
Musoma	1983	769.287	2 569.5
	1984	622.2	2 226.6
	1985	944.2	3 426.8
	1987	839.9	3 155.0
	1989	970.6	3 403.4
	1990	886.2	3 672.2
	1991	1 062.9	3 945.7
	1992	603.9	2 197.4
	1993	695.1	2 403.0
1994	890.3	3 185.3	

Table 4 cont....

Stations	Year	Annual rainfall volume(mm)	Annual Rainfall Erosivity(MJ-mm/ha-h-y)	
Naliendele	1981	1 032.9	4 105.5	
	1982	1 100.4	4 367.8	
	1983	1 189.5	5 214.1	
	1986	1 404.0	6 257.7	
	1987	1 141.6	4 673.7	
	1988	851.1	3 483.1	
	1989	1 377.4	5 984.8	
	1990	979.6	3 878.9	
	1991	1 394.7	6 367.6	
	1992	1 287.5	5 346.9	
	Shinyanga	2005	717.5	2 857.1
		2006	1167.9	4 624.1
2007		619.6	2 005.8	
2008		836.5	3 421.5	
2009		863.1	3 287.5	
Singida		2005	445.3	1 238.8
	2006	850.4	3 486.5	
	2007	605.6	2 584.4	
	2008	637.2	2 646.1	
	2009	878.0	3 205.7	
	2010	456.0	1 379.4	
Songea	1971	1 085.8	5 287.4	
	1972	1 018.9	5 018.6	
	1973	1 389.1	7 026.2	
	1975	1 081.4	4 697.3	
	1982	1 157.4	5 128.7	
	1986	1 332.0	6 483.3	
	1991	1 359.4	6 827.4	
	1994	1 122.9	4 913.7	
	2006	1 166.6	5 628.6	
	2007	859.6	3 828.3	

**Appendix 3: Regression models for individual rainfall station**

**Table 5: Regression equations relating rainfall erosivity (MJ-mm/ha-h-y) and annual rainfall volume (mm)**

Station		Regression models	R <sup>2</sup>	St. Error
Bukoba	Linear	$R = 3.827Ar + 1002.591$	0.86	386.97
	Logarithmic	$R = -53215.050 + 8145.400 \log Ar$	0.88	363.22
	Power	$R = 8.035Ar^{0.918}$	0.85	0.04
Dae es salaam	Linear	$R = 5.173Ar - 1073.858$	0.92	336.20
	Logarithmic	$R = -32083.751 + 5253.407 \log Ar$	0.90	375.52
	Power	$R = 0.716Ar^{1.251}$	0.91	0.08
Hombolo	Linear	$R = 4.848Ar - 601.347$	0.83	253.57
	Logarithmic	$R = -16969.219 + 3021.151 \log Ar$	0.86	229.33
	Power	$R = 0.313Ar^{1.391}$	0.84	0.11
Kilimanjaro (KIA)	Linear	$R = 1.740Ar + 106.108$	0.96	72.73
	Logarithmic	$R = -4427.174 + 881.206 \log Ar$	.094	98.02
	Power	$R = 3.990Ar^{0.886}$	0.94	0.09

Where, R = Annual rainfall erosivity (MJ-mm/ha-h-y), Ar = Annual rainfall volumes (mm).

Table 5 cont....

Station		Regression models	R <sup>2</sup>	St. Error
Kigoma	Linear	$R = 4.650Ar - 650.238$	0.90	219.57
	Logarithmic	$R = -26687.133 + 4448.345 \log Ar$	0.91	208.36
	Power	$R = 0.993Ar^{1.202}$	0.90	0.06
Lyamungo	Linear	$R = 4.577Ar + 96.541$	0.93	433.84
	Logarithmic	$R = -41416.404 + 6636.937 \log Ar$	0.93	416.94
	Power	$R = 3.924Ar^{1.023}$	0.94	0.55
Mbeya	Linear	$R = 5.340Ar - 1576.320$	0.96	144.88
	Logarithmic	$R = -26354.433 + 4355.336 \log Ar$	0.94	186.71
	Power	$R = 0.090Ar^{1.541}$	0.97	0.04
Morogoro	Linear	$R = 5.744Ar - 922.090$	0.93	218.78
	Logarithmic	$R = -28719.401 + 4852.935 \log Ar$	0.93	210.82
	Power	$R = 0.768Ar^{1.267}$	0.91	0.06
Musoma	Linear	$R = 3.928Ar - 235.928$	0.91	189.73
	Logarithmic	$R = -17935.429 + 3125.817 \log Ar$	0.91	196.09
	Power	$R = 2.121Ar^{1.080}$	0.93	0.05

Where, R = Annual rainfall erosivity(MJ-mm/ha-h-y), Ar = Annual rainfall volumes  
(mm)

Table 5 cont.....

Station		Regression models	R <sup>2</sup>	St. Error
Naliendele	Linear	$R = 5.318Ar - 1285.638$	0.97	181.66
	Logarithmic	$R = -37117.102 + 5963.204 \log Ar$	0.95	242.05
	Power	$R = 0.778Ar^{1.239}$	0.97	0.03
Shinyanga	Linear	$R = 4.505Ar - 549.079$	0.96	214.02
	Logarithmic	$R = -23452.052 + 3976.934 \log Ar$	0.98	154.04
	Power	$R = 0.739Ar^{1.244}$	0.94	0.08
Singida	Linear	$R = 4.758Ar - 647.458$	0.91	307.67
	Logarithmic	$R = -17564.351 + 3106.283 \log Ar$	0.95	223.92
	Power	$R = 0.223Ar^{1.433}$	0.91	0.14
Songea	Linear	$R = 5.941Ar - 1391.250$	0.93	278.96
	Logarithmic	$R = -41164.268 + 6622.014 \log Ar$	0.91	322.51
	Power	$R = 0.917Ar^{1.232}$	0.92	0.05

Where, R = Annual rainfall erosivity(MJ-mm/ha-h-y), Ar = Annual rainfall volumes

(mm)

**Table 6: Regression equations relating rainfall erosivity (MJ-mm/ha-h-y) and modified Fournier index (mm)**

Station	Regression models	R <sup>2</sup>	St. error	
Bukoba	Linear	$R = 22.310Fi + 3375.589$	0.58	689.634
	Logarithmic	$R = -22793.097 + 5758.871 \log Fi$	0.581	688.662
	Power	$R = 251.395Fi^{0.647}$	0.56	0.081
Dae es salaam	Linear	$R = 27.236Fi - 258.704$	0.67	684.591
	Logarithmic	$R = -19083.193 + 4583.935 \log Fi$	0.69	668.860
	Power	$R = 14.809Fi^{1.105}$	0.71	0.151
Hombolo	Linear	$R = 15.471Fi - 224.313$	0.58	404.234
	Logarithmic	$R = -7828.174 + 2076.641 \log Fi$	0.58	404.841
	Power	$R = 21.336Fi^{0.953}$	0.56	0.193
Kilimanjaro(KIA)	Linear	$R = 5.622Fi + 446.933$	0.36	331.999
	Logarithmic	$R = -1668.360 + 590.415 \log Fi$	0.34	335.728
	Power	$R = 80.811Fi^{0.541}$	0.29	0.351
Kigoma	Linear	$R = 19.123Fi + 989.032$	0.69	403.155
	Logarithmic	$R = -10075.455 + 2791.569 \log Fi$	0.69	402.797
	Power	$R = 90.922Fi^{0.748}$	0.67	0.113

Where, R = Annual rainfall erosivity(MJ-mm/ha-h-y),  $Fi$  = Modified Fournier index

(mm)

Table 6. cont...

Station		Regression models	R <sup>2</sup>	St. error
Lyamungo	Linear	$R = 12.299 + 2878.380$	0.60	1052.146
	Logarithmic	$R = -15858.784 + 3961.756 \log Fi$	0.65	992.218
	Power	$R = 182.194 Fi^{0.628}$	0.69	0.143
Mbeya	Linear	$R = 24.295 Fi - 826.532$	0.66	444.871
	Logarithmic	$R = -18443.351 + 4243.211 \log Fi$	0.678	436.018
	Power	$R = 3.015 Fi^{1.361}$	0.57	0.174
Morogoro	Linear	$R = 22.038 Fi + 574.761$	0.31	687.285
	Logarithmic	$R = -12194.568 + 3213.396 \log Fi$	0.34	679.661
	Power	$R = 49.183 Fi^{0.870}$	0.34	0.177
Musoma	Linear	$R = 15.980 Fi + 1109.334$	0.59	423.292
	Logarithmic	$R = -6813.542 + 2067.492 \log Fi$	0.66	389.888
	Power	$R = 99.233 Fi^{0.714}$	0.67	0.131
Naliendele	Linear	$R = 21.111 Fi + 603.347$	0.60	608.262
	Logarithmic	$R = -16726.296 + 4083.026 \log Fi$	0.67	627.826
	Power	$R = 54.911 Fi^{0.844}$	0.68	0.127

Where, R = Annual rainfall erosivity(MJ-mm/ha-h-y),  $Fi$  = Modified Fournier index

(mm)

Table 6 cont.....

Station	Regression models	$R^2$	St. error	
Shinyanga	Linear	$R = 24.688Fi - 90.698$	0.95	244.313
	Logarithmic	$R = -12357.080 + 3201.116 \log Fi$	0.93	284.863
	Power	$R = 20.637Fi^{1.030}$	0.94	0.080
Singida	Linear	$R = 14.529Fi + 232.443$	0.74	526.891
	Logarithmic	$R = -10288.674 + 2559.324 \log Fi$	0.84	412.642
	Power	$R = 7.655Fi^{1.144}$	0.75	0.241
Songea	Linear	$R = 17.152Fi + 1071.437$	0.65	637.850
	Logarithmic	$R = -18140.858 + 4268.622 \log Fi$	0.61	669.159
	Power	$R = 79.948Fi^{0.761}$	0.56	0.129

Where, R = Annual rainfall erosivity(MJ-mm/ha-h-y),  $Fi$  = Modified Fournier index

(mm)

#### Appendix 4: Data used for mapping

**Table 7: Location and long term erosivity values for rain gauge stations in Tanzania**

S/N	STATION NAME	LATITUDE (S)	LONGITUDE (E)	ALTITUDE (m)	ANNUAL EROSIVITY (MJ-mm/ha-hr-y)
1	Alavi Saisal Estate	6°50'	38°52'	151	3 935
2	Amani Malaria	5°06'	38°38'	911	8 329
3	Ambangulu Saisa Estate	5°05'	38°26'	1 220	9 336
4	Arusha Agric	3°23'	36°41'	1 372	5 240
5	Arusha Met. Station	3°22'	36°38'	1 387	3 092
6	Bablas farm	9°06'	32°51'	1432	4 585
7	Bagamoyo Agric. Office	6°25'	38°55'	9	4 351
8	Bahi	5°57'	35°18'	832	2 070
9	Balangai Coffee	4°56'	38°28'	1 402	7 626
10	Ben dhu estate	3°19'	35°22'	1 707	3 264
11	Berega Mission	6°12'	37°10'	854	2 909
12	Biharamulo	2°38'	31°19'	1 479	3 911
13	Buhanga	4°49'	29°42'	792	8 984
14	Bukoba Met. Station	1°20'	31°49'	1 144	9 033
15	Buswege	1°42'	33°56'	1 219	4 134
16	Buswete	1°14'	33°53'	1 147	3 119
17	Chamwale dam	6°30'	35°56'	1 158	1 653
18	Chapota	8°16'	31°15'	1 731	6 052
19	Chenene Primary School	5°35'	35°50'	1 194	1 164
20	Chikola	6°03'	34°50'	1 371	2 386
21	Chukwani/Kisauni	6°13'	39°13'	18	6 154
22	Dabaga Seed Farm	8°08'	35°55'	1 964	8 496
23	Dakawa Rice Farms	6°24'	37°37'	396	4 097
24	Dar es salaam air port	6°52'	39°12'	53	4 690
25	Dar es salaam laboratory	6°49'	39°18'	9	4 297
26	Darakuta Ranch	4°00'	35°35'	1 128	1 653
27	Dodoma Met. Station	6°10'	35°46'	1 120	2 010
28	Dodoma Reservoir	6°13'	35°46'	1 143	1 887
29	Echidna	8°32'	35°23'	1 920	3 608
30	Gidagamowd Wheat	4°28'	35°30'	1 676	2 142
31	Handeni Ditric Office	5°26'	38°02'	677	3 412

Table 7 cont....

S/N	STATION NAME	LATITUDE (S)	LONGITUDE (E)	ALTITUDE (m)	ANNUAL EROSIVITY( MJ-mm/ha- hr-y)
32	Heri Mission, Manyovu	4°29'	29°50'	1 584	7 029
33	Hombolo	5°32'	35°57'	640	1 653
34	Hombolo Agromet	5°54'	35°57'	640	7 029
35	Idege (Livalonge Estate)	8°42'	35°12'	1 890	7 029
36	Ifakara Katrin	8°40'	36°40'	251	5 607
37	Ifakara mission	8°09'	36°39'	274	5 526
38	Ifupira	8°30'	35°26'	1 890	4 522
39	Igabiro Estate	1°48'	31°33'	1 524	6 213
40	Igala	5°12'	29°50'	914	4 097
41	Igalula	5°14'	33°00'	1 197	5 775
42	Igeri Agromet	9°40'	34°42'	2 249	1 653
43	Igugunu	4°34'	34°37'	1 432	4 097
44	Ikizu Mission	1°56'	34°03'	1 524	2 308
45	Ilonga	6°46'	37°02'	502	4 538
46	Ilongero	4°39'	34°53'	1 600	4 097
47	Inyonga Mission	5°10'	30°35'	1 066	2 816
48	Iringa	7°47'	35°42'	1 640	2 714
49	Iringa Maji	7°47'	35°42'	1 646	1 897
50	Issuna Agriculture	5°25'	34°45'	1 402	7 518
51	Iwembe Kidodi	7°35'	37°02'	3 352	4 488
52	Iwembe Kidodi Pr. Sch.	7°18'	37°11'	335	4 830
53	Kabungu	6°16'	30°58'	1 097	4 585
54	Kabwe Primary School	7°02'	30°33'	790	7 308
55	Kagondo Mission	1°33'	31°42'	1 296	4 229
56	Kahama Distric Office	3°50'	32°36'	1 220	1 140
57	Kahe rail way	3°30'	37°26'	708	5 071
58	Kahunda	2°24'	32°08'	1 143	4 585
59	Kakoma	5°47'	32°27'	1 158	5 074
60	Kakonko Pri. School	3°17'	30°57'	1 219	8 979
61	Kala Mission	8°09'	31°00'	793	8 984
62	Kalinzi Agric. Station	4°38'	29°43'	3 048	5 265
63	Karimi Estate	5°14'	38°35'	286	5 563
64	Kasekele Research	4°38'	29°36'	792	4 097
65	Kasiha	6°07'	29°47'	770	5 386
66	Kasulu	4°34'	30°06'	1 381	6 052
67	Kate Mission	7°52'	31°12'	833	4 097
68	Kawalinda Coffee Estate	1°34'	31°43'	1 296	4 585

Table 7 cont....

S/N	STATION NAME	LATITUDE (S)	LONGITUDE (E)	ALTITUDE (m)	ANNUAL EROSIVITY( MJ-mm/ha- hr-y)
69	Kentesia Farm	9°12'	32°58'	1 554	3 880
70	Ketaketa Mission	9°07'	36°46'	548	1 509
71	Kibaha Agro	6°50'	38°42'	167	7 518
72	Kibaya	5°17'	36°34'	1 457	4 600
73	Kibondo Airport	3°31'	30°39'	1 286	9 757
74	Kibondo Mission	3°35'	30°42'	1 518	3 867
75	Kibosho Mission	3°15'	37°19'	1 479	7 308
76	Kigoma Met	4°52'	29°38'	777	7 308
77	Kigomasha	5°52'	39°41'	15	3 571
78	Kikwetu Estate	9°51'	39°44'	61	7 992
79	Kilema Mission	3°18'	37°30'	1 433	2 386
80	Kilimanjaro(KIA)	3°25'	37°04'	896	7 332
81	Kilimatinde Agric.Stn	5°51'	34°51'	1 089	6 397
82	Kilindoni Mafia	7°55'	39°40'	21	3 999
83	Kilombero Suga	7°40'	37°00'	491	3 613
84	Kilosa Agric. Office	6°50'	37°00'	491	4 013
85	Kilwa Kivinje	8°45'	39°25'	9	4 097
86	Kilwa Masoko	8°55'	39°31'	14	3 491
87	Kinole Primary School	6°54'	37°46'	304	4 341
88	Kinyangiri Court	4°27'	34°27'	1 200	3 852*
89	Kisuke Primary School	4°03'	32°26'	1 050	3 364*
90	Kipalapala Seminary	5°06'	32°48'	1 220	4 097
91	Kirando Primary School	7°22'	30°32'	770	4 736
92	Kisaki Tazara Railways	7°30'	37°43'	178	4 556
93	Kisanga hydromet	7°35'	35°46'	1 359	4 194
92	Kishanda Met. Station	1°42'	31°34'	1 463	2 142
93	Kitete Primary School	7°41'	37°09'	300	4 455
94	Kititimu	4°50'	34°48'	1 524	8 984
95	Kitundu Coffee	1°27'	32°10'	1 645	6 052
96	Kivere Mufindi	8°38'	35°14'	1 981	8 163
97	Kivukoni Village	8°38'	36°26'	244	4 365
98	Kizimbani	6°05'	39°16'	67	5 343
99	Kome Mission	2°21'	32°58'	1 134	2 620
100	Komera Coffee Estate	9°09'	32°56'	1 585	2 264
101	Kondoa maji	4°55'	35°48'	1 372	1 685
102	Korogwe Ditric Office	5°10'	38°28'	292	4 713
103	Kurio Mission	5°13'	35°23'	1 372	2 332

\*the altitude and rainfall of the rain gauge stations estimated from Atlas map

Table 7 cont....

S/N	STATION NAME	LATITUDE (S)	LONGITUDE (E)	ALTITUDE (m)	ANNUAL EROSIVITY( MJ-mm/ha- hr-y)
104	Kwiro Mission	8°25'	36°39'	1 006	7 518
105	Kyela Boma	9°35'	33°51'	549	12 118
106	Likode Seminary	10°47'	35°06'	1 219	4 970
107	Lindi Met	10°00'	39°43'	9	3 868
108	Liparamba Mission	11°21'	35°03'	1 006	3 657
109	Lituhi Mission	10°34'	34°36'	518	5 563
110	Liuli Mission	11°05'	34°38'	503	4 072
111	Liwale	9°47'	37°58'	457	7 332
112	Luangala Mission	10°31'	39°30'	457	3 530
113	Lubanga Rural	3°39'	33°24'	1 143	10 153
114	Luisenga, Mufindi	8°37'	35°35'	2 057	3 279
115	Lumemo Maji	8°10'	36°40'	244	8 007
116	Lupiro Tarafani	8°15'	36°07'	457	6 052
117	Lupode	9°34'	34°40'	2 134	2 389
118	Lushoto Agric. Office	4°47'	38°17'	1 396	4 097
119	Lyam	3°14'	37°15'	1 250	5 213
120	Mabamba Mission	3°36'	30°29'	1 219	4 600
121	Mabilibili	6°26'	29°54'	780	6 669
122	Madaba Maji	9°56'	35°24'	1 085	7 029
123	Madibira Mission	8°14'	34°49'	1 159	4 585
124	Magugu	4°00'	35°46'	1 000	6 052
125	Magunga Estate	5°00'	38°38'	610	2 156
126	Mahenge Hospital	8°41'	36°43'	1 107	2 556
127	Mahenje Mission	9°55'	35°22'	1 067	5 934
128	Malangali School	8°43'	34°55'	1 524	5 422
129	Malaya Agric	3°00'	33°29'	1 251	8 784
130	Malolo Dam	4°07'	32°52'	1000	3 315*
131	Mang'onysi	5°15'	34°55'	1 371	3 630
132	Manow Mission	9°16'	33°48'	1 524	2 288
133	Manyoni District Office	5°73'	34°50'	1 249	8 251
134	Maruku	1°24'	31°48'	1 219	2 205
135	Masaki Mission	10°42'	38°49'	457	8 572
136	Masuguru Pri. School	11°22'	38°26'	250	3 608*
137	Matambulu Dam	6°18'	35°46'	1 067	3 564
138	Matendo Ujamaa Village	4°53'	29°53'	1 219	1 164
139	Matiazo Pri. School	4°36'	29°44'	1 676	4585
140	Mauwa Seminary	3°16'	37°19'	1 167	9 473

\*the altitude and rainfall of the rain gauge stations estimated from Atlas map

Table 7 cont....

S/N	STATION NAME	LATITUDE (S)	LONGITUDE (E)	ALTITUDE (m)	ANNUAL EROSIVITY( MJ-mm/ha- hr-y)
141	Mazinde Factory	4°49'	38°13'	439	9 542
142	Mbamba Bay Customs	11°18'	34°46'	488	2 821
143	Mbarali Irrig. Scheme	8°40'	34°15'	1 047	8 496
144	Mbeya Boma	8°54'	33°27'	1 768	2 199
145	Mbeya Met. Station	8°56'	33°28'	1 759	3 642
146	Mbimba Coffee	9°04'	32°52'	4	3 451
147	Mbimba Coffee Research	9°4'	32°58'	1 524	5 984
148	Mbuji Village	11°00'	34°52'	1100	4 097*
149	Mbulu Boma	3°52'	35°33'	1 738	4 341
150	Mchombe Missionary	8°13'	36°38'	457	3 207
151	Mgambo Village	5°58'	29°52'	914	7 029
152	Mhiga Village	11°13'	35°17'	600	4 830*
153	Mikindani	10°16'	40°07'	18	4 585
154	Milepa Pr.School	8°05'	31°57'	914	3 520
155	Milo Mission	9°53'	34°37'	1 220	4 341
156	Milo Mission	9°53'	34°37'	1 220	5 636
157	Minazi (Itete) Village	8°40'	36°22'	366	8 007
158	Misechela Pri. School	11°08'	37°47'	350	5074*
159	Mitalula	9°22'	33°37'	1 219	9 442
160	Mizimbe Farm	8°24'	31°42'	179	4 585
161	Mkoani	5°22'	39°39'	15	9 126
162	Mkoe Plantation	9°32'	39°39'	91	3 603
163	Mkokotoni	5°52'	39°15'	9	6 545
164	Mkwese Primary School	5°38'	34°48'	1 371	2 142
165	Mlingano Agromet	5°03'	38°28'	290	4 874
166	Mlowa Dam	6°33'	35°45'	914	1 408
167	Mondulu	3°19'	36°27'	1 585	3 297
168	Morning Side Farm	6°54'	36°40'	1 371	10 603
169	Morogoro Agric. Office	6°51'	37°40'	579	3 559
170	Morogoro Met. Station	6°50'	37°39'	526	4 585
171	Morogoro Teacher's Col	6°50'	37°42'	609	3 481
172	Moshi Met. Station	3°21'	37°20'	813	4 657
173	Mpwapwa Vet.Office	6°20'	36°30'	1 128	2 572
174	Msimbazi Mission	6°48'	39°15'	15	4 136
175	Msingi Training Centre	4°20'	34°34'	1100	4 585*
176	Msolwa Wildlife	7°48'	37°02'	243	8 007
177	Mtambile	5°23'	39°42'	46	10 333

\*the altitude and rainfall of the rain gauge stations estimated from Atlas map

Table 7 cont....

S/N	STATION NAME	LATITUDE (S)	LONGITUDE (E)	ALTITUDE (m)	ANNUAL EROSIVITY( MJ-mm/ha- hr-y)
178	Mtanga Office	8°10'	35°49'	2 073	8 007
179	Mtera	7°05'	35°55'	682	1 565
180	Mtimbira Mission	8°10'	36°37'	330	5 563
181	Mtotohovu	4°43'	39°09'	46	4 429
182	Mtwara Air Port	10°21'	40°11'	113	4 585
183	Mugumu Primary School	1°52'	34°43'	1 523	4 683
184	Muhukuru Village	11°31'	35°27'	1067	5 319
185	Mungaa Primary School	4°56'	34°53'	1500	5 074*
186	Mulera Primary School	4°26'	29°57'	1417	8 007
187	Musekera Estate	9°20'	33°41'	1 220	10 304
188	Musoma Met. Station	1°30'	33°48'	1 148	3 564
189	Mvumi Mission	6°23'	35°55'	1 067	1 868
190	Mvumi Village	6°37'	37°10'	487	4 097
191	Mwadhubi	2°59'	33°15'	1 175	3 062
192	Mwanhala	4°24'	33°09'	1 250	3 279
193	Mwanza Agri. Office	2°31'	32°54'	1 131	4 092
194	Mwanza Air Port	2°28'	32°55'	1 141	4 636
195	Mwangaa Ujamaa Village	4°55'	34°32'	1100	5 074*
196	Mwaya Hospital	9°34'	33°56'	488	4 708
197	Mwazye Primary School	8°27'	31°44'	1 828	9 473
198	Mwese	6°15'	30°20'	1 845	4 097
199	Mwita	10°17'	40°05'	51	4 097
200	Mwitika Estate	9°22'	33°43'	1 067	3 569
201	Naberera	4°13'	36°36'	1 524	8496
202	Nachingweya Agric	10°21'	38°45'	463	1 183
203	Nakopi Primary School	11°04'	38°13'	200	3 119*
204	Naliendele. Agric	10°22'	40°10'	120	3 326
205	Namanyera	7°30'	31°03'	1 570	3 795
206	Nanyamba Mission	10°42'	39°51'	183	4 686
207	Narok Forest	3°20'	36°40'	1 829	8 061
208	Ndanda Mission	10°30'	39°02'	305	3 784
209	Ndengu Agricultural	11°03'	34°54'	1000	6 052*
210	Ndolela	9°54'	35°12'	1 100	5 074
211	Newala	10°57'	39°18'	793	3 999
212	Ngara	2°28'	30°38'	1 799	4 082
213	Ngaraya Coffee Estate	5°01'	38°27'	1 067	7 606
214	Ngerengere Railway S	6°46'	38°07'	195	4 585

\*the altitude and rainfall of the rain gauge stations estimated from Atlas map

Table 7 cont....

S/N	STATION NAME	LATITUDE (S)	LONGITUDE (E)	ALTITUDE (m)	ANNUAL EROSIVITY( MJ-mm/ha- hr-y)
215	Ngombezi Sisal Estate	5°10'	38°25'	335	4 615
216	Ngudu Estate	2°57'	33°21'	1 220	3 016
217	Nduguti Court	4°18'	34°42'	1300	3 217*
218	Ngurumahamba Estate	10°02'	39°38'	21	3 970
219	Njombe	9°20'	34°64'	1 829	4 463
220	Nyambuyumbu Mission	3°40'	30°48'	1 219	6 052
221	Nyanza Salt Mines	5°05'	30°22'	1 128	4 830
222	Nyasanga National Park	4°40'	29°36'	762	8 984
223	Nyumba Ya Mungu	3°40'	30°48'	1 219	1 282
224	Nzega Hydromet	4°15'	33°13'	1250	4 585*
225	Nzega District Office	4°13'	33°11'	1 220	2 992
226	Old Shinyanga	3°33'	33°24'	1 220	3 041
227	Olmotonyi Forest	3°18'	36°39'	1 610	3 945
228	Pangani District Office	5°26'	38°59'	9	5 583
229	Paranga Primary School	5°09'	35°52'	1400	2 142
230	Peramiho Mission	10°34'	35°28'	1 159	4 581
231	Rombo Mission	3°12'	37°36'	1 433	6 443
232	Rubya Mission	1°45'	31°37'	1 433	5 617
233	Ruembe Sugar Estate I	7°43'	37°04'	300	4 683
234	Rungwa	7°21'	31°39'	883	4 097
235	Rungwe Tea Estate	9°10'	33°35'	1 372	8 007
236	Ruvu Estate	6°48'	38°43'	37	3 833
237	Sakare Coffee Estate	4°59'	38°25'	1 372	8 427
238	Sakura Estate	5°37'	38°53'	40	4 879
239	Same Met. Station	4°05'	37°44'	860	1 965
240	Sekenke	4°15'	34°11'	1 219	2 960
241	Selian Coffee Estate	3°21'	36°36'	1 402	3 559
242	Shanwa	3°10'	33°46'	1 341	2 933
243	Shinyanga Hydromet	3°40'	33°25'	1 118	3 237
244	Shinyanga Met. Station	3°39'	33°42'	1 000	3 490
245	Sikonge Mission	5°39'	32°47'	1 524	2 396
246	Singano Village	11°06'	39°06'	600	4 097*
247	Singida District Office	4°48'	34°45'	1 498	3 085
248	Singu Estate	4°12'	35°40'	1 738	4 669
249	Songea Met. Station	10°42'	35°40'	1 166	4 341
250	Stiegler's Gorge	7°48'	37°55'	152	4 341
251	Sua S.M.C. Mazimbu	6°47'	37°37'	591	3 232

\*the altitude and rainfall of the rain gauge stations estimated from Atlas map

Table 7 cont....

S/N	STATION NAME	LATITUDE (S)	LONGITUDE (E)	ALTITUDE (m)	ANNUAL EROSIVITY(MJ- mm/ha-hr-y)
252	Sumbawanga	7°57'	31°36'	1 723	3 251
253	Sumvwe Mission	2°46'	33°13'	1 220	3 520
254	Tabora Observatory	5°02'	32°49'	1 266	5 744
255	Tanga Town Council	5°04'	39°06'	9	5 744
256	Tarime	1°22'	34°23'	1 524	5 426
257	Tengeru Coffee Estate	3°22'	36°48'	1 463	4 818
258	Themí Estate	3°24'	36°42'	1 372	5 074
259	Tschimbande Camp.	11°30'	36°41'	518	11 223
260	Tukuyu District Office	9°15'	33°38'	1 616	4 097
261	Tulia Primary School	4°07'	34°20'	1000	3 803*
262	Tumbi Tobacco	5°04'	32°44'	1 219	4 273
263	Tunduru District	11°06'	37°22'	701	6 052
264	Tunduru Maji	11°08'	37°22'	500	5 074*
265	Tunduru Mbesa	11°21'	37°05'	1 200	3 412
266	Tungi Saisal Estate	6°46'	37°42'	503	3 985
267	Ubungo Moji	6°47'	39°12'	61	3 422
268	Ujiji Mission	4°55'	29°41'	777	4 486
269	Ulemo Primary School	4°24'	34°24'	1150	6 052*
270	Ulyankulu Tobacco	4°45'	32°19'	1100	3 608*
271	Urambo Farm	5°04'	32°04'	1 322	4 382
272	Ushirombo Mission	3°30'	32°00'	914	3 774
273	Usoke Mission	5°12'	32°22'	1 219	4 341
274	Utete. Distric Office	8°01'	38°45'	52	4 341
275	Uvinza Salt Mine	5°07'	30°22'	911	3 574
276	Wesha	5°14'	39°44'	30	8 461
277	Wete Pemba	5°04'	39°43'	18	8 452
278	Zanka Village	5°50'	35°45'	1 153	1 897

\*the altitude and rainfall of the rain gauge stations estimated from Atlas map