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SPATIAL – TEMPORAL CHARACTERISTICS OF RAINFALL EVENTS IN KENYA

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Declaration

I declare that this dissertation is my original work and has not been submitted elsewhere for examination or publication. Where other authors' work has been used in this dissertation, proper acknowledgements and referencing has been done.

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Dedication

I dedicate this study to my wonderful family. My parents Francis and Christine, and my siblings Steve and Gloria, for believing in me and encouraging me each step of my studies. My husband Cornelius for his unwavering support through this study period. My children Laurine, Crispus and Patience who complete my purpose in life.

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Abstract

Rainfall is very important for all life on earth because it is the main source of fresh water which is essential for survival of mankind, plants and animal. However as human populations continue to grow, the search of better livelihoods has seen an increase in the number of people living in urban centres. This has left communities vulnerable to extreme rainfall events. During the rainy season's road, bridges and other infrastructure are damaged by rainfall events, costing the government a lot of money, all of which could be avoided by research for development in this study.

Many countries around the world have done a lot of research on the spatial and temporal characteristics of rainfall in their regions. Countries such as Nepal (Devkota 2018), Denmark (Madisen et al 2000), and Italy (Languise & Venaziano 2000) among others have published studies detailing the spatial temporal characteristics of rainfall in their regions. In Africa, Rwanda (Wangesho & Claire 2016), Nigeria (Antiga & Ogarekpe, 2013), Benin (Agbazo et al., 2016), Egypt (Awadalla et al., 2017) have all published studies of the rainfall characteristics for their region.

This study seeks to understand the spatial and temporal characteristics of rainfall events using hourly data from the Trans-African Hydro Meteorological Observatory, TAHMO automatic weather AWS stations all around the country. This study sought to understand how long rainfall events last (duration), the intensity (mm/hr) of rainfall received, and the variation rainfall events in Kenya (thresholds) and to establish intensity duration frequency curves of rainfall events in Kenya. Percentage distribution was used to categorise the duration from one to eight hour and determine the most prevalent durations. The Average intensities of the rainfall events were also analysed and categorised into drizzles (>0.9mm/hr), light rains (1-4.9mm/hr), moderate rains (5-9.9 mm/hr), heavy rains (10-19.9 mm/hr) and very heavy rains (<20mm/hr) and percentage distribution was used to show the variation of these categories. Curve analysis was used to establish the peak durations and the average intensities at the peak durations. These were then plotted and sufer graphical analysis was used to show their variations all around the country. Gumbels' Extreme Value analysis was used to calculate the intensities of rainfall for durations of 1 to 8 hours at return periods of 10, 25, 50, 100, 500, 1000 and 10,000 years. These intensities for every station were then plotted together for each station to show the IDF curves for that given region.

This study has shown that most of the rainfall events recorded in Kenya last one to two hours. Light to moderate rainfall events are the most common ones experienced (<10mm/hr). However significant number of extreme rainfall events are experienced (>20mm/hr). The rainfall thresholds

(peak duration and average intensity at peak duration) vary greatly all across the country. The peak duration varies from 0.7 hours to 1.5 hours with the average intensities varying greatly all across the country. This is because the topographical variation of the country's terrain. The duration as to when the peak rainfall intensity is achieved varies all around the country. With regions such as north eastern Kenya, achieving the peak duration in the shortest periods while the highlands in central Kenya take the longest duration to achieve their peak durations.

Maximum rainfall intensities were analysed for durations of one to eight hour for the return periods of 10, 25, 50, 100, 500, 1000 and 10000 years. These were then plotted together to show the IDF curves for different regions of our country. Each region showed its unique characteristics

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List of Acronyms

AWS – Automatic Weather Station

DC – District commissioner

ENSO – El Nino Southern Oscillation

GLS – Generalised least squares

IDF – Intensity Duration Frequency

IOD – Indian Ocean Dipole

IPCC – Intergovernmental Panel on Climate Change

ITCZ – Inter Tropical Convergence Zone

LPT III – Log Pearson Type III

MAM – March – April – May

NOD – November-October-December

PDF – Probability Distribution Function

PDS – Partial Duration Series

PS – Primary School

QBO – Quasi Biannual Oscillation

RFA – Regional Frequency Analysis

SS – Secondary School

SST – Sea Surface Temperature

TAHMO – Trans-African Hydro Meteorological Observatory

UoN – University of Nairobi

CHAPTER ONE: INTRODUCTION

Hydro-climate information is an essential tool for environmental resource and water management (Chowdhury *et al.,* 2016). The hydrological cycle is the continuous movement of water through different phases as it travels through the atmosphere, the ground and the oceans (Chahine, 1992). Precipitation is the movement of water, in any form, liquid or ice, from the atmosphere to the earth's surface. Types of precipitation include snow, rainfall, freezing rain, hail and sleet. Rainfall is a form of precipitation where droplets of water fall from the sky to the earth's surface. Rainfall is the main form of precipitation experienced in Kenya. The rainfall events in Kenya usually include rain storms, showers and drizzles.

Availability of water is essential for all living things on Earth. It is responsible for sustaining all human activities and bio ecological diversity in the world (Ssen tongo *et al*. 2018). In Kenya, rainfall is the main source of fresh water that is extremely important for sustaining life in all forms hence studying the characteristics of rainfall is of uttermost importance. Rainfall is non homogeneous in space time distribution and understanding its distribution is very important.

However extreme rainfall events can cause adverse effects to human lives, communities and environment, some even resulting in loss of life and property. Over time an increase in populations, has led to an increase in the number of people moving from rural areas to urban centres in of search for livelihoods. This has left many people predisposed to hydro meteorological hazards such as heavy rains and floods, and eventually loss of lives and destruction of properties and livelihoods (IPCC 2012, Melcher and Bower, 2015, Sane *et al*., 2015).

It is very vital to understand the temporal and spatial characteristics of rainfall in hydrological and Climatological research. Rainfall intensity, duration and frequency greatly affects how plants intercept water, the processes of infiltration of rain water to the underground storage, evaporation as well as surface runoff.

Water is a critical resource in Kenya. The country is listed by the united nations as being chronically water scarce, because it natural annual renewable fresh water supply is at $647m^3$ per capita which is less than $1000m^3$ per capita which is set for water scarcity (Mogaka *et al*., 2006). Rainfall is the main source of fresh water in Kenya and hence understanding the spatial characteristics of our rainfall events is very important for the water management sector of our economy.

Hydrological studies normally divide rainfall into events. Any rain storm is characterised by the intensity, duration, the amount of water and the frequency of occurrence (reoccurrence). Rainfall time series shows a considerable variability over a given period varying from within storms, between storms, as well as seasonal and annual variations (Menabde and Sivapalan, 2000). Dividing rainfall into events is complicated by the fact that rainfall temporal and spatial distributions is highly irregular. The most common way of defining a rainfall event is by defining a dry period between rains.

A rainfall event is defined as a specific rainfall amount distributed over a given period of time. In Kenya, the most common precipitation events are, light rains (< 2.5mm/hr), moderate rains (2.5-7.5 mm/hr) and heavy rains (> 7.5 mm/hr) (Subramanya, 1995). For the precise definition of rainfall, the minimum amount of rainfall taken to consideration is 0.1mm/hr (Shaw, 1991).

Rainfall intensity is defined as the amount of precipitation received per unit area and time. It is measured using a rain gauge and expressed in millimetres per hour (mm/hr). 1 mm/hr is equivalent to 1kg of water per meter squared per hour ($1kg.m^{-2}.h^{-1}$). For any given rain event the intensity varies from low to high intensity. In many cases high intensity correspond to short duration events like storms while lower intensity corresponds to longer duration events like drizzles (Al-Awadi 2016).

The duration of a given rain event is defined as the amount of time a given rainfall intensity continues at a constant rate (Al-Awadi 2016). To analyse the frequency of a rainfall event one has to calculate the total amount of rainfall received over a known area in a specified duration with a known frequency in a given year (Okonkwo & Mbajiorgu 2010).

In hydrology, frequency analysis relates the magnitude of an extreme rainfall event to its frequency of occurrence through the use of probability distribution (Chow *et al*., 1988).

The Intensity-Duration-frequency is an accurate illustration that relates rainfall intensity, duration and expected recurrence interval (Al-Anazi and Sebaie 2013, Koutsoyiannis *et al*., 1998, Nhat *et al*., 2006). The regional analysis of design storms gives the probable rainfall intensity for a given storm duration and return period (Almaw and Chaoka 2016).

In general, more frequent events have less average intensity as compared to less frequent events. Intense rainfall events are most likely caused by convective activities and lasts more than two hours of time (Shaw, 1991). Hydrological analysis have established that very high intensity events are highly correlated with convective activities and events occur less frequently and do not contribute much to the seasonal and annual totals of a given river basin (Ward and Robinson, 1985).

The probable maximum precipitation is hypothetically maximum amount of rainfall for a specified duration that is physically probable for known drainage area at a known time of the year (Ward and Robinson, 1985).

In this study the rainfall threshold is the average amount of rainfall received at the peak duration of a given region.

1.1 Problem statement

Flooding is a serious problem for Kenyan cities and towns especially during the rainy season. Water resource managers need the information on the temporal and spatial characteristics of rainfall events in order to plan and establish appropriate drainage systems for our cities and towns (Alhassoun, 2010). Every year during the rainy season, flash floods sweep away bridges, damage roads and other infrastructure. Structural engineers need the knowledge of spatial and temporal distribution of rainfall events in Kenya to build structures which can withstand these rainfall events.

Fresh water is a critical resource in Kenya especially since the country is listed by the united nations as being recurrently water scarce, because it natural annual renewable fresh water supply is at $647m^3$ per capita which is less than $1000m^3$ per capita which is set for water scarcity (Mogaka *et al*, 2006). During the dry season many parts of the country experience water shortage. During the rainy season there so much water which can be saved in dams for use during the dry season. The information on spatial and temporal distribution of rainfall events can help water resource managers to build enough dams to provide the people with water for use during the dry season.

Several part in Kenya experience flooding. Hydro meteorologists need to understand the spatial and temporal characteristics of rainfall in order to give better flood warnings and keep everyone in these areas safe. IDF characteristics are an important addition to flood monitoring systems (Nhat 2006, Borga *et al*., 2008).

Aviation meteorologists in Kenya need to know the IDF rainfall characteristics for issuing severe weather warnings. Duration and intensity of storms affect the amount of water falling on the runway and how wet the runway is. Wet runways could lead to accidents hence this tool will help keep everyone safer (Pasindu 2015).

Establishing Intensity-Duration-Frequency curves for rainfall is an authoritative way of estimating the risks of rainfall related natural hazards. IDF curves help in estimation of maximum events as well as to estimate return periods of such events

The study of spatial and temporal characteristics of rainfall is also important to geomorphologists who relate how different types of soils are likely to be affected by different storm magnitudes and frequencies in terms of soil erosion. Different physical structures are formed from soil erosion due to some extreme rainfall events. Kenya is an agricultural country with many parts of the country relying on rain fed agriculture.

This study seeks to solve the above problems and add knowledge on the spatial temporal characteristics of rainfall in Kenya by answering the following questions,

i. How long do rainfall events last?
ii. What is the average intensity of rainfall events in Kenya?
iii. Do all the regions in our country receive the same amount of rainfall?
iv. What is intensity-duration-frequency characteristics of rainfall events Kenya?

1.2 Objectives

The major objective of this research was to examine the spatial-temporal characteristics of rainfall in Kenya. The specific objectives are to;

i. Analyse the duration of rainfall events in Kenya

This will insights as the average durations of most of the rainfall events, from one to eight hours.

ii. Analyse the average intensity of rainfall events

This will show the most common rainfall intensities experiences in Kenya.

iii. Analyse the thresholds of rainfall events in Kenya

This will show a representation of the average intensity of rainfall received during the peak duration and its comparison for different parts of the country.

iv. Develop the rainfall intensity-duration-frequency curves for different station around Kenya.

This will give information on the extreme rainfall intensities likely to be experienced at different durations and return periods. For every station these values are plotted together to show the IDF curves for that location.

1.3 Conceptual framework

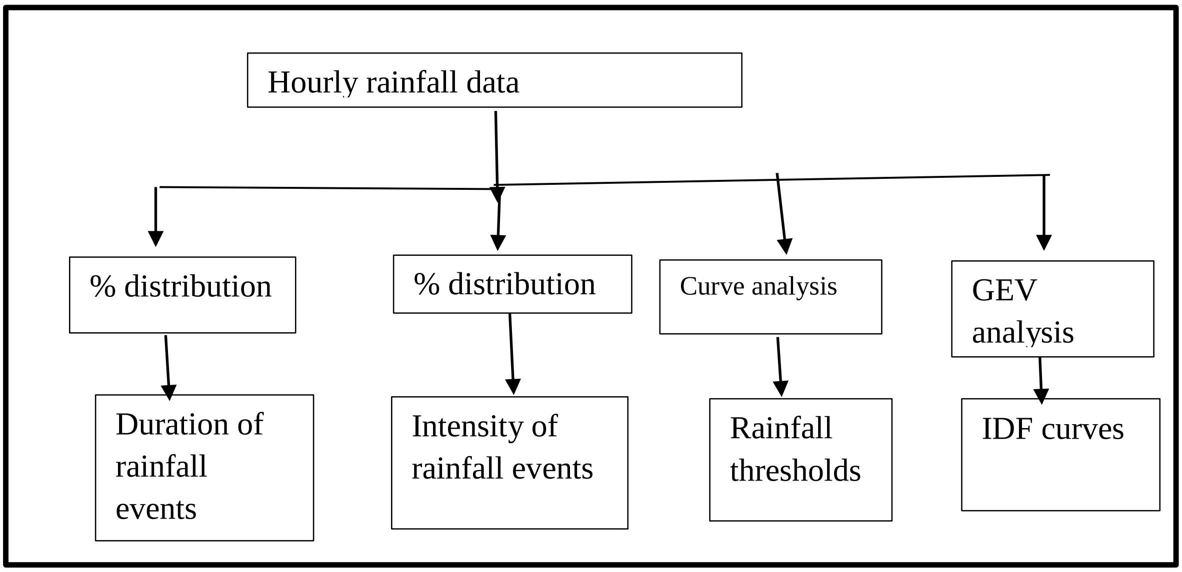

Figure 1: The conceptual framework of the study

1.4 Justification

It is important to carry out analysis of the rainfall for water specialists in different sectors of any country's economy. Mohymont et al (2003), says there is need for more studies about the characteristics of rainfall in the tropical regions of Africa.

Studying the characteristics of rainfall intensity, duration and frequency is very important for different sections of the economy. Water resource managers use this information to planning and design purposes (Alhassoun, 2010, Mirhossein *et al*., 2013). Structural engineers are interested in the IDF regime of rain events in Kenya for designing durable structures which can withstand the rainfall intensity of the storms in Kenya. Every year there are cases of bridges, roads and other infrastructure are damaged by rainfall events. The rainfall intensity-duration-frequency (IDF) correlation is commonly used in hydraulic and hydrological engineering in order to design structures that manage storm runoff and flooding. As our country continues to grow in industrialization, there is need to have more studies on rainfall characteristics including studying the extreme rainfall events and distribution of rainfall events, because these studies are important for different parts of our economy to build structures that can withstand our rainfall events.

IDF is an important tool in hydro meteorology for forecasting and predicting floods (Nhat 2006). Knowing the probability of a storm helps the hydro-meteorologist predict the expected intensity of a storm well in advance.

Aviation meteorologist are tasked with issuing precise hour to hour forecasts of weather elements including rainfall and thunderstorms for facilitation of efficient air transportation. They therefore need to understand the intensity-duration-frequency characteristics of rainfall, this will help them give accurate forecasts of the intensity and duration of rainfall events. The duration and intensity of rain events determines how wet the runway is for runway occupational safety, during landing and takeoff. Many aircraft accidents happening on the runway due to skidding have been reported on many parts of the world (Pasindu 2015).

Planners in the agriculture sector require knowledge of rainfall spatial distribution. The intensity of rainfall determines the rate of erosion. Heavier rainfall events with longer durations lead to higher rates of erosion and loss of topsoil and minerals as compared to lighter events (Fraiser *et al*., 1999). A majority of Kenyans depend on rain fed agriculture for food and sustainability and could use this information for better planning and reducing food insecurity.

Knowledge about the intensity and duration of rainfall of rain events is important to everyone in order to understand the probability of flash floods after rain events for safety and reduction of accidents related to flooding (Ssentongo *et al*. 2018). Forecasting and understanding the probability of flash floods require the knowledge of the temporal and spatial distribution of rainfall events. Understanding the IDF pattern of a Kenya will help hydrologists in making better predictions and warnings about flash foods (Borga *et al*., 2008).

1.5 Area of study

1.5.1 Geographical location

The republic of Kenya is a country in the eastern part of the African Continent. It borders the Indian Ocean and Somalia on the east, Ethiopia and South Sudan to the north, Uganda to the West and Tanzania to the south. It lies squarely on the equator between latitudes 5.5°N and 5.0°S and longitudes 34°E to 42° E. It covers an area approximately 580 370 km^2.

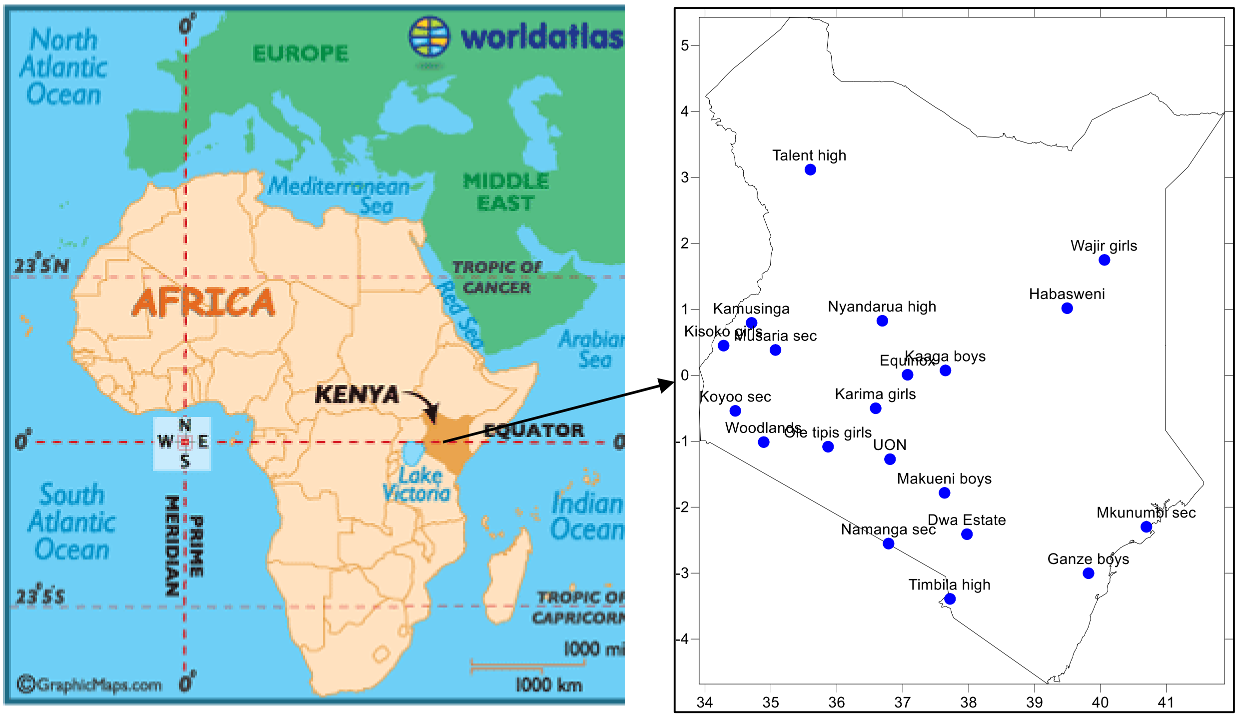

Figure 2: Map of Kenya

Source: https://www.worldatlas.com/webimage/countrys/africa/ke.htm

1.5.2 Climate of Kenya

Kenya enjoys a warm tropical climate, with the northern and northern eastern parts of the country, as well as parts of south eastern Kenya being arid and semi-arid regions, the coastal strip is hot and humid and the rest of the country is temperate. The average rainfall received is approximately 630mm with the high ground areas receiving lots of rainfall, approximately 2300mm per annum on the slopes of Mt Kenya, while the drier areas record as low as 320mm per annum in the northern regions, while the Chalbi desert region in Marsabit receives approximately 200mm (Osbahr and Viner 2006).

There are two rainfall seasons coinciding with the passage of the Inter tropical convergence zone, which are the March-April-May season and the October-November-December season. The June-July-August season is usually the coldest season while January-February is the hottest season. Kenyan temperatures also vary with altitude with the coastal regions being hot while the higher ground regions are much cooler. The elevation varies from sea level to more than 4000m above sea level around the mountainous regions.

1.5.3 Rainfall regime of Kenya

Kenya has a bimodal rainfall regime (Miller, 1931). This means that every year there are two distinct rainfall seasons. The March – April – May season also known the long rain season and the October – November – December rainfall season fondly referred to as the short rain season. There are different factors influencing the rainfall patterns in Kenya, these include, Inter-Tropical Convergence Zone (ITCZ), El-Nino Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), Quasi biannual oscillation (QBO), easterly waves, as well as the different topographical features in this country (Ogallo, 1989).

The seasonal rains in Kenya are closely related with the passage ITCZ. This is an equatorial trough of low pressure which closely trails North-south movement of the sun. It is overhead in Kenya in March and September. The Inter-tropical convergence zone ITCZ is usually the meeting area of the North-eastern and South-eastern monsoon circulation. The ITCZ is linked with a quasi-continuous band of convection clouds, and many times rainy weather (Folland *et al*. 1991). The convergence of these winds produces strong ascendant movement of air that causes rainfall if sufficient moisture is available. The passage of ITCZ precedes the start of the rainy season by 3-4 weeks, but this may varies from season to seasons due to the relations between the ITCZ and other components of the global climate circulation, in addition to the smaller scale circulations due to land surface heterogeneity brought about by topography, large inland lakes and inconsistent vegetation characteristics (Mutai and Ward, 2000; Indeje *et al*., 2000, Saji *et al*., 2003).

Elnino southern oscillation ENSO is a coupled Ocean-Atmospheric circulation in the equatorial Pacific Ocean. It involves a periodic variations in the Sea surface temperatures SSTs and the air pressure in the overlying atmosphere. This modulates the walker circulation enhancing or reducing the rainfall in Kenya. Camberlin *et al*., 2001 studied the seasonality and atmospheric dynamics of the association between the African rainfalls and established the ENSO relationship. Mutai & Ward 2010 did a study on the East African rainfall and the tropical circulation/convection on Intra-seasonal to inter-annual timescales and confirmed this relationship as well.

The ENSO phenomena is known to be a fundamental and quasi-periodic feature of the Ocean-Atmosphere system, with periodicities ranging from seasonal to about 8 years (Rasmusson and Carpenter, 1983; Halpert and Ropelewski, 1992). Some extreme rainfall anomalies in East Africa have been associated with ENSO (Ropelewski and Halpert, 1987; Janowiak, 1988; Ogallo, 1988). The Indian Ocean Dipole is a coupled ocean-Atmosphere circulation which happens in the equatorial Indian Ocean. There is a regular cycle of warming and cooling of the waters within the east and west equatorial Indian Ocean alternatively. A positive IOD means negative sea surface (SST) anomalies in the Central and eastern equatorial Indian Ocean and positive sea surface anomalies on the eastern side of the Indian Ocean, meaning cooler than usual SSTs in the east and warmer than usual SSTs on the west. A negative IOD means is the reverse of this. The land areas adjacent to the warmer SSTs receive more than average rainfall while areas near the cooler than average SSTs receive less below normal rainfalls. A positive IOD leads to above average rainfall in Kenya while negative IOD leads to below normal rainfall in Kenya (Lim and Hedon 2017, Saji and Yamagata, 2003).

Kenya has different topographical variations which modulate the rainfall regimes of different regions within the country, mountainous areas and higher altitude areas have more rainfall as compared to lower ground areas inducing orographic rainfall to those regions. Different lakes modulate the rainfall regime for areas around them with land and sea breeze circulations as well the regions adjacent to the coast line.

1.5.4 Rainfall formation in Kenya

Rainfall occurs when air rises, cools and forms clouds. There are several methods of rainfall formation which are, convection, orographic lifting and cyclonic or frontal rainfall. In Kenya orographic lifting and convection rainfall are the most predominant.

Convection rainfall occurs when isolation from the sun warms the earth's surface, which warms the air near the earth's surface. The air then expands and rises. If this air has sufficient moisture, it cools according to the dry adiabatic lapse rate and condenses forming deep convective clouds and thunderstorms. It is characterised by heavy downpour over short periods of time accompanied by thunder and lightning mainly in the afternoon (Subramanya 1995, Bharatdwaj 2006).

Orographic lifting is a way of rainfall formation where air is forced to rise by terrain and mountain barriers that lie across the direction of the wind. The rising air continues to rise according to the dry adiabatic lapse rate (10ºC for every 1000m) and becomes saturated and clouds begin to form. Latent heat of condensation is released which pushes the air further upwards according to the moist adiabatic lapse rate. The ascending air continues to rain as it goes up the hill/mountains. The side of the mountain facing the wind direction is called the wind ward side and receives the maximum amounts of rain while the side of the mountain away from the oncoming wind direction is the leeward side and receives considerably less precipitation because as air flows down the mountain it warms dry adiabatically reducing the humidity levels. The rainfall amounts increases with height of the mountain with maximum rainfall occurring higher up in the mountains on the windward side of the mountain. Orographic rainfall can occur any time (Subramanya 1995, Bharatdwaj 2006).

CHAPTER TWO: LITERATURE REVIEW

This chapter highlights different published research on the spatial-temporal characteristics of rainfall all around the world.

2.1 Spatial-temporal characteristics of rainfall

Analysis of the spatial-temporal characteristics of rainfall was done as early as 1932. Sherman, (1932) analysed the frequency and Intensity of Excessive Rainfalls at Boston-Massachusetts. Since then, different parts of the world have published studies on the spatial-temporal characteristics of rainfall for their regions (Nhat *et al*., 2006). However many developing countries, including Kenya, still need more studies into the characteristics of rainfall for their regions. In the United States of America, Hershfield (1961) came up with several rainfall contour maps to show the design rainfall depths for different durations and return periods. Bell (1969), projected a general IDF formula using the hourly, 10 years rainfall depth index, P_1. Chen (1983) came up with a general IDF formula applicable all over the United States to describe the geographical variations of rainfall.

Madsen *et al*., (2002) studied extreme rainfall in Denmark using generalized least squares regression of partial duration series statistics. This study showed a general presentation of a regional study analysing and modelling extreme rainfall characteristics using partial duration series. In this method, all events beyond a given threshold level were analysed. The mean value of the above the threshold, the average annual number of events above the threshold and the coefficient of variation were regarded as regional variables. Using a generalised least regression model, they accounted for correspondence of different stations within a given site and sampling uncertainties was applied for evaluating the regional heterogeneity of the partial duration series parameters. The generalized least squares model was used for explaining the variation from Climatological and geographical characteristics for parameters that showed a considerable regional variability. This was used for analysing the exponential distribution and various two parameter distribution in order to determine the proper regional parent distribution in the partial duration model. They found that this model was a suitable tool for estimating the intensity-duration-frequency distribution of rainfall at any random location in their country.

Devkota *et al*., (2018), analysed the rainfall characteristics of the monsoon rainfall in the Pan Chase region of Nepal. They used empirical model for data scarce situations. Daily rainfall data from eight homogeneous stations were grouped into hydrological annual series. The day-to-day rainfall was broken down to hourly synthetic data series using a stochastic model. This data was calibrated using the recorded daily data. They came up an intensity-duration-frequency relationship using

Gumbel frequency factor. A mathematical model was then used to estimate the intensity-duration-frequency characteristics for individual stations using the most conforming probability distribution function and calibrated them using the reference stations. They were able to estimate the rainfall characteristics for ungauged locations using this method.

Langousis and Veneziano (2006) studied the rainfall characteristics for the country of Italy. They used three different models representing the varying characteristics of rainfall for this region. Their model classified both the spatial and temporal characteristics of rainfall intensity at different storm scales. This model was then used to interpolate the spatial-temporal characteristics of rainfall for much longer return periods than the existing historical data records.

Menabde and Sivapalan (2000) calculated the precipitation time series and maximum events using bounded random cascaded and levy stable distributions. Using a model for simulating rainfall time series, they discovered that the intensity and duration of individual precipitation storms are best modelled by examining the levy stable distribution. Downscaling the temporal characteristics of specific events was calculated using random cascade modelling. This successfully modelled the statistical behaviours of individual storm.

Dourte *et al.*, 2015 analysed the characteristics of rainfall for the Andra Pradesh region of India. They used hourly data from two rain gauge stations for the periods 1993-2011 to generate the precipitation thresholds and intensity-duration-frequency characteristics of the region. Their analysis was able to give an update to the then available Intensity-duration-frequency curves for durations of 1, 2, 4,8,24 hours and return periods of 2, 5, 10, 15, 25, 50, 75 and 100years.

Michele and Salvadori (2003) studied the rainfall characteristics of the Bisango region in Italy. They used stochastic rainfall models to study the relationship between the intensity and duration of rainfall storms. They realised that spatial temporal characteristics of rainfall is best categorised using heavy tailed Pareto-like distributions and that the duration and intensity of storms are highly related. They came up with an intensity – duration model which gave a relationship between average intensity and duration of storms. They were able to use this model to estimate the extreme rainfall as suggested by the generalized extreme value law.

Kalita and Talukdar (2017), came up with Intensity-duration-frequency formulas for rainfall in Puthimari Basin, Assam. They used the conventional method of coming up with IDF curves which includes, First they established a suitable probability distribution function for each duration sample, then using the estimated distribution function to calculate the return periods and finally using a parametric equation for each return period to come up with the IDF curves for each return period. The Gumbel's distribution technique was used to calculate the return period, and curve fitting method was used to produce the IDF curves. The maximum intensity for return period of 2 years, 5 years, 10 years and 50 years were then calculated.

Al wadi (2016) did an analysis of rainfall characteristics of the Baghdad city in Iraq. Their main objective was to estimate the relationship between rainfall intensity, duration, total amount of rainfall and the frequency of reoccurrence. Their equations conformed to the recorded rainfall characteristics of rainfall in the region.

Al-Nazie and El-Sabaie, 2013, analysed the spatial-temporal characteristics of rainfall of the Abha city in Saudi Arabia. They used a data series of 34 years of rainfall for this region. They carried different frequency analysis technique such as Gumbels extreme analysis, Log-Normal and Log-Pearson Type III. They came up with equations connecting the rainfall intensity, storm duration and return periods. They were able to design the IDF curves for the durations of 10, 20, 30, 60, 120,180, 360 and 120 minutes and return periods of 2, 5, 10, 25, 50 and 100 years. Their rainfall equations conformed to the rainfall characteristics of their region.

Ben-Zvi, 2008 studied the rainfall characteristics for Israel. Data from four stations was used. Partial duration series of the data was extracted and the generalised Pareto distribution used to obtain the intensities for different durations and return periods. The main advantages of this method is that it allowed them to select more data than the available years of data with no extrapolations.

Bougadis and Adamowski, 2006, analysed the rainfall characteristics of the province of Ontario, Canada. Gumbel’s Extreme Value analysis was used to obtain intensities for different return periods and durations (5, 10, 15, 30 minutes, 1, 2, 6, 12 and 24 hours). Their research showed that the results conformed to the rainfall characteristics of this region.

Alhassaoun (2010) established mathematical equations to evaluate rainfall intensity in Riyadh region using the intensity-duration-frequency curves. The IDF curves were produced using 32 year rainfall data from this region. These IDF relate rainfall to duration and various return periods. They used a combination of Gumbel method, Log Pearson III and Log normal method to plot IDF curves for different durations and frequencies.

Endreny and Imbeah (2009) estimated the IDF parameters for Ghana two probability distribution frequency analysis methods. They used two separate rainfall datasets from 381 satellite precipitation sampling points all around the country. These were used to generate the extreme value type II probability distributions.

El-Hadji and Singh (2002) investigated the time and space variability of rainfall and runoff in the Casamance river basin in Southern Senegal in West Africa using long term precipitation and runoff data for 1951 to 1990. Manabdee *et al*., (1999) came up with the intensity duration frequency curves for Melbourne, Australia using a 25 years data set, containing 6 minutes rainfall intensities logged electronically.

Okonkwo and Mbajiorgu (2010) established the IDF analysis for south eastern Nigeria. They used graphical and statistical methods to evaluate rainfall data from locations around here. They used the generalized rainfall patterns and merged them with their local rainfall data. This pattern was then used to disintegrate the recorded day to day rainfall amounts into sets of shorter duration rainfall data. For the statistical analysis the Gumbel distribution was used to approximate the relevant parameters of the IDF model. Then the Kolmogrorov-Smirnov tests was used to test the validity of the fitted distributions for the locations.

Awadalla *et al*., 2017 studied the characteristics of extreme rainfall for the country of Egypt with the aim of establishing the intensity-duration-frequency equations for building sewage networks for the country. They used a combination of rainfall data from the existing synoptic stations and rainfall data from satellites. They were able to make corrections on the existing extreme rainfall studies and understood why infrastructure was always being damaged by floods before and established an appropriate estimation of extreme rainfall for their country.

Agbazo *et al.,* 2016 studied the spatial-temporal characteristics of rainfall in the West African country of Benin. They used Gumbels extreme value analysis on rainfall data from ten rain gauge stations. They analysed the intensity of rainfall for different durations ranging from 5 minutes to 24 hours. They used simple scaling models and were able to obtain rainfall projections for durations ranging from minutes to hours at different return periods.

Akpen, 2016 studied the spatial-temporal characteristics of rainfall in Makurdi Metropolis, Benue state in Nigeria. Gumbels extreme value distribution was used on precipitation records gotten from the Nigerian Meteorological Department. They evaluated the correlation between the rainfall intensity and duration at different return periods for both annual series and partial duration series. This research showed that power models were the best suited to describe the rainfall characteristics of this region.

Alemaw and Chaoka, 2016, analysed the characteristics of rainfall in Botswana. They identified three regions of homogeneous rainfall characteristics depending on topographical and rainfall characteristics using K-Means clustering algorithms. For each homogeneous region, the 24 hours annual maximum rainfall intensity were obtained. Gamma and Lognormal probability distributions were used to estimate rainfall intensity for 1-24 hours and return periods of up to 100 years. They were then able to draw the intensity-duration-frequency curves for these homogeneous regions.

Antigha and Ogarekpe, 2013, studied the rainfall characteristics of rainfall in Calabar Metropolis in Southern Nigeria. Using daily data from the Nigeria Meteorological agency, they extracted peak rainfall values and the corresponding durations for 23 years. They then used Gumbel's Extreme Value analysis to come up with the intensity-duration-frequency relationship for the region and calculated the intensities for durations 2, 5, 10, 15, 30, 60, 120, 240 and 320 minutes for return periods between 2-100 years.

De Paola *et al*., 2014 studied the intensity-duration-frequency characteristics of rainfall for African cities. They analysed daily rainfall data for Addis Ababa in Ethiopia, Dar es Salaam (Tanzania) and Douala (Cameroon), and came up with a rainfall model which was able to simulate the rainfall patterns for these three cities and disintegrate the rainfall into smaller time durations of 10 minutes, 30 minutes, 1 hour, 3 hours 6 hours and 12 hours. They were able to generate the Intensity-duration-frequency curves and factor in the effects of climate change on the rainfall characteristics using climate simulations for the time period 2010-2050, and calculated the maximum probable rainfall for these cities.

Wangesho and Claire 2016, analysed the rainfall intensity-duration characteristics of Rwanda. They used daily rainfall data from 26 rainfall gauging stations around the country representing the different geographical locations within the country and data records varying between 14 to 83 years. They obtained the day to day maximum rainfall for several years and were able to disaggregate it into smaller durations such as 30 minutes, 1 hour, 3 hours, 6 hours and 12 hours. They used probability distributions and quantile estimation to draw intensity-duration-frequency curves for different return periods and durations. This research divide the country into five similar region using the recorded rainfall data.

2.2 Analysis of intensity-duration-frequency of rainfall

The IDF equation is a concise mathematical equation relating the duration of a rain storm with its frequency of occurrence, also known as the return period (Koutsoyiannis *et al*., 1998). It can also be described as a graphical illustration of the amount of rainfall that is experienced in a given area within a given period of time (Al-Awadi, 2016).

There are three steps to establishing IDF curves; first an appropriate distribution function of the given data set is established, it can either be the probability distribution or cumulative distribution. The maximum rainfall intensity for each duration is matched with its corresponding return period from the distribution function. Then, rainfall intensities for different return periods and durations are calculated. This data is then plotted to show the IDF Curves relating the intensity of rainfall againist duration for different return periods (Nhat *et al*, 2006).

There are many theoretical distribution functions used in creation of IDF equations. Examples include Gumbel distribution theory, Log Pearson Type III and Log Normal distribution. Gumbel's distribution theory was proposed by Gumbel (1941) for analysis of flood frequencies. It utilises the extreme values or the maximum value events. The highest intensities and statistical values (mean and standard deviation) for a given duration (0.25hr, 0.5hrs, 1hr, 2hrs, 3hrs, 6hrs, and 24hrs) are calculated (Alnazi and Sebaie, 2013, Alawadi, 2016). The advantages to this method is that it is easy and clear to use.

The Log Pearson Type III (LPT III) probability distribution function generates various rainfall durations and return periods of rainfall intensity which give the IDF curves of the desired area. This distribution function utilizes the logarithms of the calculated values. The mean and standard deviation are determined using logarithmically transformed data. The same formulas as with Gumbel's distribution are used, except the distribution frequency factor which depends on the return period and the Skewness coefficient (Alnazi and Sebaie, 2013, Alawadi, 2016).

In log Normal distribution the frequency factor depends on the return period. The frequency factor is calculated the same way as the LPT III distribution and the value of the extreme rainfall intensity is converted into logarithms. The extreme rainfall is calculated using the same equation as the formula for the Gumbel's distribution function and the K_T is obtained from the water resource references for the desired region.

Empirical IDF equations are mathematical representations showing the correlation between maximum rainfall intensity (as a dependant variable), rainfall duration and frequency (as independent variables) (Nhat *et al.*, 2006).

Endarwin *et al*., 2014 studied the temporal and spatial characteristics of rainfall in Indonesia using a modified convective stratiform technique and satellite data. They used data from 23 different points over Indonesia they estimated received rainfall from satellite cloud data and verified it using the observed data. They then classified hourly the rainfall as follows, No rainfall (0 -1 mm/hr), light rains (≥ 1 – 5 mm/hr), moderate rainfall (≥ 5 – 10), heavy rainfall (10 - 20) and very heavy rainfall (≥ 20 mm/hr). They were able to come up with a good model for estimation of hourly precipitation.

CHAPTER THREE: DATA AND METHODOLOGY

This chapter explains in details the type of data used and different operations undertaken to help understand the rainfall thresholds in Kenya as well as to evaluate the Intensity, frequency and duration distribution of rainfall in Kenya.

3.1 Data

The data was obtained from Automatic weather stations AWS installed by the Trans-African hydro-meteorological Observatory TAHMO school to school initiative. TAHMO has a vast network of AWS all across Africa which process hourly data for rainfall, temperature, humidity, wind speed and direction, pressure and radiation.

This study required rainfall data for different stations around Kenya. The following are the data stations obtained. These stations where installed on different dates from 2015 to 2017, as shown in the diagram below and have full sets of data since installation up to date. This is hourly data and has given enough information on the characteristics of individual rainfall storms experienced within this period.

Table 1: Data stations used for this study

STATION		LONGITUDE	LATITUDE
1.	Dwa Estate Kenya	37.9734	-2.4101
2.	Equinox Horticulture	37.0722	0.0074
3.	Ganze Boys Secondary School	39.8167	-3.0023
4.	Habasweni DC offices	39.493	1.0168
5.	Kaaga Boys High School(Nyeri)	37.6469	0.072959
6.	Kamusinga Friends Boys Secondary School	34.70662	0.794043
7.	Karima Girls High School	36.5885	-0.5006
8.	Kisoko Girls Secondary School	34.2824	0.449276
9.	Koyoo Secondary School	34.46	-0.5397
10.	Makueni Boys School	37.6333	-1.7833
11.	Mkunumbi Secondary School	40.6943	-2.29836
12.	Musaria Secondary School	35.06875	0.383228
13.	Namanga Mixed Secondary School	36.7839	-2.5521
14.	Nyandarua High School	36.6897	0.826
15.	Ole Tipis Girls Secondary School	35.8667	-1.0833
16.	Talent High School	35.5988	3.1184
17.	Timbila High School	37.71624	-3.3913
18.	Wajir Girls	40.0586	1.7488
19.	Woodlands 2000 Trust	34.8905	-1.01361
20.	University of Nairobi, Chiromo	36.8077	-1.2764

The following map shows the distribution of the stations around Kenya.

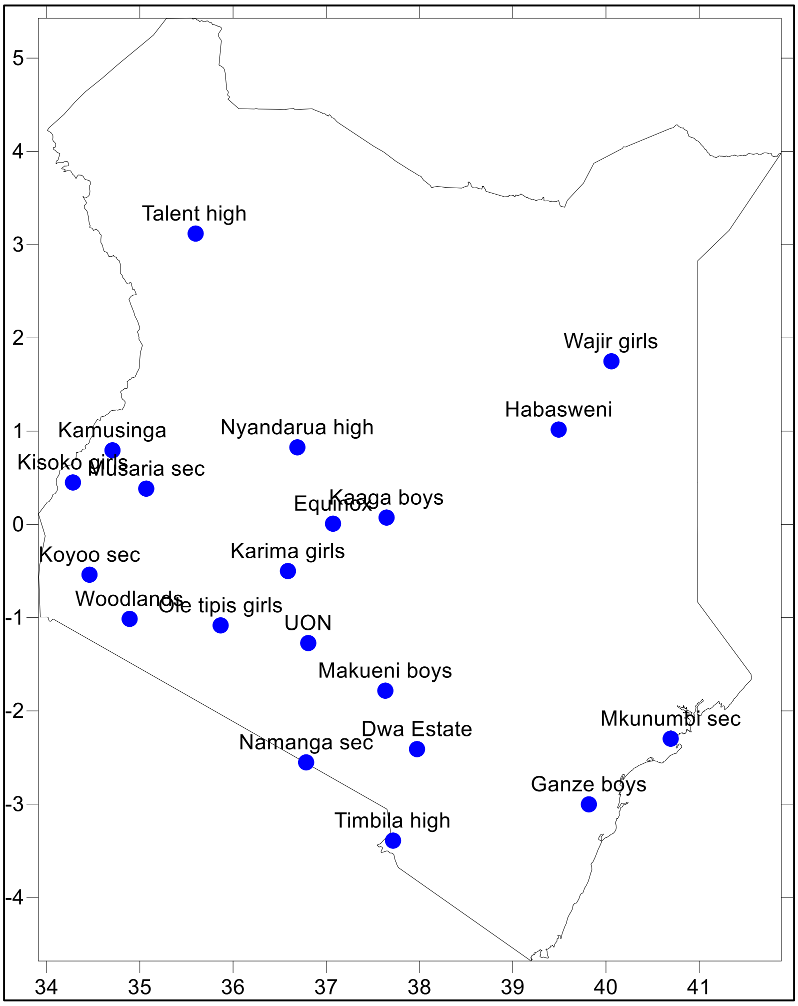

Figure 3: Distribution of the AWS stations around Kenya

3.2 Methodology

Data used for scientific research should be of highest quality. Therefore it is important to carry out data quality control.

The data used for this research was obtained from Automatic weather stations installed by the TAHMO school to school initiative in different institutions all around the country. So far all data sets obtained were complete and no missing data.

Time series of the data were plotted to show the distribution and continuity of the data. A time plot/time series is a graph displaying a variable (y axis) against time (x axis). These plots are good for showing how time varies over time. A histogram is a plot that allows the researcher to see the data frequency distribution of a given data set. It enables one to scrutinize the data for its underlying distribution, outliers, skewness etc. In order to come up with a histogram from a data set, the data is split into intervals called bins, then the frequency of each bin is counted. The distribution of data for this research was done using the excel data analysis function. Histograms for all the stations were generated.

3.2.1 Analysis of the duration of rainfall events in Kenya

To compute the duration of the rainfall events, the total number of events for each duration is determined, as well as the total number of events, the percentage distribution of events is then calculated using the formula below

$$D\% = \frac{N_d}{E} \times 100 \qquad \text{…………………………………………………… 1}$$

Where D% is the percentage distribution of the number of events N_d in a given duration out of the total events recorded E. Once all the percentage distribution for all the stations for different hours where calculated, the average durations for different durations are computed and plotted.

3.2.2 Analysis of average intensity of rainfall in Kenya

To analyse the average intensity of rainfall, If logical statements in Excel 2013 to be used to categorise the average intensity of the rainfall events. Plots of average intensity of rainfall against their frequencies to be plotted.

The hourly rainfall events to be categorised into the following, The rainfall intensities were classified as follows, Drizzle, 0.1-0.9mm/hr, Light rains 1-4.9mm/hr. moderate rains 5-9.9mm/hr, heavy rains 10-19.9 mm/hr, and very heavy rains >20mm/hr (Safwan, *et al*., 2014). The percentage distribution of intensities was calculated using the following formula,

$$D = \frac{M}{N} \times 100 \qquad \text{…………………………………………………… 2}$$

Where D is the percentage distribution of the number of events in a given classification, M, out of the total number of events, N.

3.2.3 Analysing the thresholds of rainfall events in Kenya

Rainfall threshold analysis is done by determining the duration when the peak rainfall intensity is experienced. Curve analysis techniques were used to determine the peak duration of rainfall for every station. This was them matched with the average intensity of rainfall for that given duration.

A plot of the duration of rainfall events against the probability of their occurrence was plotted and curve fitting techniques used to establish the peak duration of the rainfall events. The mean of the intensities of rainfall for different durations were plotted for each station and the average intensity of the peak duration for each data set was established. To calculate the probability of flash floods, the following formula was used.

$$c = \frac{f}{p} \qquad \text{………………………………………………………………3}$$

Where c is the probability of flash floods, f is the average intensity of rainfall at the peak duration (threshold) and p is the peak duration of rainfall.

The calculated rainfall thresholds for all the stations are then plotted using Sufer graphical analysis. This data is used to interpolate the threshold for all the regions in Kenya. This shows the variation of rainfall thresholds all over Kenya.

3.2.4 Developing the intensity-duration-frequency curves for rainfall in Kenya

To calculate and plot IDF curves, first partial duration series was applied to the data sets to find a series of data with independent daily maximum rainfall intensities. This series was then converted to annual series using an empirical formula. The empirical factors for converting partial duration series into an annual series are as follows as shown in (Chow, 1964).

Table 2: Empirical conversion factors

Return period	Conversion factor
2 years	0.88
5 years	0.96
>10 years	0.99

Gumbel’s extreme value analysis is then applied for IDF analysis shown by the following formulas.

$$i_T = i_{av} + k_T * S \qquad \text{……………………………………………….4}$$

Where i_T represents the design rainfall in mm/hr, i_{av} is the average intensity for each duration with a specified return period T, and S is the standard deviation. k_T is the frequency factor obtained using the following

$$k_T = -\frac{\sqrt{6}}{\pi}\left[0.5772 + \ln\left(\ln\left\{\frac{T}{T-1}\right\}\right)\right] \quad \ldots\ldots 5$$

This analysis gives different intensities for different return periods and duration which are then plotted to show the IDF curves and tables for different stations.

CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter details the findings from this project.

4.1 Data quality control

All the data used for this study of good quality, consistent and had no missing values.

4.2 Analysis of the duration of rainfall events in Kenya

In this section, the duration of all the events were analysed. Figure 4 shows the distribution of rainfall durations in Kenya. 63% of all the recorded events lasted one hour, 19% lasted two hours, 6% lasted three hours, 3% lasted 4 hours, 2% lasted five hours and six to eight hours received 1% each of the remaining events. This shows that for all the data stationed analysed, short duration events are the most prevalent.

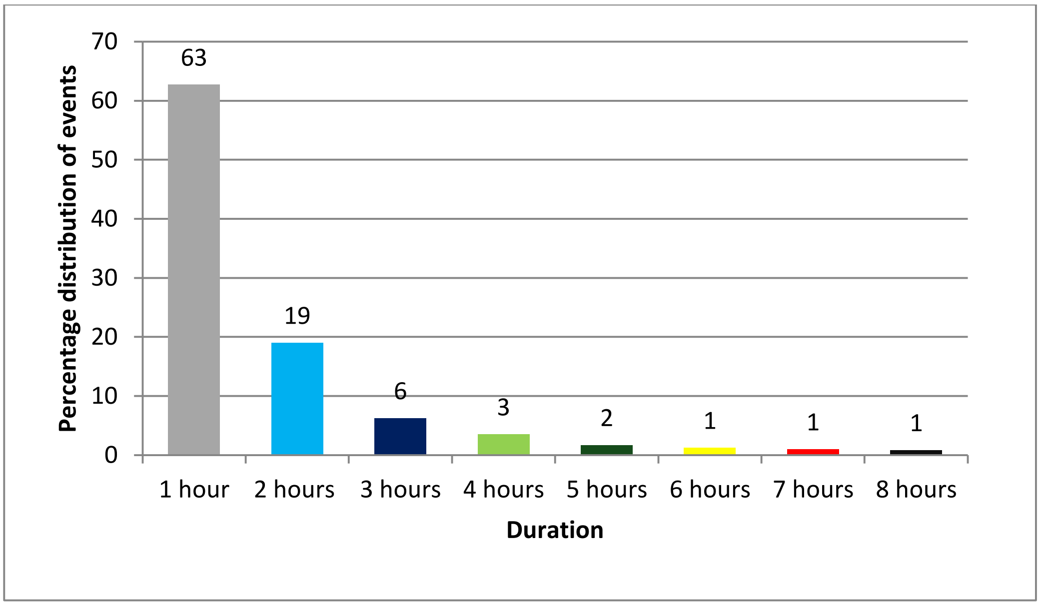

Figure 4: Distribution of rainfall durations in Kenya

Figure 5 shows the distribution of rainfall events in Ganze boys' high school. 67% of all the recorded events lasted one hour, 21% percentage lasted two hours, 7% lasted three hours, 2.5% lasted four hours, and only 2.5% of the events recorded lasted five to eight hours.

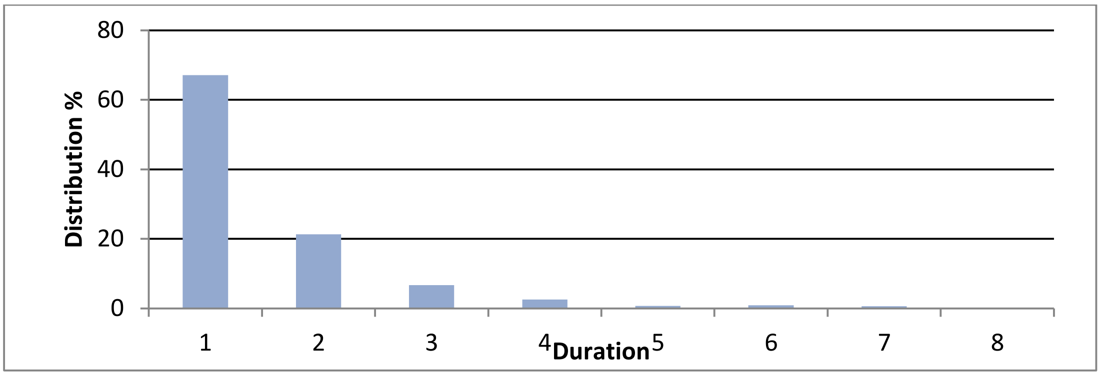

Figure 5: Distribution of rainfall durations at Ganze boys

The figure 6 below shows the distribution of rainfall events in Habasweni DC Office. 62% of all the recorded events lasted one hour, 22% percentage lasted two hours, 4% lasted three hours, 6% lasted four hours, and only 3% of the events recorded lasted five to eight hours.

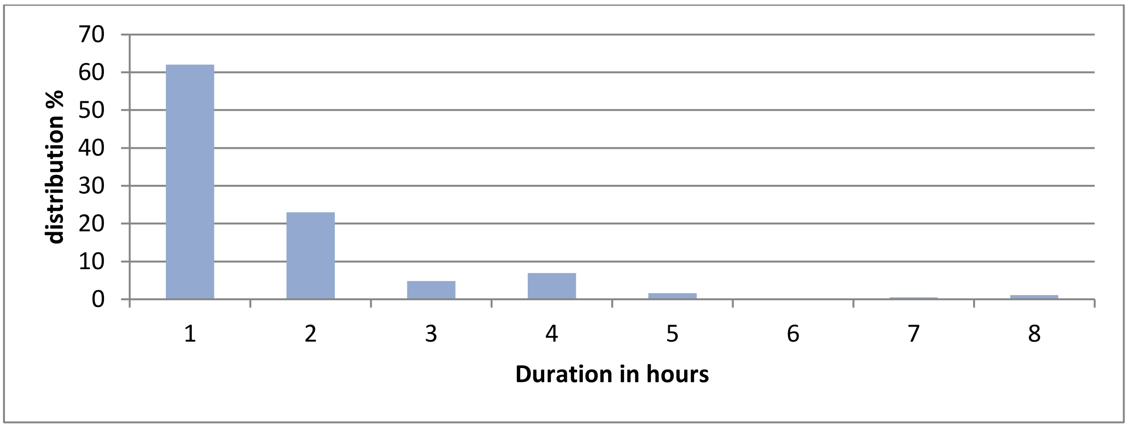

Figure 6: Distribution of rainfall durations at Habasweni DC Office

The figure 7 shows the distribution of rainfall durations at Kaaga boys' high school. 57% of all the recorded events lasted one hour, 22% percentage lasted two hours, 9% lasted three hours, 1% lasted four hours, and only 3% of the events recorded lasted five to eight hours.

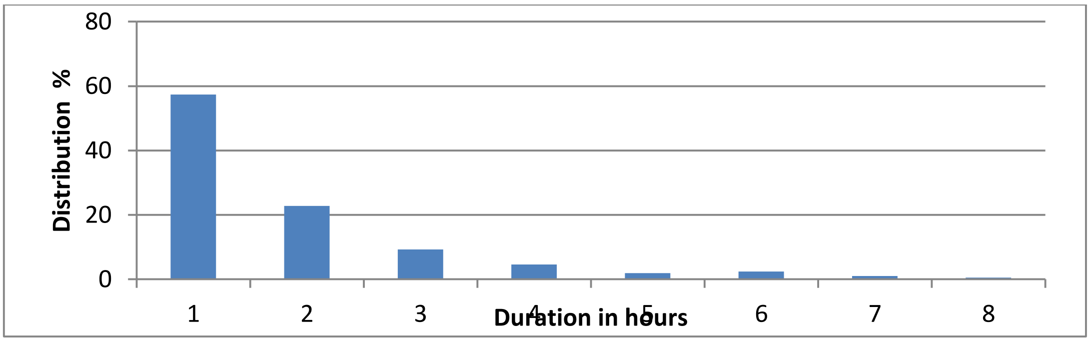

Figure 7: Distribution of rainfall durations at Kaaga boys

Figure 8 below shows the distribution of rainfall event durations in Kamusinga friends' school. 68% of all the recorded events lasted one hour, 19% percentage lasted two hours, 7% lasted three hours, 3% lasted four hours, and only 3% of the events recorded lasted five to eight hours.

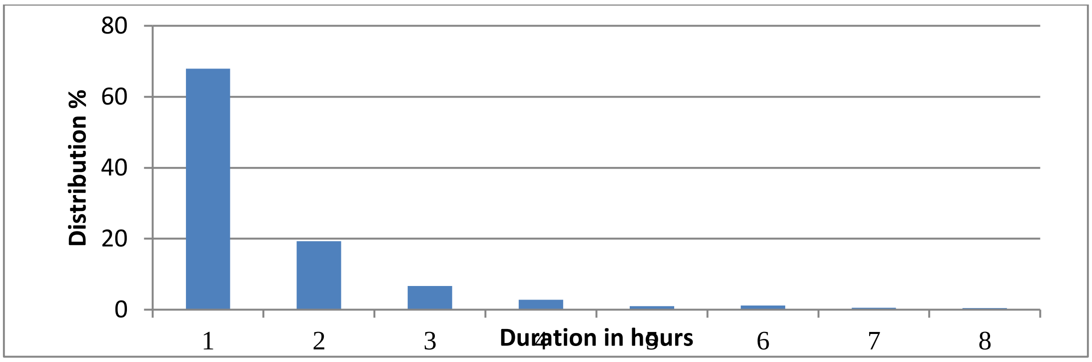

Figure 8: Distribution of rainfall durations in Kamusinga friends' school in Nyeri

Figure 9 below shows the distribution of rainfall event durations in Karima girls' school. 63% of all the recorded events lasted one hour, 22% percentage lasted two hours, 7% lasted three hours, 3% lasted four hours, and only 3% of the events recorded lasted five to eight hours.

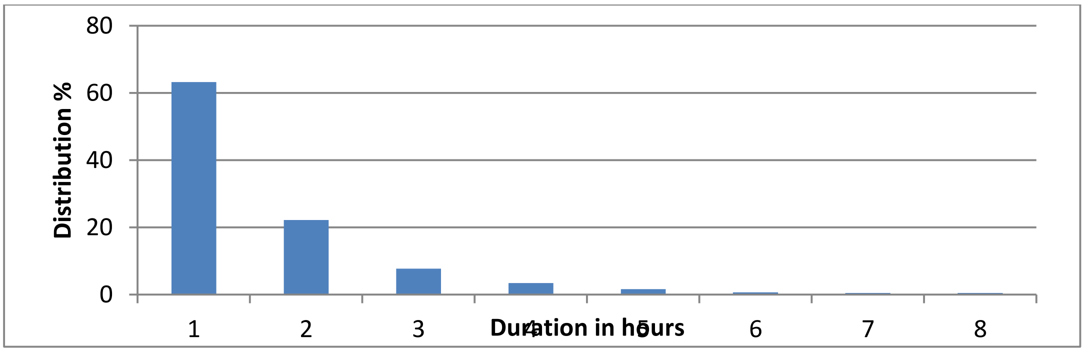

Figure 9: Distribution of rainfall events in Karima girls' high School

Figure 10 shows the distribution of rainfall event durations in Kisoko girls' school. 69% of all the recorded events lasted one hour, 20% percentage lasted two hours, 4% lasted three hours, 2% lasted four hours, and only 4% of the events recorded lasted five to eight hours.

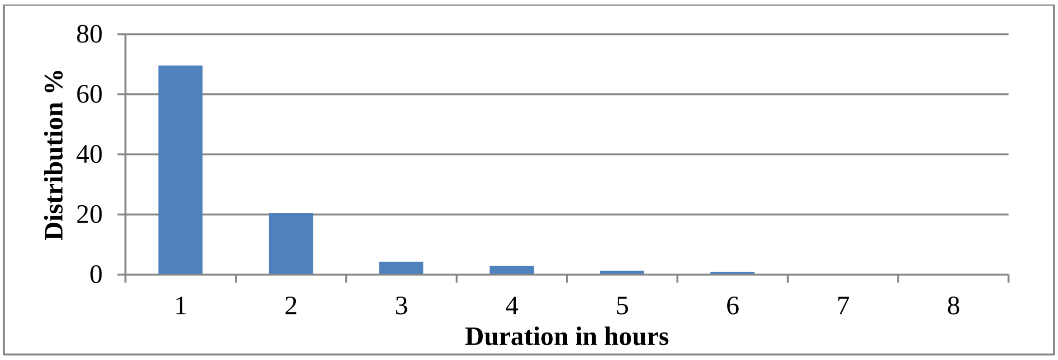

Figure 10: Distribution of rainfall events in Kisoko girls.

Figure 11 shows the distribution of rainfall events in Koyoo secondary school. 70% of all the recorded events lasted one hour, 19% percentage lasted two hours, 6% lasted three hours, 3% lasted four hours, and only 2% of the events recorded lasted five to eight hours.

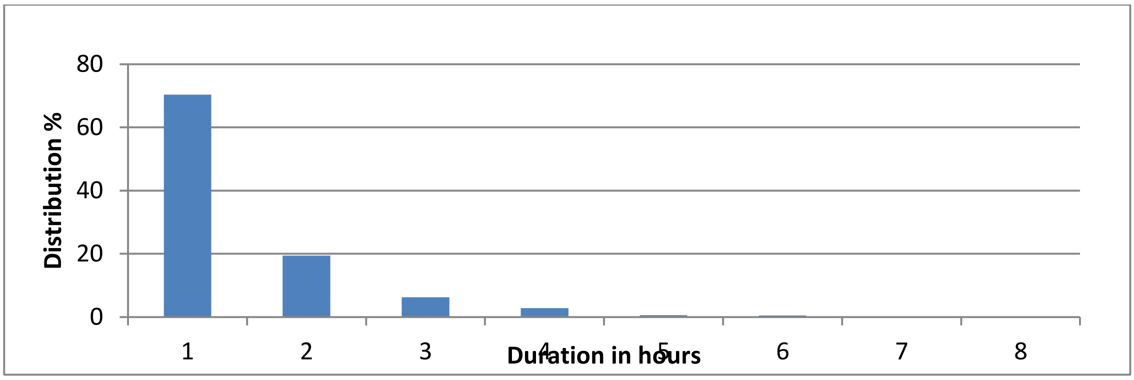

Figure 11: Distribution of rainfall events in Koyoo secondary school.

Figure 12 shows the distribution of rainfall events in Makueni boys' high school. 65% of all the recorded events lasted one hour, 22% percentage lasted two hours, 6% lasted three hours, 3% lasted four hours, and only 4% of the events recorded lasted five to eight hours.

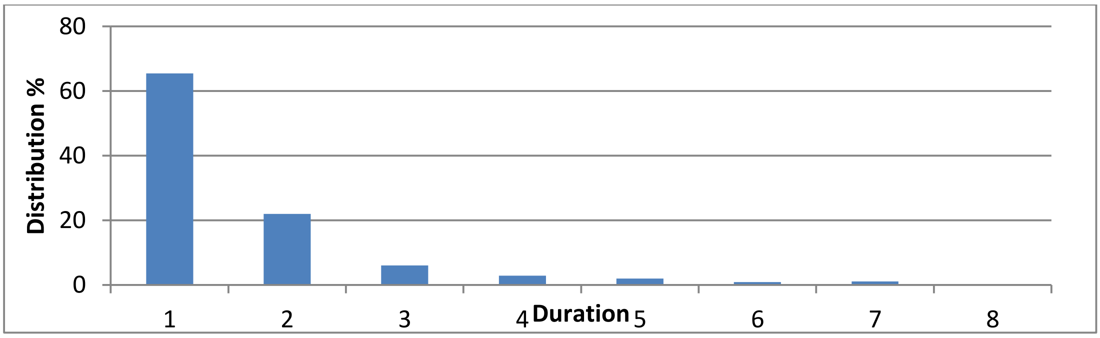

Figure 12: Distribution of rainfall events durations in Makueni boys

Figure 13 shows the distribution of rainfall events in Mkunubi secondary school. 71% of all the recorded events lasted one hour, 19% percentage lasted two hours, 6% lasted three hours, 2% lasted four hours, and only 1% of the events recorded lasted five to eight hours.

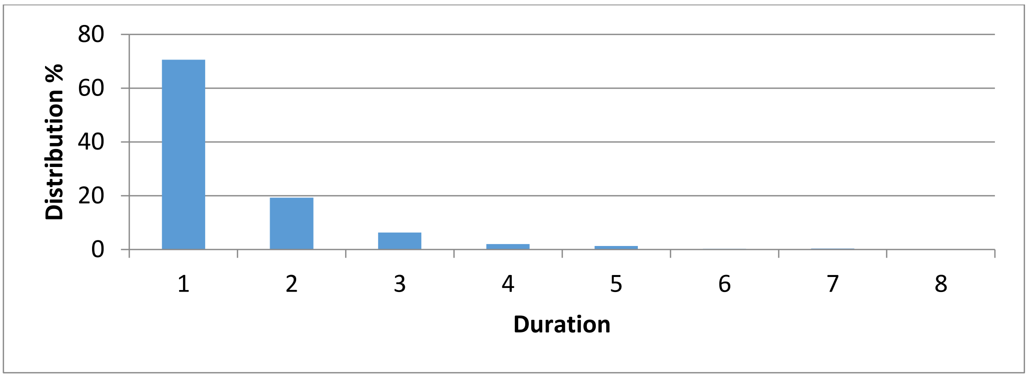

Figure 13: Distribution of rainfall events in Mkunubi secondary school

Figure 14 shows the distribution of rainfall events in Musaria secondary school. 71% of all the recorded events lasted one hour, 19% percentage lasted two hours, 6% lasted three hours, 2% lasted four hours, and only 1% of the events recorded lasted five to eight hours.

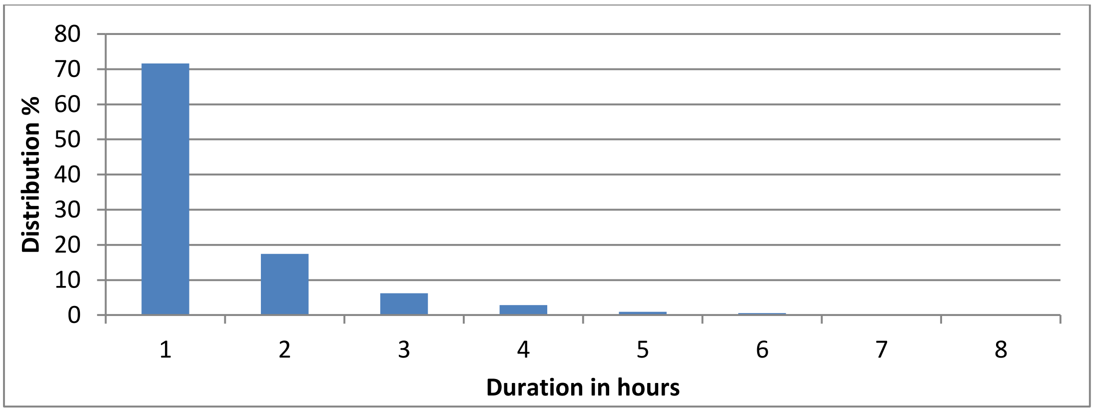

Figure 14: Distribution of rainfall events durations at Musaria secondary

Figure 15 shows the distribution of rainfall events in Namanga secondary school. 72% of all the recorded events lasted one hour, 15% percentage lasted two hours, 6% lasted three hours, 4% lasted four hours, and only 2% of the events recorded lasted five to eight hours.

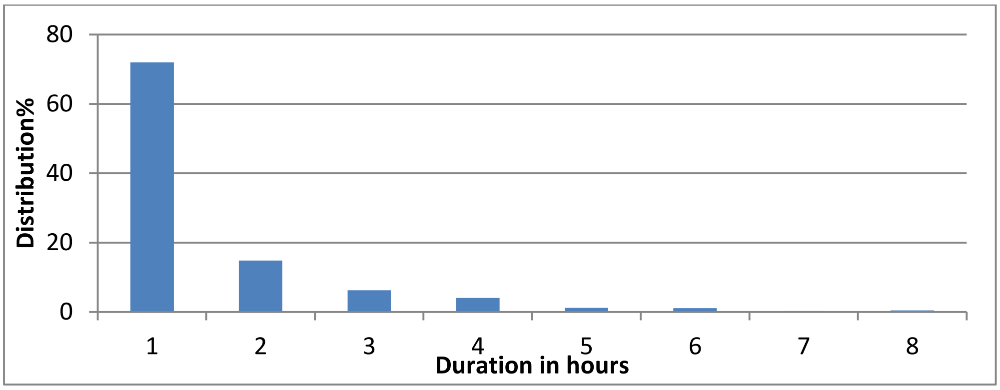

Figure 15: Distribution of rainfall events in Namanga

Figure 16 shows the distribution of rainfall events in Nyandarua. 59% of all the recorded events lasted one hour, 23% percentage lasted two hours, 9% lasted three hours, 5% lasted four hours, and only 4% of the events recorded lasted five to eight hours.

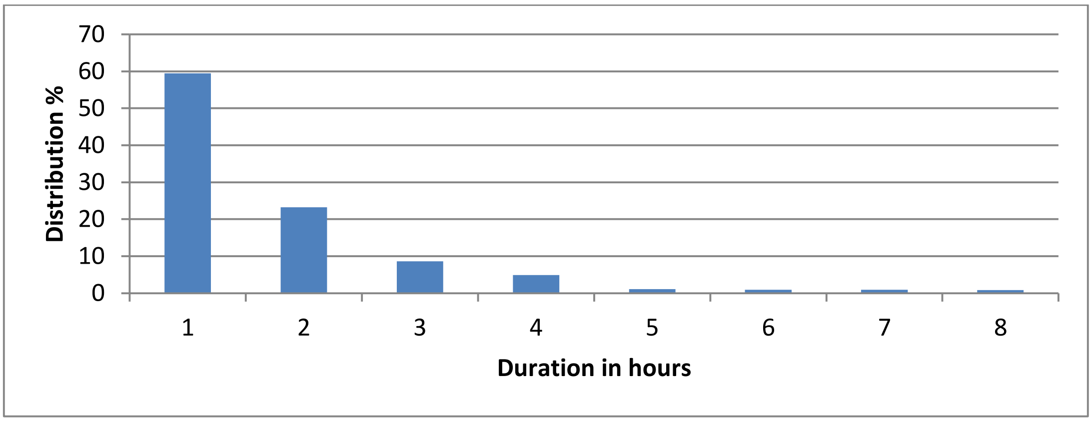

Figure 16: Distribution of rainfall events in Nyandarua

Figure 17 shows the distribution of rainfall events in Timbila. 69% of all the recorded events lasted one hour, 19% percentage lasted two hours, 6% lasted three hours, 2% lasted four hours, and only 3% of the events recorded lasted five to eight hours.

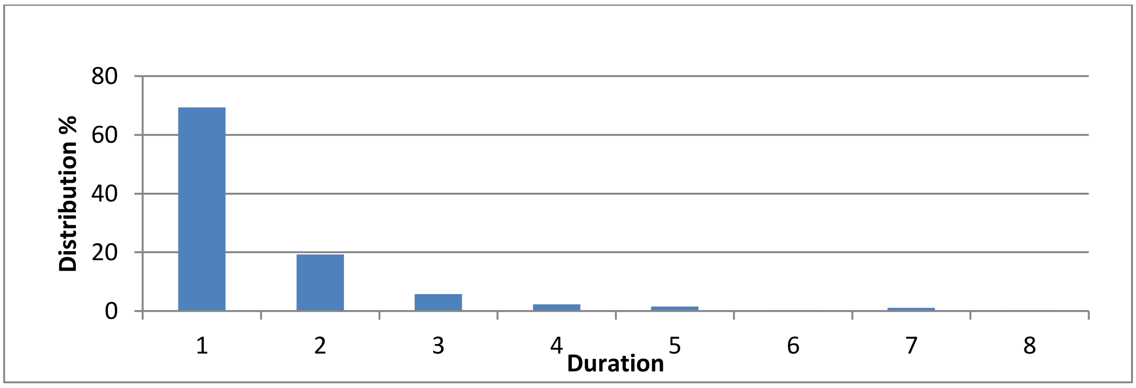

Figure 17: Distribution of rainfall events in Timbila high school

Figure 18 shows the distribution of rainfall events in UON Chiromo. 69% of all the recorded events lasted one hour, 20% percentage lasted two hours, 6% lasted three hours, 2% lasted four hours, and only 2% of the events recorded lasted five to eight hours.

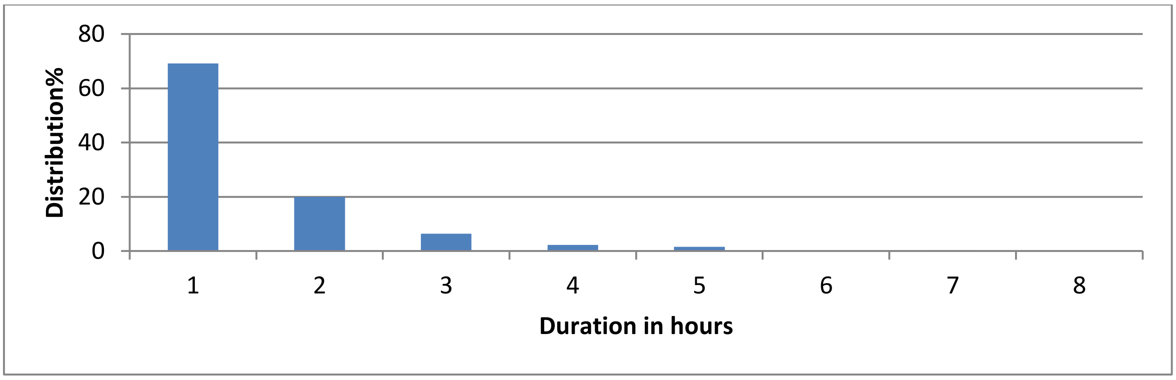

Figure 18: Distribution of rainfall events in UON Chiromo campus

Figure 19 shows the distribution of rainfall events in Wajir girls. 67% of all the recorded events lasted one hour, 17% percentage lasted two hours, 6% lasted three hours, 5% lasted four hours, and only 7% of the events recorded lasted five to eight hours.

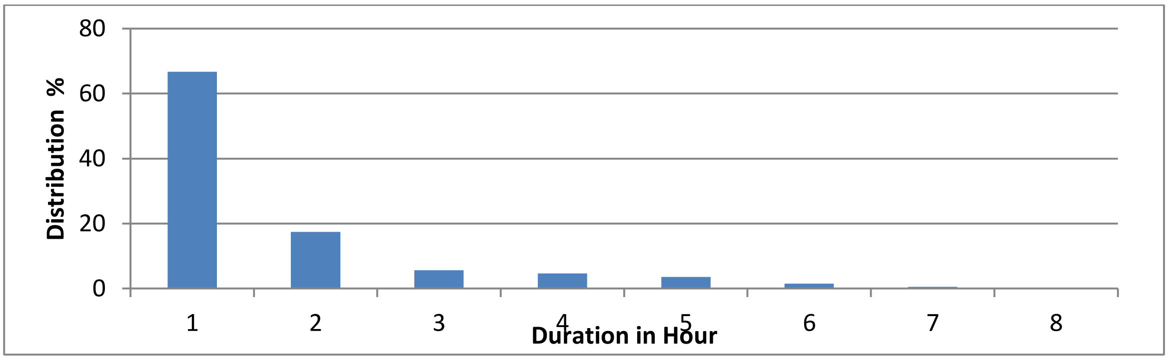

Figure 19: Distribution of rainfall events in Wajir

4.3 Analysis of the intensities of rainfall events in Kenya

To evaluate the average Intensities of rainfall events, the following classifications were considered and the number of rainfall events within each classification was counted us If logical statements in Excel 2013. The rainfall intensities were classified as follows, Drizzle, 0.1-0.9mm/hr, Light rains 1-4.9mm/hr. moderate rains 5-9.9mm/hr, heavy rains 10-19.9 mm/hr, and very heavy rains >20mm/hr (Safwan, *et al*., 2014).

The percentage distribution of the rainfall intensities was calculated for all the station and the average percentages computed as shown by figure 20. The results show that low intensity events are the most common, Drizzles(0.1-0.9 mm/hr) constituted 60% of the recorded events, While light rains (1-4.9 mm/hr) constituted 30% of the recorded events, moderate rains (5-9.9 mm/hr) constituted 6% of the recorded events, heavy rains (10-19.9mm/hr) constituted 4% and very heavy rains (> 20 mm/hr) only constituted 1%.

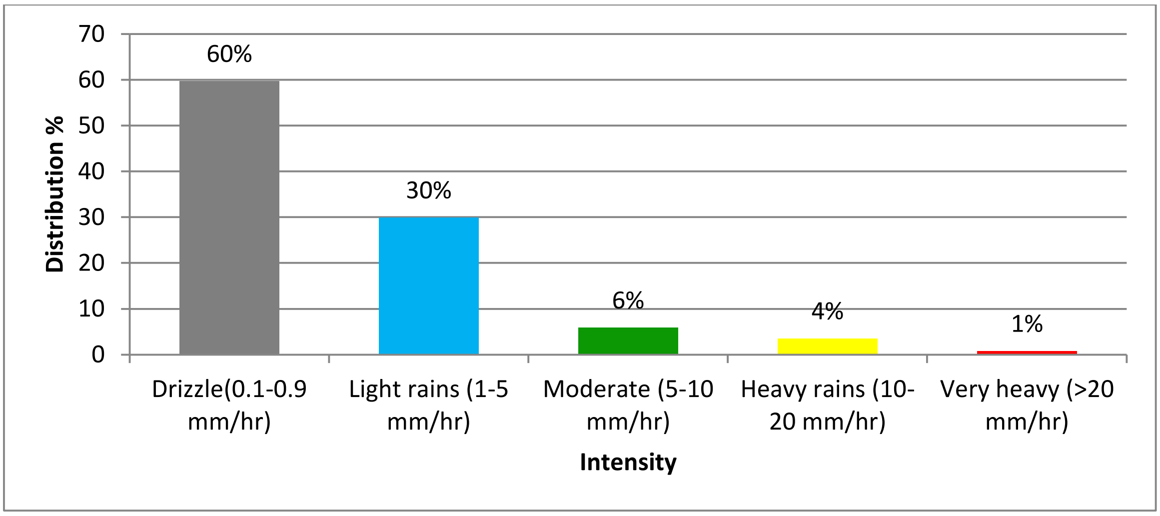

Figure 20: Average rainfall intensities in Kenya

The hourly rainfall intensity and frequencies for different stations were analysed as follows. For every intensity the number of events where counted using If logical statements in excel 2013. The plots of the number of events against the thresholds were plotted. All the stations analysed show that a large percentage of the events recorded are of less than 5mm/hr. However isolated events recording very high intensities were also recorded.

Figure 21 presents the Percentage distribution of rainfall intensities in Ganze boys. Here, drizzles (0.1-0.9 mm/hr) are the most common events recorded making up 64% of the total number of events, light rains (1-4.9 mm/hr) constituted 25% of the recorded events, moderate rains (5-9.9 mm/hr) made up 9% of the recorded events, while heavy rains (10-20 mm/hr) made up 2% of the recorded events. The maximum intensity event in was 18 mm/hr.

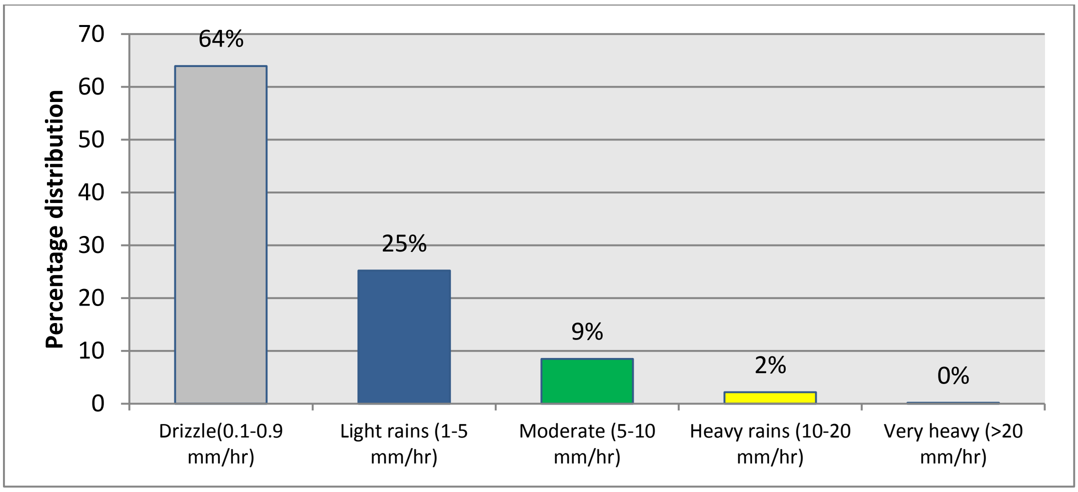

Figure 21: Percentage distribution of rainfall intensities in Ganze boys

The distribution of the events for different intensities is as shown in Figure 22 below.

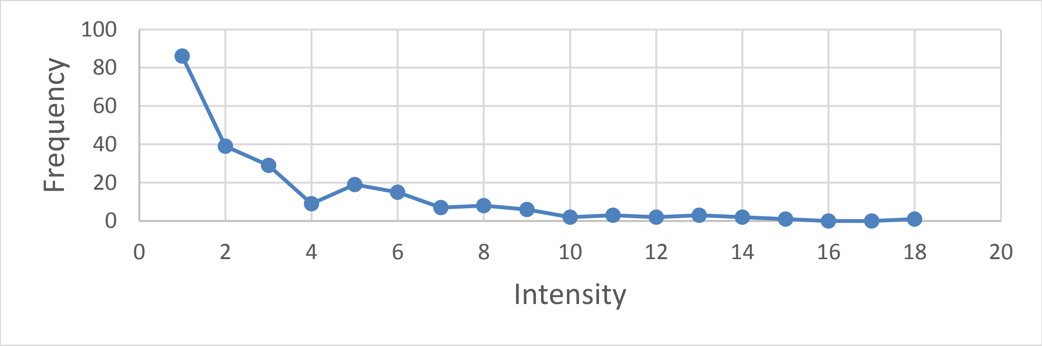

Figure 22: Distribution of rainfall intensities in Ganze boys

At Habasweni DC Office (Figure 23), drizzles (0.1-0.9 mm/hr) are the most common events recorded making up 51% of the total number of events, light rains (1-4.9 mm/hr) constituted 36% of the recorded events, moderate rains (5-9.9 mm/hr) made up 7% of the recorded events, while heavy rains (10-20 mm/hr) made up 5% of the recorded events. No events greater than 20 mm/hr where recorded. The distribution of these events are shown in figure 24

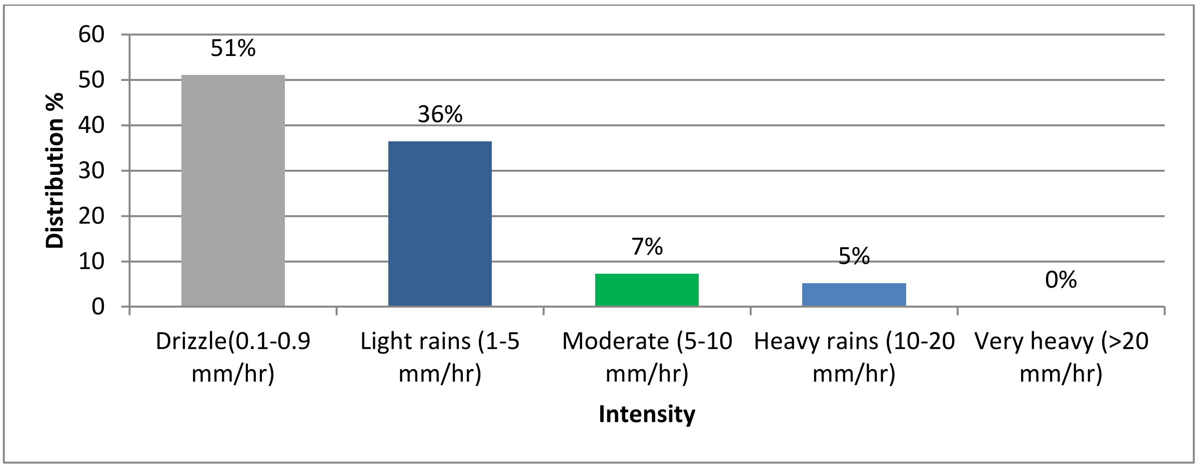

Figure 23: Percentage distribution of rainfall intensities in Habasweni DC offices

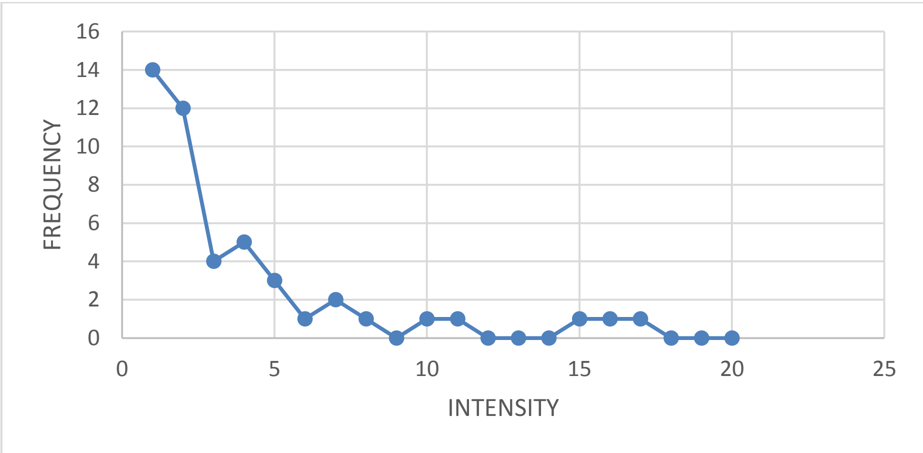

Figure 24: Distribution of rainfall intensities in Habasweni DC offices

At Kaaga Boys High school, drizzles (Figure 25), (0.1-0.9 mm/hr) were the most common events recorded making up 73% of the total number of events, light rains (1-4.9 mm/hr) constituted 19% of the recorded events, moderate rains (5-9.9 mm/hr) made up 5% of the recorded events, while heavy rains (10-20 mm/hr) made up 3% of the recorded events. No events greater than 20 mm/hr where recorded. The distribution of these events are as shown in figure 26.

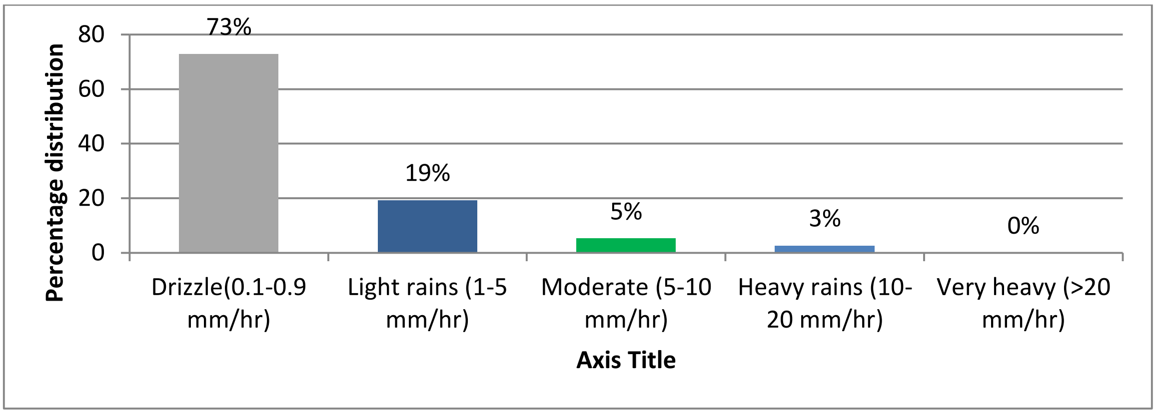

Figure 25: Percentage distribution of rainfall intensities in Kaaga boys' high school

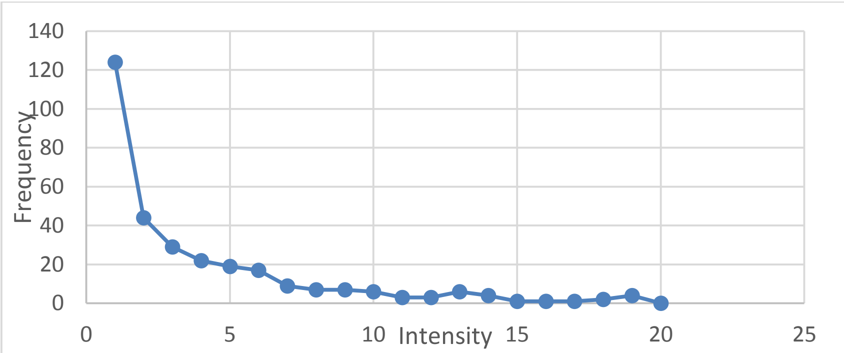

Figure 26: Distribution of rainfall intensities in Kaaga boys' high school

At Kamusinga friends' school, drizzles (Figure 27) (0.1-0.9 mm/hr) were the most common events recorded making up 55% of the total number of events, light rains (1-4.9 mm/hr) constituted 36% of the recorded events, moderate rains (5-9.9 mm/hr) made up 5% of the recorded events, while heavy rains (10-20 mm/hr) made up 3% of the recorded events. Only 1% of the events recorded where greater than 20 mm/hr. The distribution of these events are as shown in figure 28.

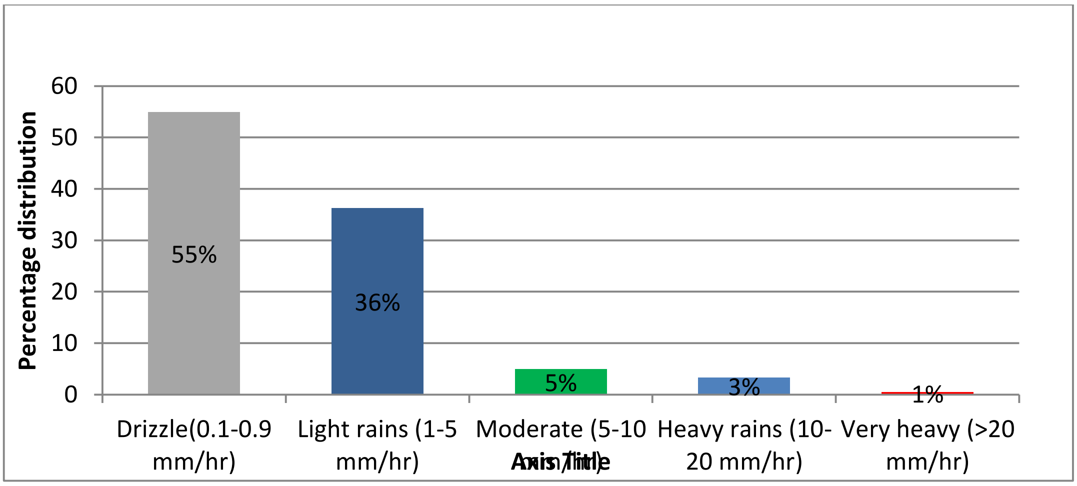

Figure 27: Percentage distribution of rainfall intensities in Kamusinga friends' school

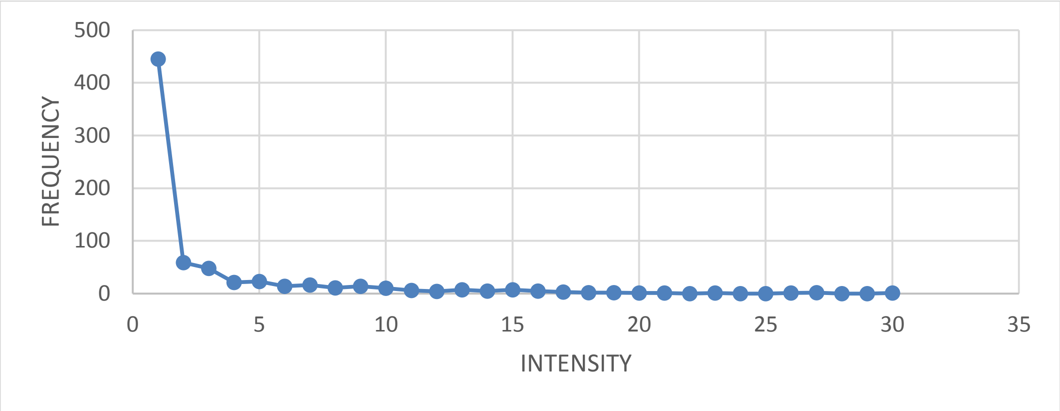

Figure 28: Distribution of rainfall intensities in Kamusinga friends' school

At Karima girls' secondary school, drizzles (Figure 29), (0.1-0.9 mm/hr) were the most common events recorded making up 65% of the total number of events, light rains (1-4.9 mm/hr) constituted 27% of the recorded events, moderate rains (5-9.9 mm/hr) made up 5% of the recorded events, while heavy rains (10-20 mm/hr) made up 2% of the recorded events. Only 1% of the events recorded where greater than 20 mm/hr. The distribution of these events are as shown in figure 30.

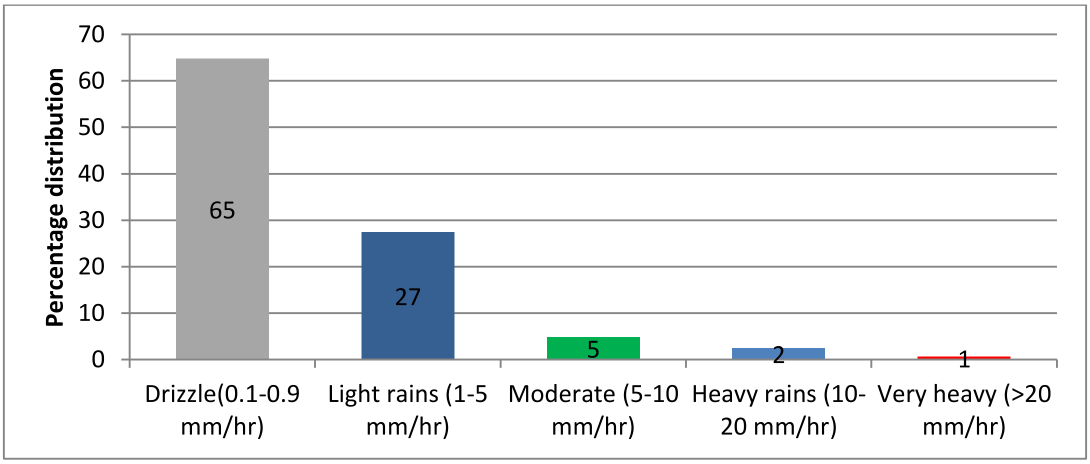

Figure 29: Percentage distribution of rainfall intensities in Karima girls

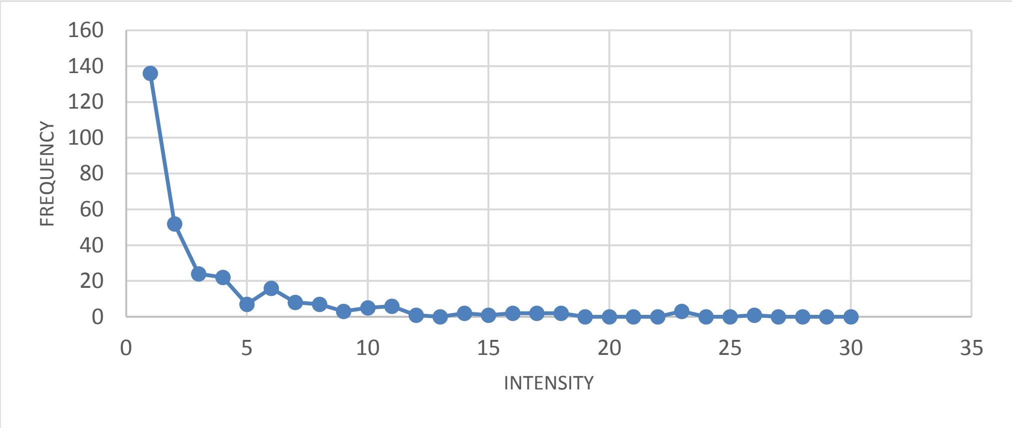

Figure 30: Distribution of rainfall intensities in Karima girls

At Kisoko girls' secondary school (Figure 31), drizzles (0.1-0.9 mm/hr) were the most common events recorded making up 59% of the total number of events, light rains (1-4.9 mm/hr) constituted 26% of the recorded events, moderate rains (5-9.9 mm/hr) made up 8% of the recorded events, while heavy rains (10-20 mm/hr) made up 6% of the recorded events. Only 1% of the events recorded where greater than 20 mm/hr. The distribution of these events are as shown in Figure 32.

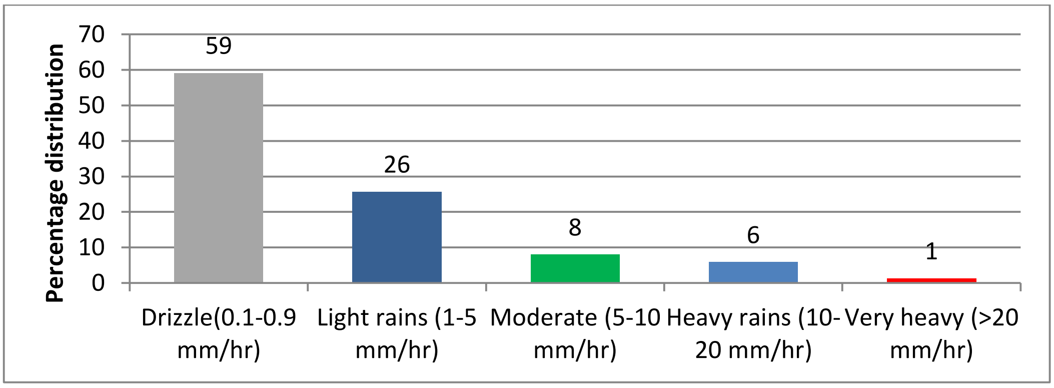

Figure 31: Percentage distribution of rainfall intensities in Kisoko girls' sec school

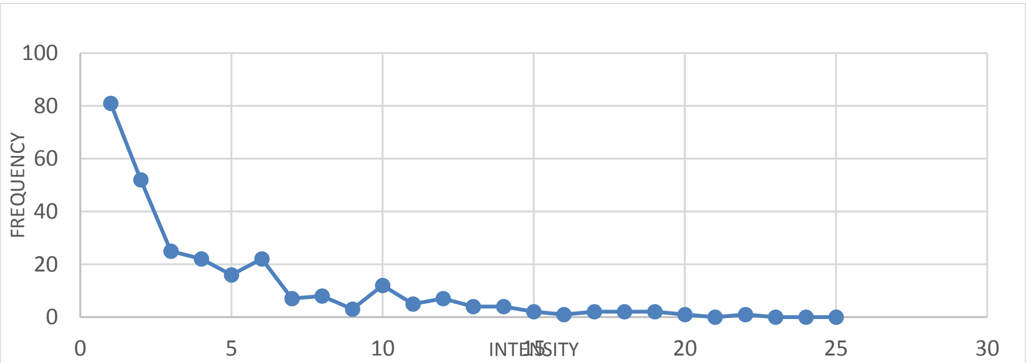

Figure 32: Distribution of rainfall intensities in Kisoko girls' sec school

At Koyoo secondary school (Figure 33), drizzles (0.1-0.9 mm/hr) were the most common events recorded making up 53% of the total number of events, light rains (1-4.9 mm/hr) constituted 33% of the recorded events, moderate rains (5-9.9 mm/hr) made up 5% of the recorded events, while heavy rains (10-20 mm/hr) made up 6% of the recorded events. Only 2% of the events recorded where greater than 20 mm/hr. The distribution of these events are shown in figure 34

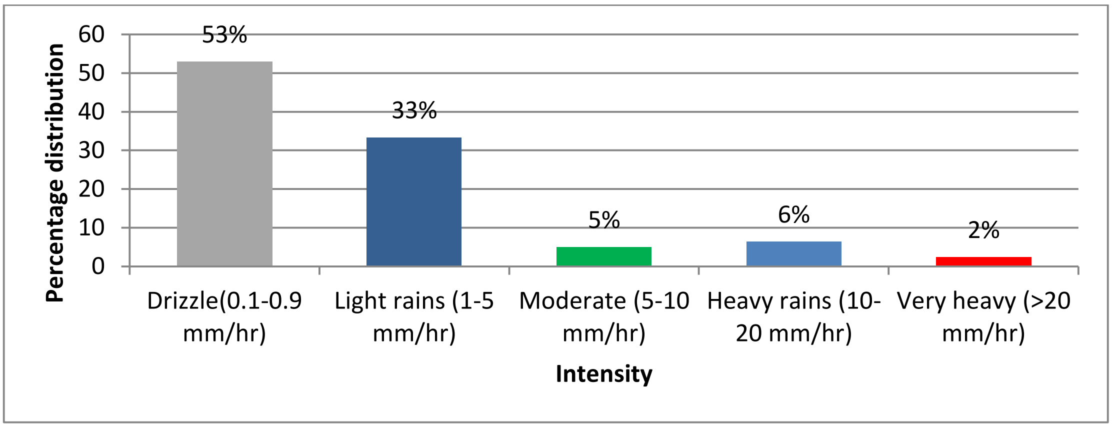

Figure 33: Percentage distribution of rainfall intensities in Koyoo sec. school

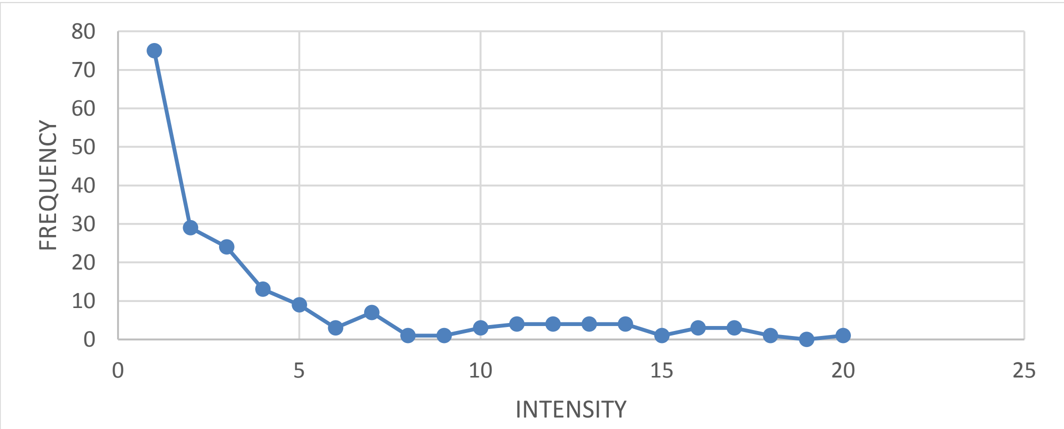

Figure 34: Percentage distribution of rainfall intensities in Koyoo sec. school

At Makueni Boys high school (Figure 35), drizzles (0.1-0.9 mm/hr) were the most common events recorded making up 60% of the total number of events, light rains (1-4.9 mm/hr) constituted 28% of the recorded events, moderate rains (5-9.9 mm/hr) made up 8% of the recorded events, while heavy rains (10-20 mm/hr) made up 4% of the recorded events. Only 1% of the events recorded where greater than 20 mm/hr. The distribution of these events are as shown in Figure 36

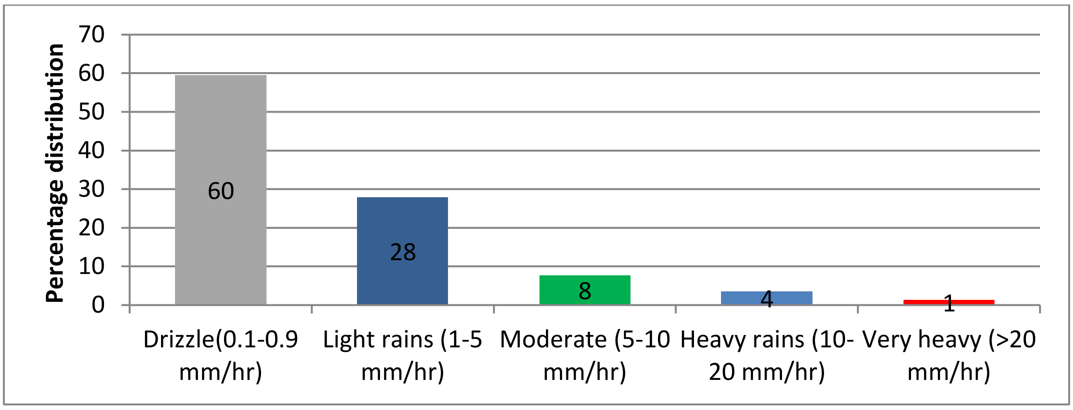

Figure 35: Percentage distribution of rainfall intensities in Makueni boys

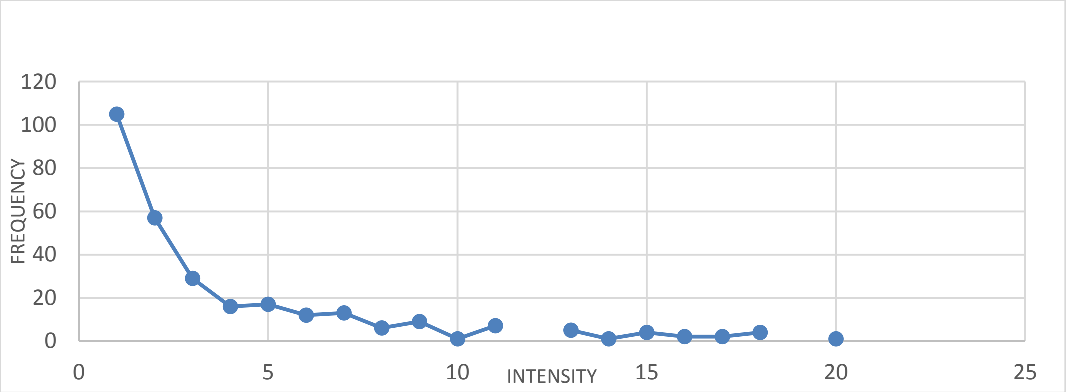

Figure 36: Percentage distribution of rainfall intensities in Makueni boys

In Mkunubi secondary school (Figure 37), drizzles (0.1-0.9 mm/hr) were the most common events recorded making up 61% of the total number of events, light rains (1-4.9 mm/hr) constituted 30% of the recorded events, moderate rains (5-9.9 mm/hr) made up 6% of the recorded events, while heavy rains (10-20 mm/hr) made up 2% of the recorded events. Only 1% of the events recorded where greater than 20 mm/hr. The distribution of these events are as shown in Figure 38

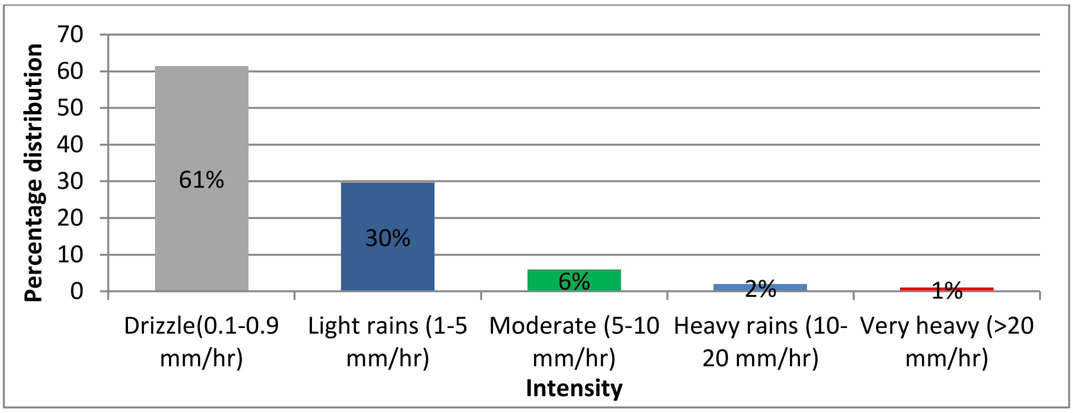

Figure 37: Percentage distribution of rainfall intensities in Mkunubi sec school

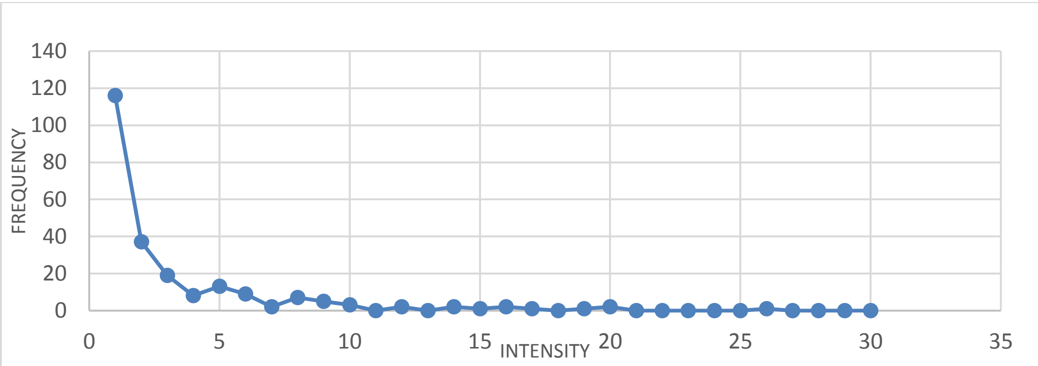

Figure 38: Distribution of rainfall intensities in Mkunubi sec school

At Musaria secondary school (Figure 39), drizzles (0.1-0.9 mm/hr) were the most common events recorded making up 61% of the total number of events, light rains (1-4.9 mm/hr) constituted 26% of the recorded events, moderate rains (5-9.9 mm/hr) made up 7% of the recorded events, while heavy rains (10-20 mm/hr) made up 5% of the recorded events. Only 2% of the events recorded where greater than 20 mm/hr. The distribution of these events are as shown in Figure 40.

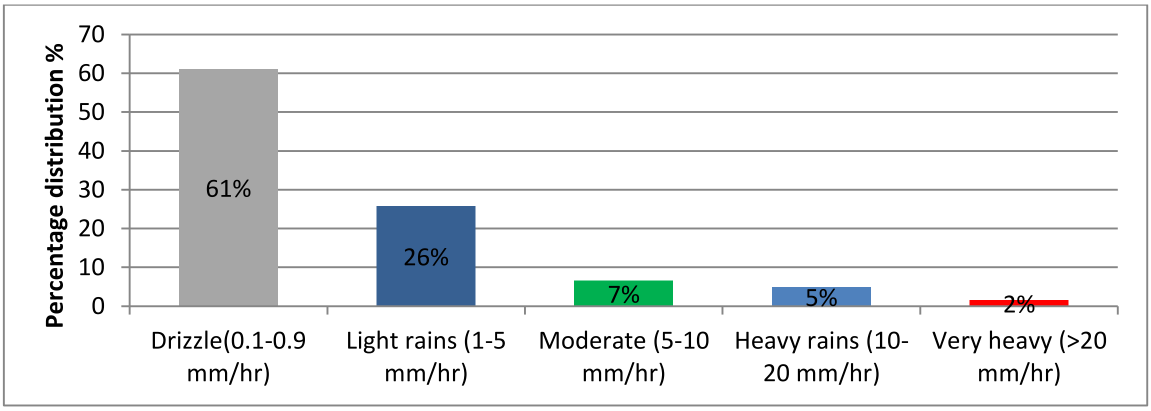

Figure 39: Percentage distribution of rainfall intensities in Musaria sec school

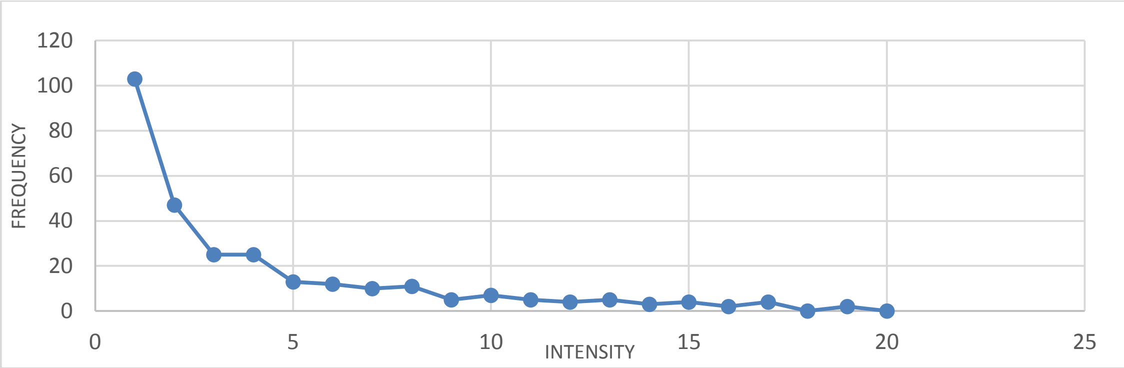

Figure 40: Distribution of rainfall intensities in Musaria sec school

In Namanga secondary school (Figure 41), drizzles (0.1-0.9 mm/hr) were the most common events recorded making up 53% of the total number of events, light rains (1-4.9 mm/hr) constituted 36% of the recorded events, moderate rains (5-9.9 mm/hr) made up 6% of the recorded events, while heavy rains (10-20 mm/hr) made up 4% of the recorded events. Only 1% of the events recorded where greater than 20 mm/hr. The distribution of rainfall intensities at Namanga is as shown in Figure 42.

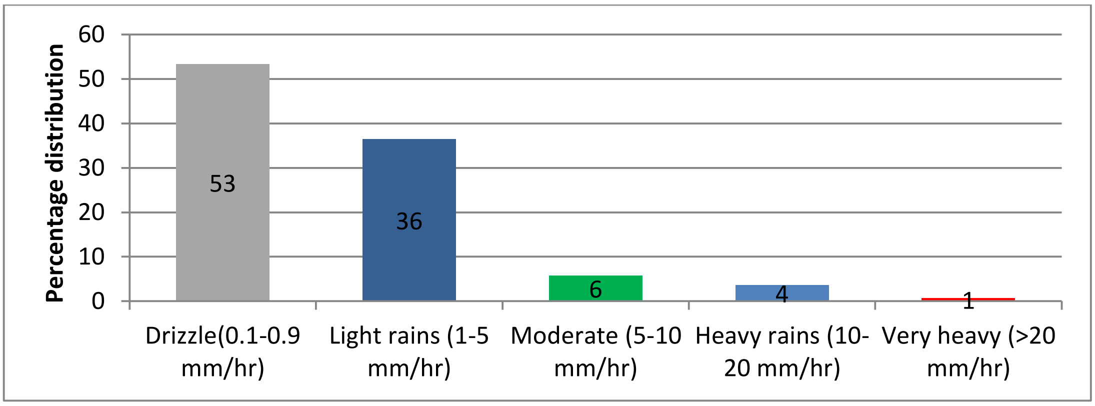

Figure 41: Percentage distribution of rainfall intensities in Namanga secondary school

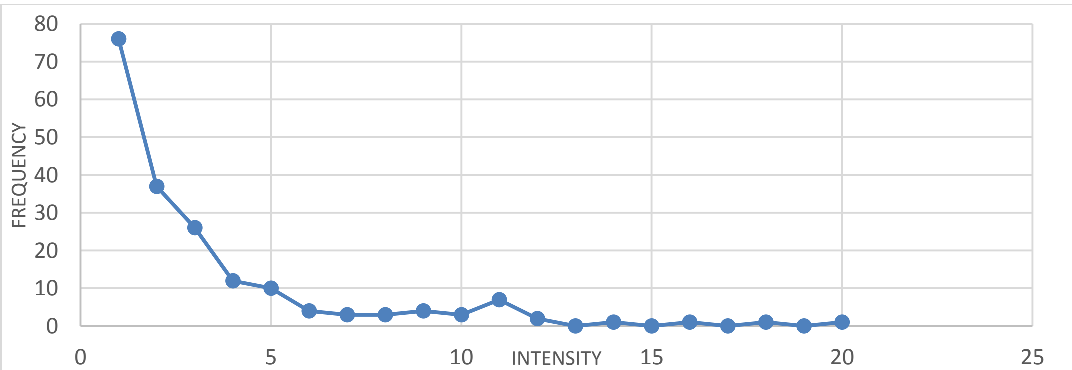

Figure 42: Distribution of rainfall intensities in Namanga secondary school

In Nyandarua (Figure 43), drizzles (0.1-0.9 mm/hr) were the most common events recorded making up 73% of the total number of events, light rains (1-4.9 mm/hr) constituted 24% of the recorded events, moderate rains (5-9.9 mm/hr) made up 3% of the recorded events, while heavy rains (10-20 mm/hr) made up 1% of the recorded events. There were no events recorded greater than 20 mm/hr. The distribution of these events are as shown in Figure 44.

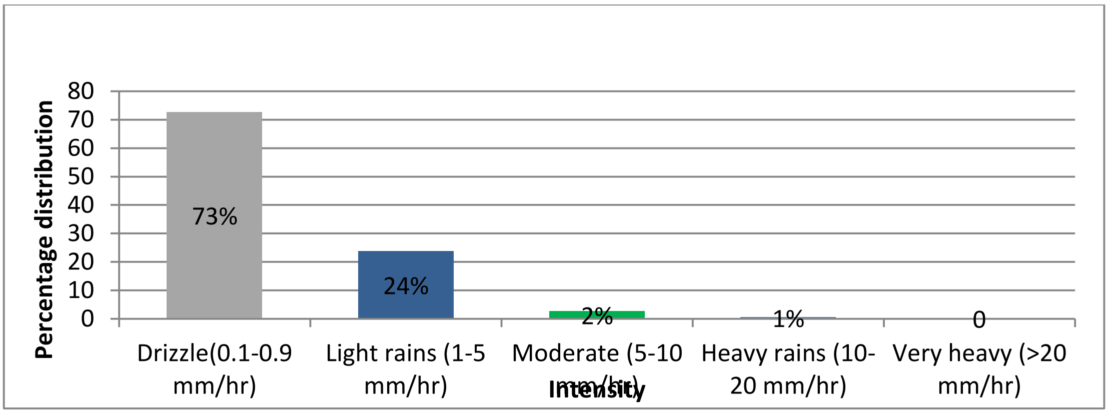

Figure 43: Percentage distribution of rainfall intensities in Nyandarua

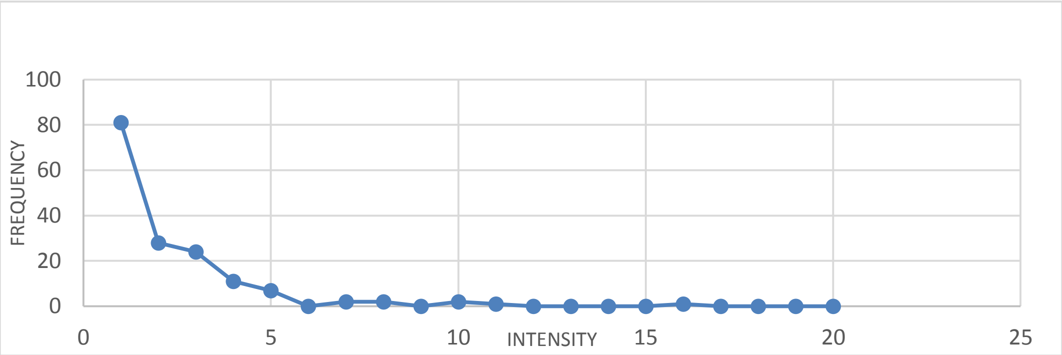

Figure 44: Distribution of rainfall intensities in Nyandarua

In Timbila high school (Figure 45), drizzles (0.1-0.9 mm/hr) were the most common events recorded making up 52% of the total number of events, light rains (1-4.9 mm/hr) constituted 35% of the recorded events, moderate rains (5-9.9 mm/hr) made up 7% of the recorded events, while heavy rains (10-20 mm/hr) made up 5% of the recorded events. Only 2% of the events recorded were greater than 20 mm/hr. The distribution of the intensities are as shown in Figure 46.

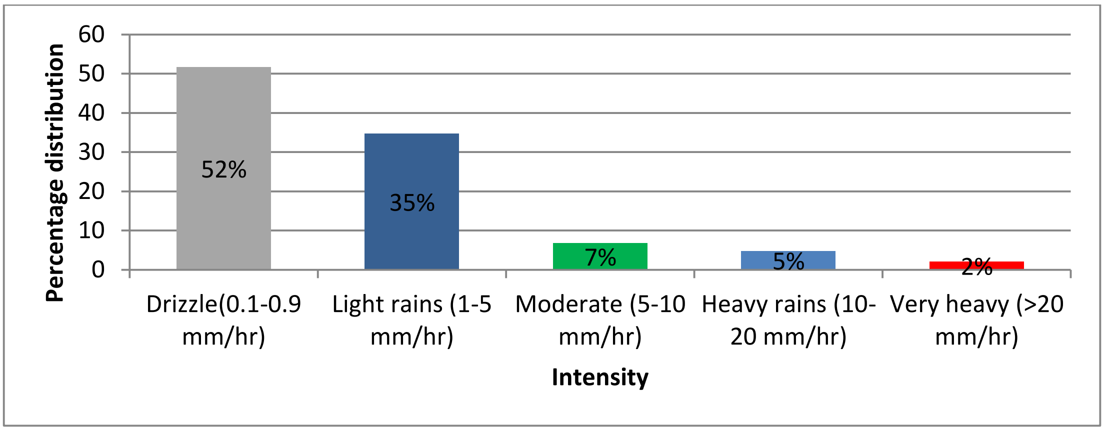

Figure 45: Percentage distribution of rainfall intensities in Timbila high school

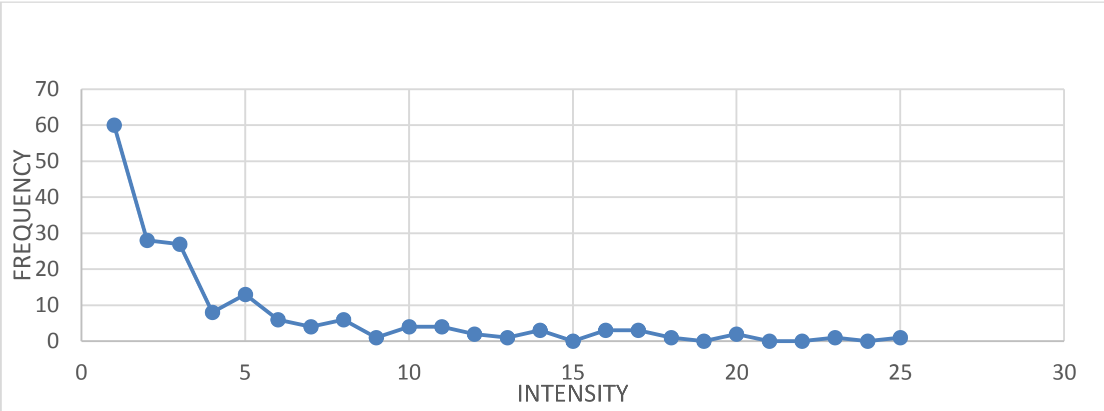

Figure 46: Percentage distribution of rainfall intensities in Timbila high school

In University of Nairobi, Chiromo campus (Figure 47), drizzles (0.1-0.9 mm/hr) were the most common events recorded making up 62% of the total number of events, light rains (1-4.9 mm/hr) constituted 31% of the recorded events, moderate rains (5-9.9 mm/hr) made up 5% of the recorded events, while heavy rains (10-20 mm/hr) made up 1% of the recorded events. Only 1% of the events recorded were greater than 20 mm/hr.

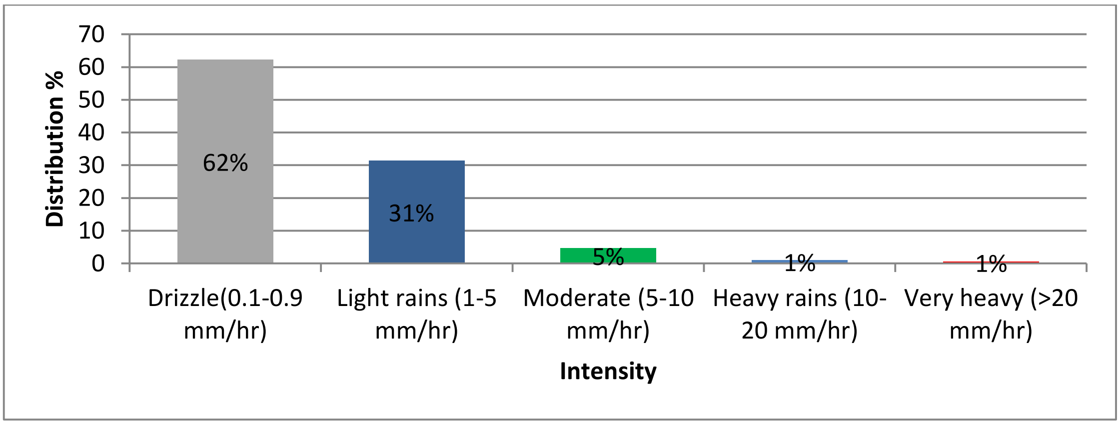

Figure 47: Percentage distribution of rainfall intensities in UON Chiromo

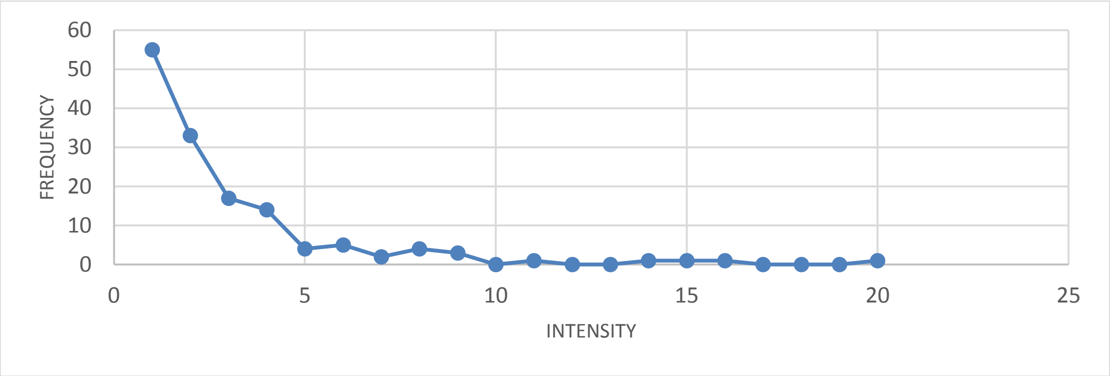

Figure 48: Distribution of rainfall intensities in UON Chiromo

In Wajir girls (Figure 49), drizzles (0.1-0.9 mm/hr) were the most common events recorded making up 54% of the total number of events, light rains (1-4.9 mm/hr) constituted 36% of the recorded events, moderate rains (5-9.9 mm/hr) made up 5% of the recorded events, while heavy rains (10-20 mm/hr) made up 5% of the recorded events. No events recorded were greater than 20 mm/hr. The distribution of the rainfall intensities are shown in Figure 50.

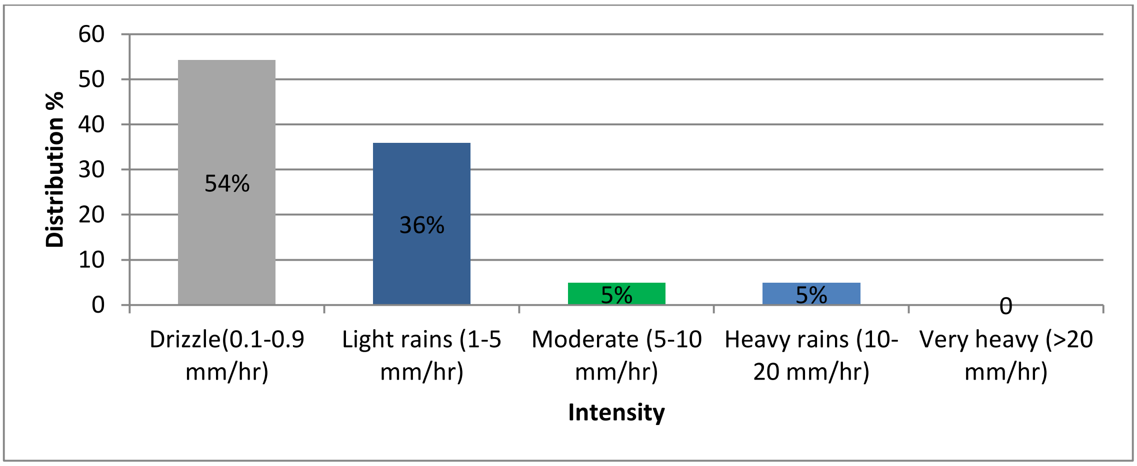

Figure 49: Percentage distribution of rainfall intensities in Wajir girls

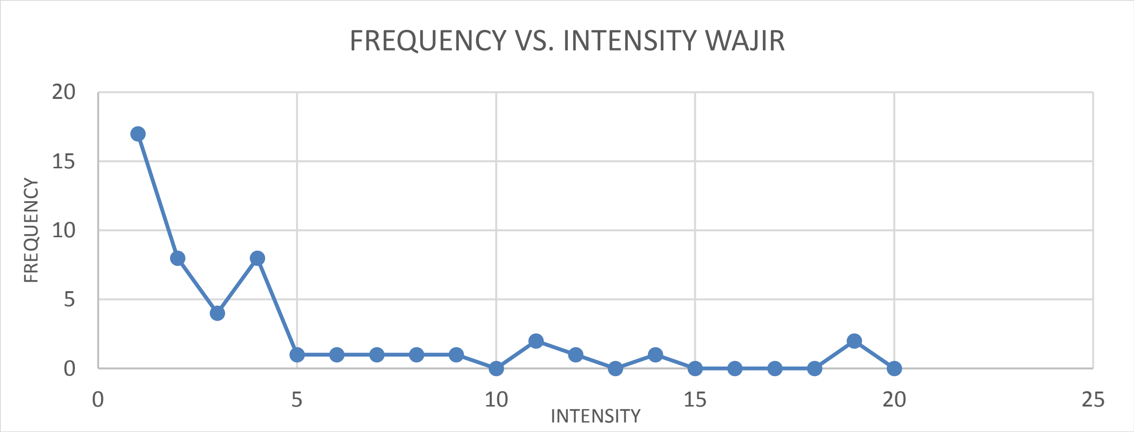

Figure 50: Distribution of rainfall intensities in Wajir girls

In Talent high school (Figure 51), drizzles consisted 66% of the total events recorded, Light rains consisted of 35%, moderate rainfall events consisted of 7%, and heavy rainfall events consisted of 5% with a significant 2% of very heavy rainfall events. The distribution of the rainfall events are as shown in Figure 52.

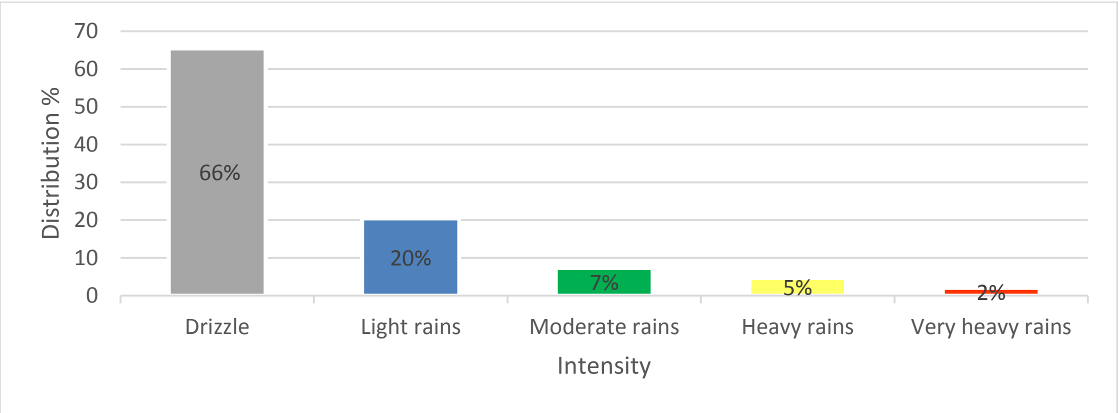

Figure 51: Distribution of rainfall intensities in Talent high school

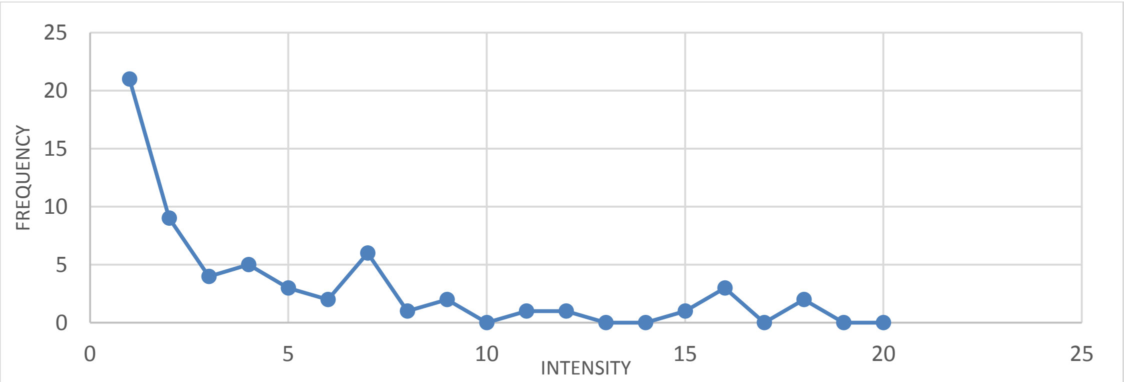

Figure 52: Distribution of rainfall intensities in Talent high school

At equinox horticulture (Figure 53), 57% of the total recorded events were drizzles, 23% light rains, 4% moderate rains, 7% heavy rains, and 9% very heavy rains (≥ 20mm/hr). The distribution of the intensities of these events is as shown in Figure 54.

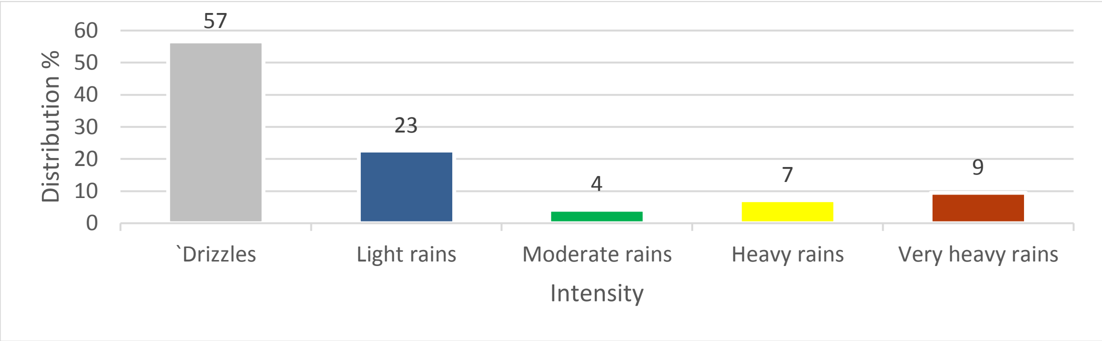

Figure 53: Percentage distribution of rainfall intensities at equinox horticulture

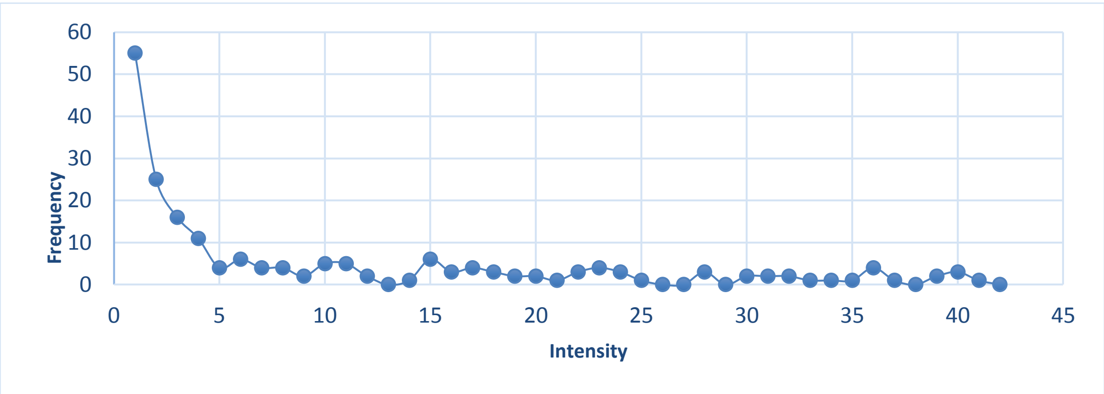

Figure 54: Distribution of rainfall intensities at equinox horticulture

Dwa estate recorded 52% drizzles, 31% light rain events, 10% moderate rainfall events, 4% heavy rains and 3% of very heavy rainfall events, as shown by Figure 55. The distribution of the intensity is as shown by figure 56.

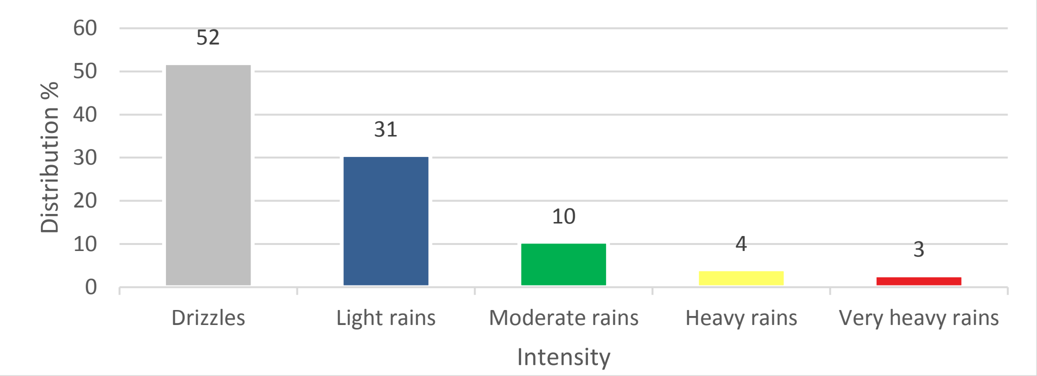

Figure 55: Percentage distribution of rainfall intensities at equinox horticulture

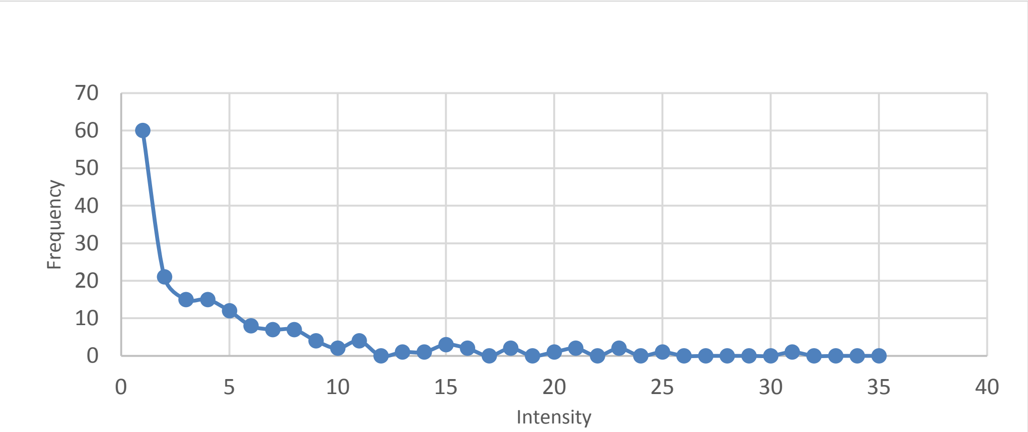

Figure 56: Distribution of rainfall intensities at equinox horticulture

Woodlands trust recorded 61% drizzles, 28% light rain events, 6% moderate rainfall events, 2% heavy rains and 2% of very heavy rainfall events, as shown by Figure 57. The distribution of these events are as shown in Figure 58.

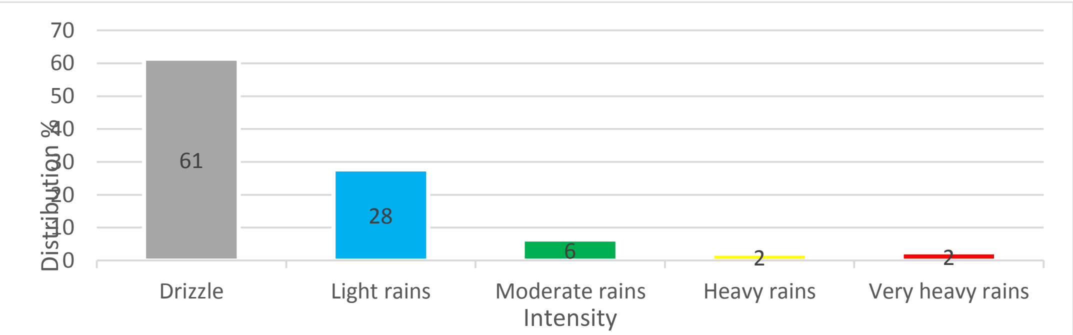

Figure 57: Percentage distribution of rainfall intensities at woodlands trust

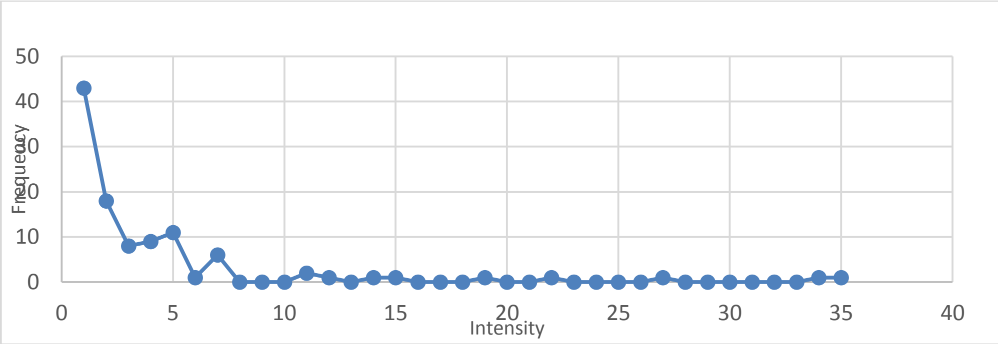

Figure 58: Distribution of rainfall intensities at woodlands trust

Ole Tipis girls' high school recorded 60% drizzles, 28% light rain events, 8% moderate rainfall events, 2% heavy rains and 2% of very heavy rainfall events as shown by Figure 59. The distribution of these events are shown in Figure 60.

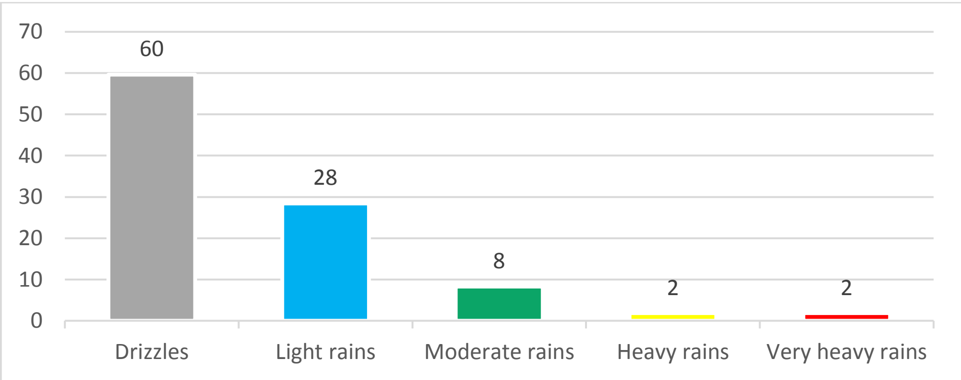

Figure 59: Percentage distribution of rainfall intensities at Ole Tipis

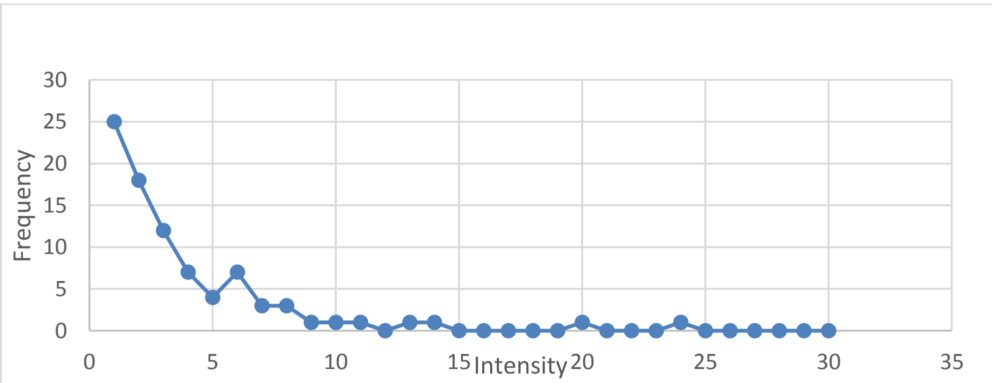

Figure 60: Distribution of rainfall intensities at Ole Tipis

4.4 Rainfall thresholds in Kenya

Rainfall threshold is a critical value of defining the average amount of rainfall received during the peak rainfall duration. A comparison of the rainfall thresholds shows how rainfall varies over different parts of the country. For this section of the study the peak duration was determined for all the stations and the average intensity at the peak duration noted.

Different regions of Kenya have different values of rainfall thresholds. Figure 61 show the variation of the rainfall thresholds in Kenya against the topographical variations of the country. Regions of higher altitudes generally have lower thresholds while regions with lower altitude have higher thresholds.

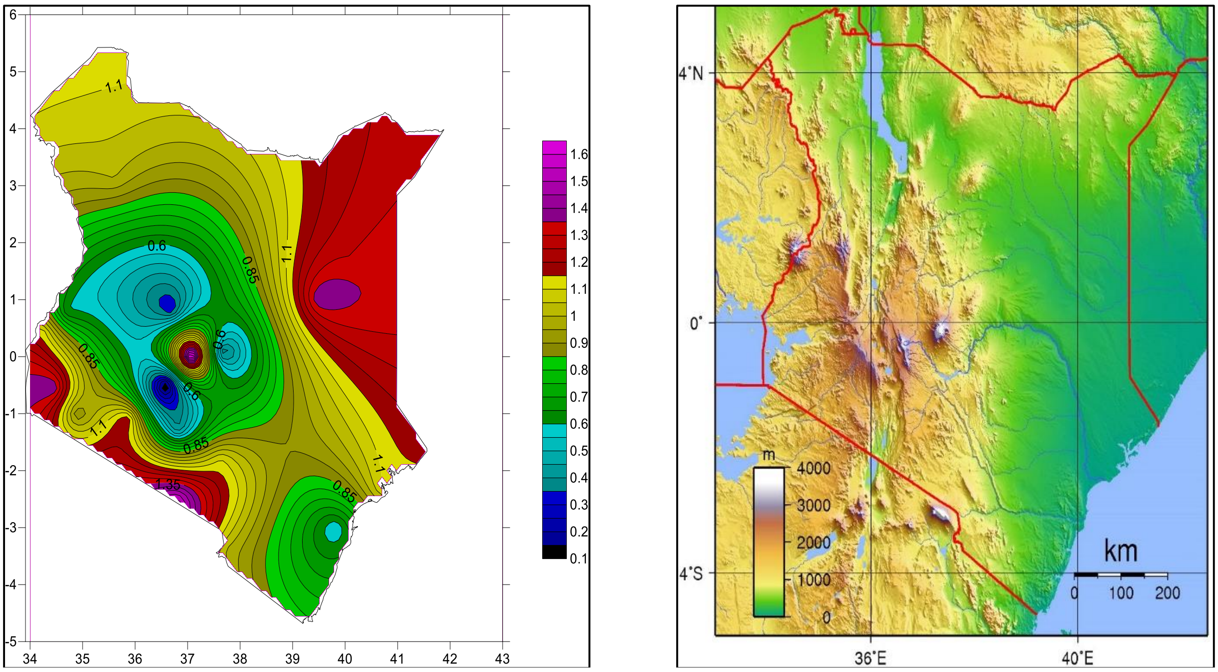

Figure 61: Variation of rainfall thresholds with topography in Kenya

The regions with the highest thresholds are the north eastern Kenya, the lake basin region and the southern part of Kenya. Higher values of rainfall thresholds indicate that rainfall in these regions is receive higher amount of rainfall within a shorter duration of time. The central part of Kenya has the lowest rainfall thresholds, this area consists of high ground areas and rainfall here is received in events of low intensity lasting longer durations.

Figure 62 shows the variation of rainfalls peak duration for different parts around the country against the probability of flash floods.

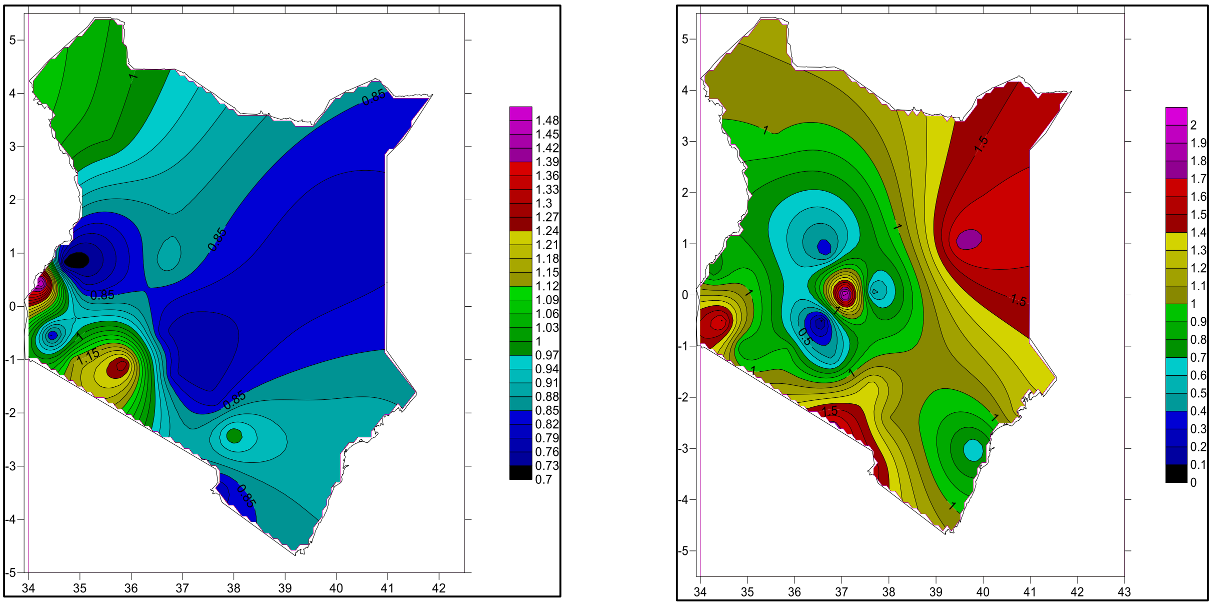

Figure 62: Peak durations of Kenya (left) against the probability of flash floods (right) in Kenya

When the rainfall peak duration and the rainfall thresholds are compared, some of the regions experiencing the highest rainfall thresholds also shown to have the shortest rainfall durations. This means that those regions have the highest probabilities of experiencing flash floods after rainfall events. The right map above shows the probability of flash floods for different parts of the country. The North eastern counties, the lake basin and the southern parts of the country are most likely to experience flash floods.

Regions with the highest rainfall thresholds are most prone to flooding because they receive the rainfall with the highest intensity over shorter duration. Rainfall events in these areas occurs in form of intense rain storms as opposed to light to moderate showers of longer durations.

The following sections details the analysis for different stations around the country.

Figure 63 shows the variations of rainfall probability and the average intensity for Kaaga boys. The significant rainfall duration for Kaaga boys was found to be 0.9 hours or 54 minutes, with an average intensity of 0.58mm/hr.

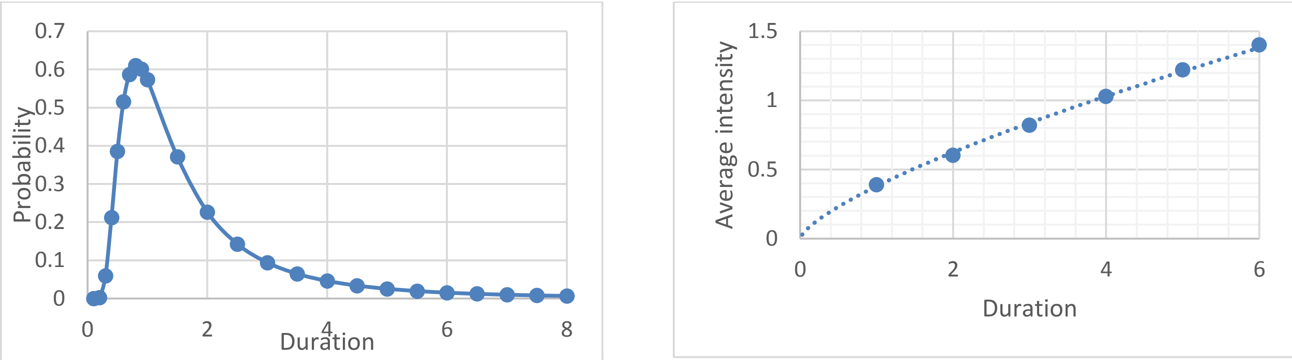

Figure 63: Variation of probability of rainfall over duration and the average intensity at Kaaga boys' high school

Figure 64 shows the variations of rainfall probability and the average intensity for Ganze boys' high school. The significant rainfall duration for Ganze was found to be 0.9 hours or 54 minutes, with an average intensity of 0.6mm/hr.

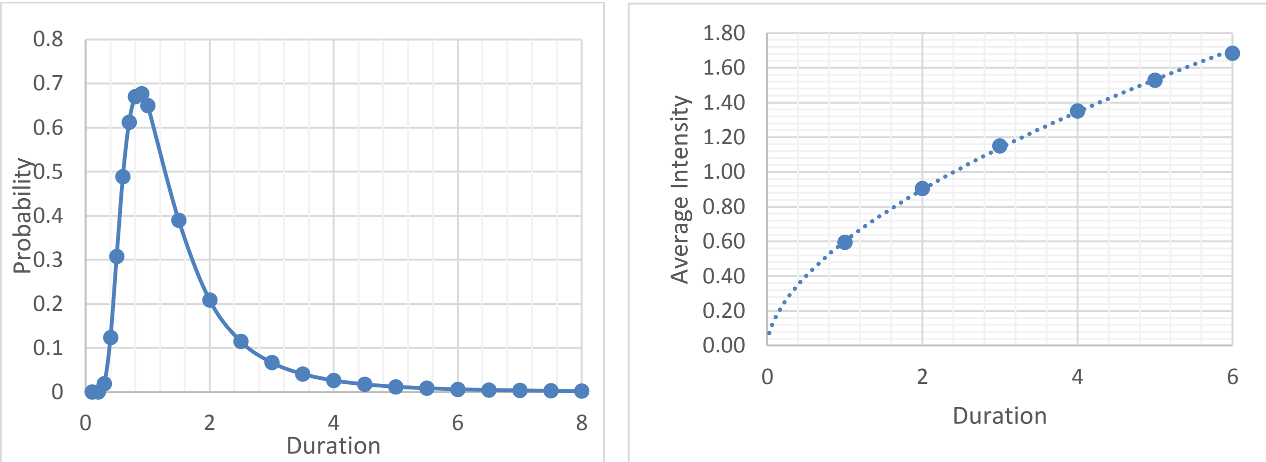

Figure 64: Variation of probability of rainfall with duration and the average intensity with duration at Ganze

Figure 65 shows the variations of rainfall probability and the average intensity for Habasweni DC offices. The peak duration was 0.8 hrs/ 48 minutes with an average intensity of 1.4 mm/hr.

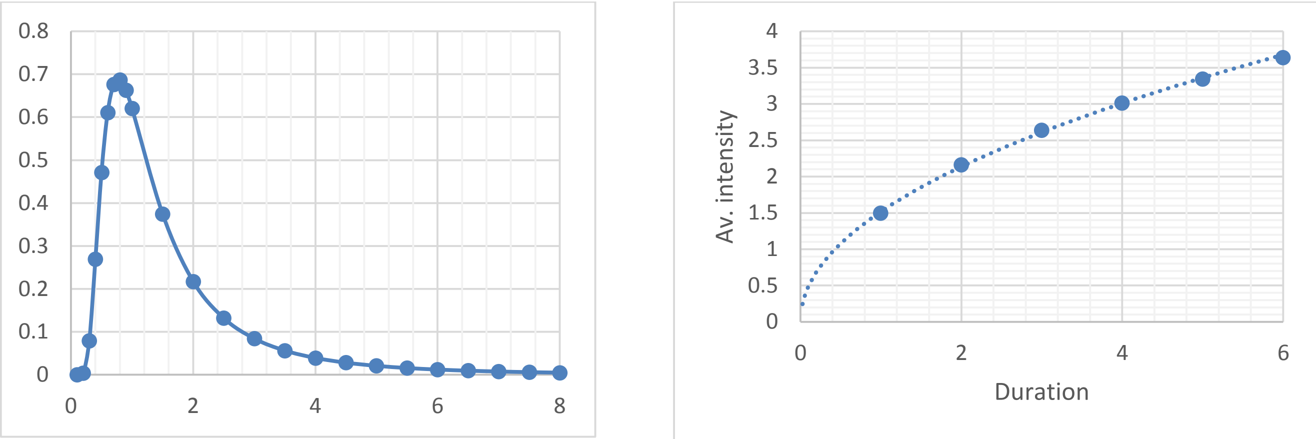

Figure 65: Variation of probability of rainfall over duration and the average intensity at Habasweni DC. Office

Figure 66 shows the variations of rainfall probability and the average intensity for Kamusinga friends' school. The significant duration and average intensity are 0.7 hours and 0.6 mm/hr respectively.

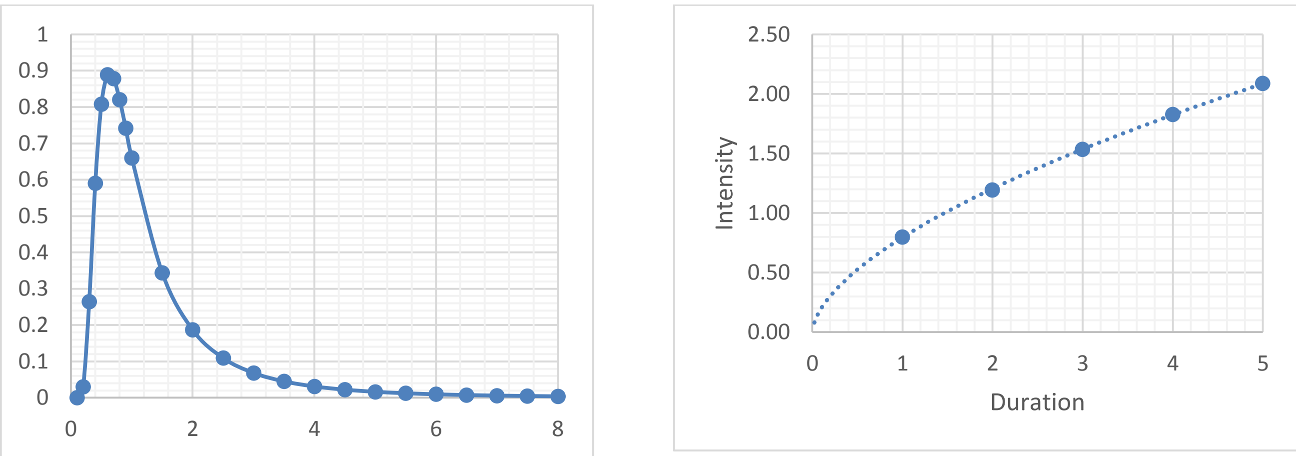

Figure 66: Variation of probability of rainfall over duration as compared to the average intensity at Kamusinga

Figure 67 shows the variations of rainfall probability and the average intensity at Karima girls secondary school. The significant rainfall duration and average intensity is 0.8 hours and 0.05 mm/hr respectively.

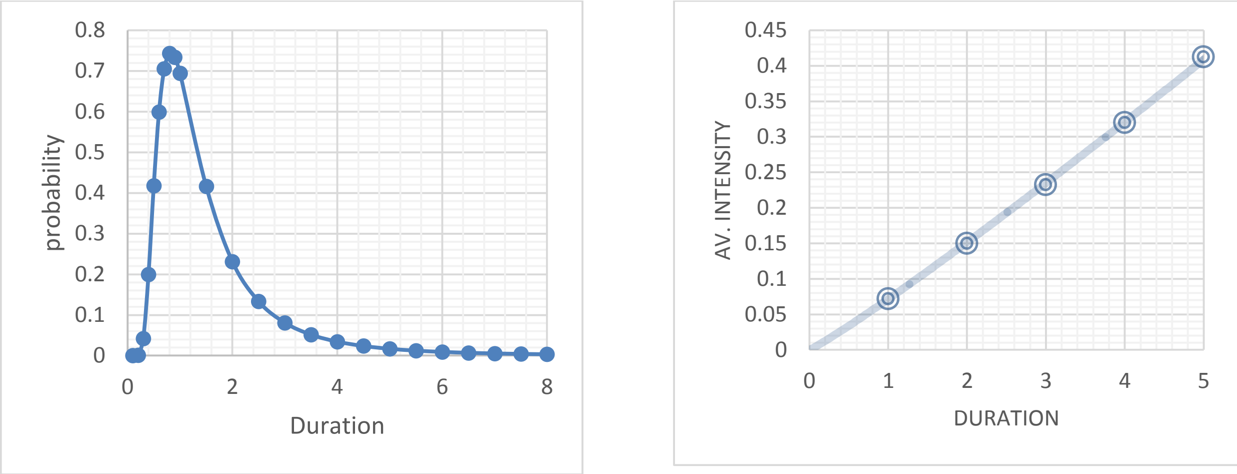

Figure 67: Variation of probability of rainfall and average intensity with duration over duration at Karima girls

Figure 68 shows the variations of rainfall probability and the average intensity at Koyoo. The significant duration is 0.8 hrs /48 mins, and the corresponding an average intensity is 1.4 mm/hr.

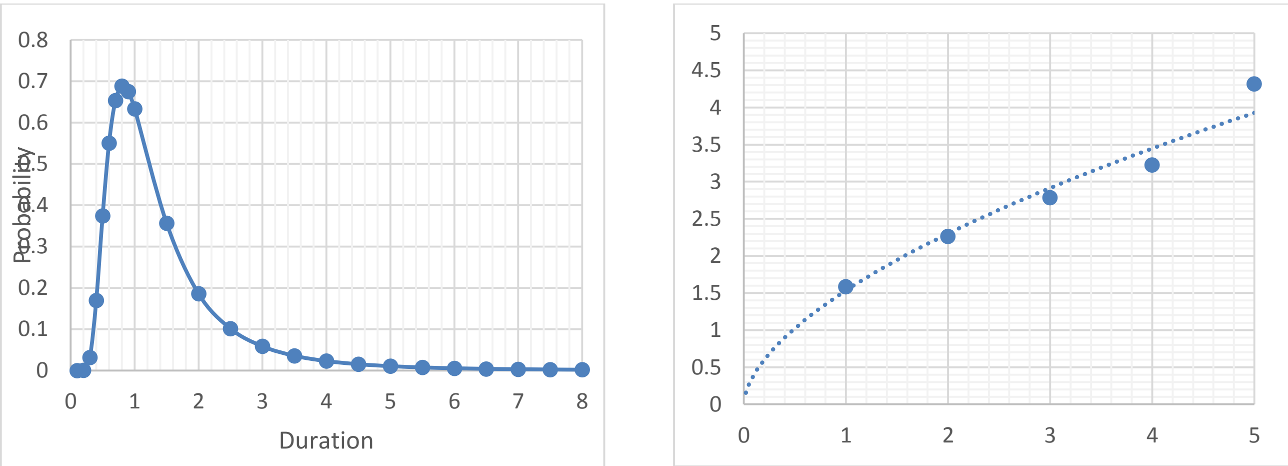

Figure 68: Variation of probability of rainfall over duration at Koyoo secondary school

Figure 69 shows the variations of rainfall probability and the average intensity at Makueni boys High school. The significant duration is 0.8 hours/48 minutes, with an average intensity of 1.1 mm/hr.

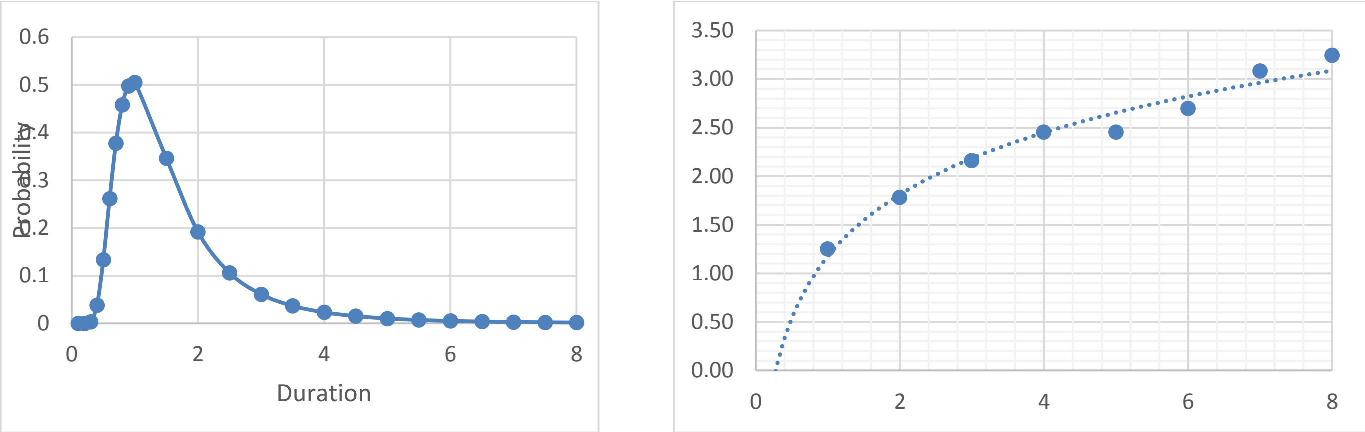

Figure 69: Variation of probability of rainfall and average intensity over duration at Makueni Boys

Figure 70 shows the variations of rainfall probability and the average intensity at Mkunubi secondary school. The significant rainfall duration is 0.8 hours with an average intensity of 1.1mm/hr.

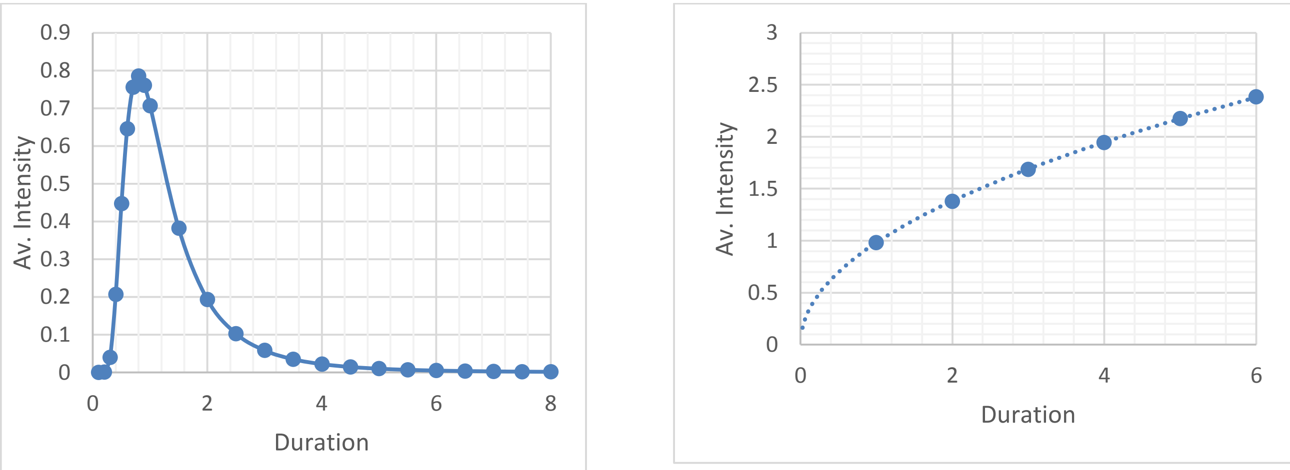

Figure 70: Variation of probability of rainfall and average intensity over duration at Mkunubi secondary school

Figure 71 shows the variations of rainfall probability and the average intensity at Musaria Secondary school. The peak rainfall duration is 0.7 hours, with an average intensity of 0.75 mm/hr.

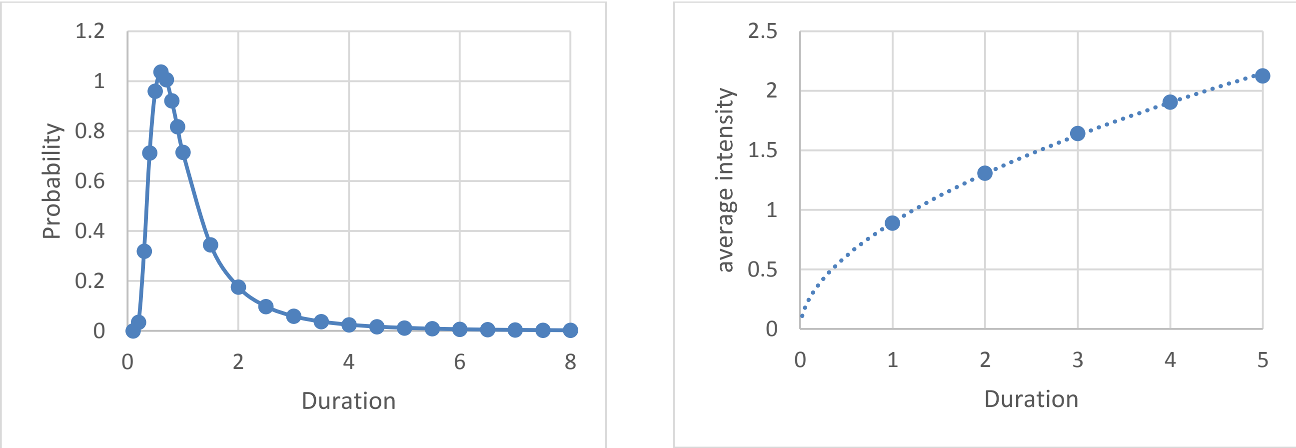

Figure 71: Variation of probability of rainfall and average intensity over duration at Musaria secondary school

Figure 72 shows the variations of rainfall probability and the average intensity at Nyandarua. The peak rainfall duration is 0.9 hours or 54 minutes, with an average intensity of 0.29 mm/hr.

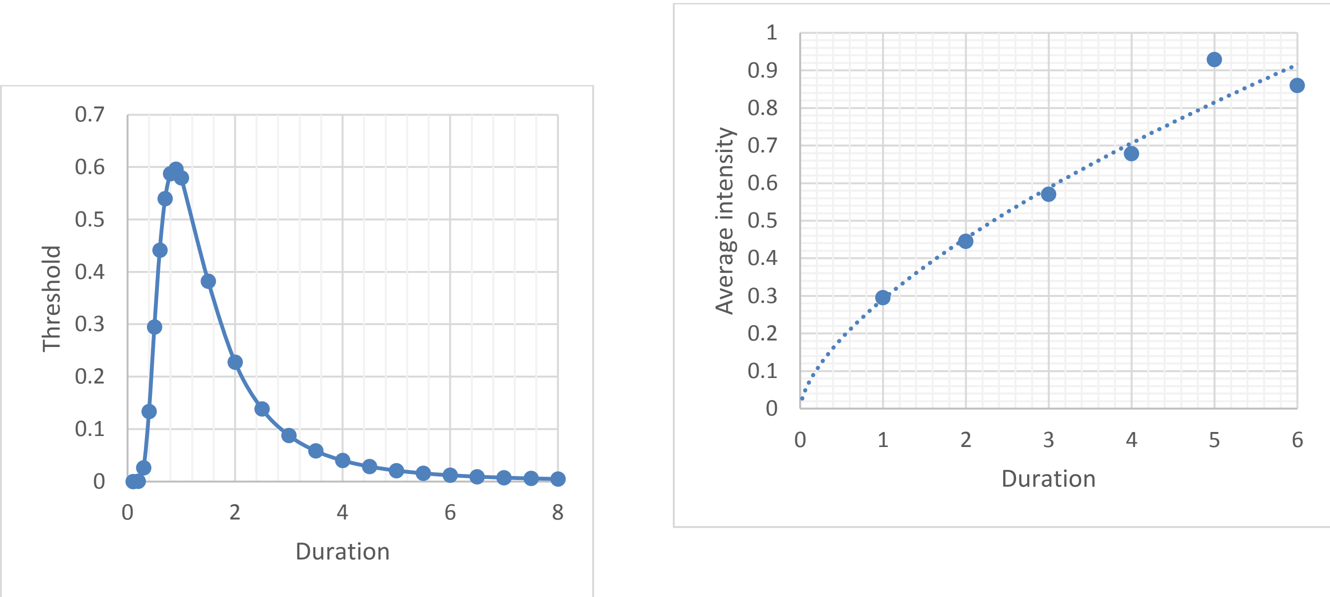

Figure 72: Variation of probability of rainfall and intensity over duration at Nyandarua secondary school

Figure 73 shows the variations of rainfall probability and the average intensity at Timbila high school. The peak rainfall duration is 0.65 hours/39 minutes with an average intensity of 1.1 mm/hr.

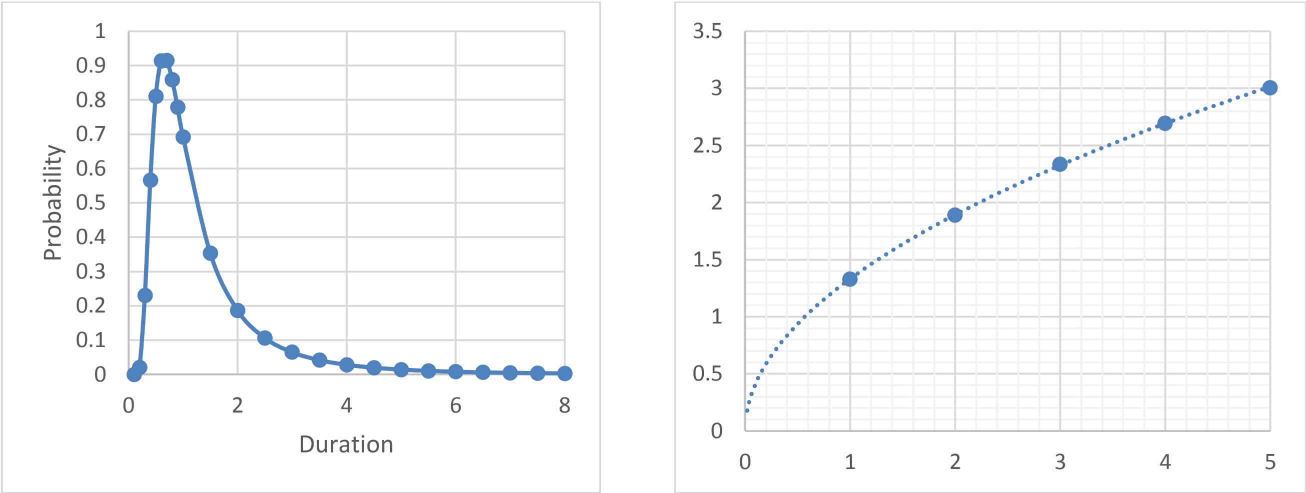

Figure 73: Variation of probability of rainfall and average intensity over duration at Timbila high school

Figure 74 shows the variations of rainfall probability and the average intensity at UoN Chiromo, the significant duration is 0.9 hours/ 54 minutes with an average intensity of 0.4mm/hr.

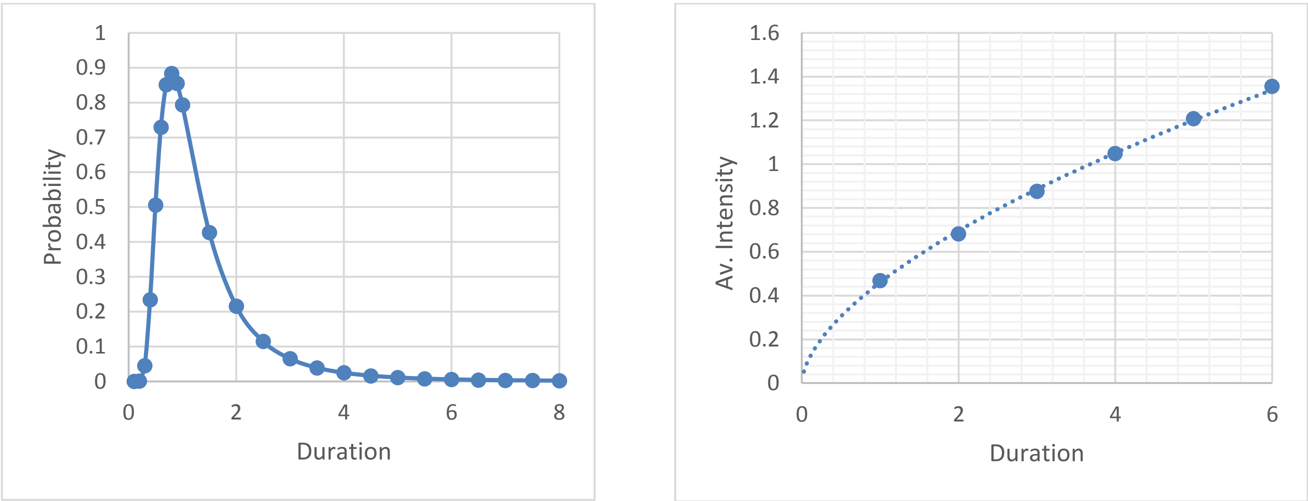

Figure 74: Variation of probability of rainfall over duration at UON Chiromo Campus

Figure 75 shows the variations of rainfall probability and the average intensity at Dwa estate. The peak duration is 0.9 hours/54 minutes with an average intensity of 1.1 mm/hr.

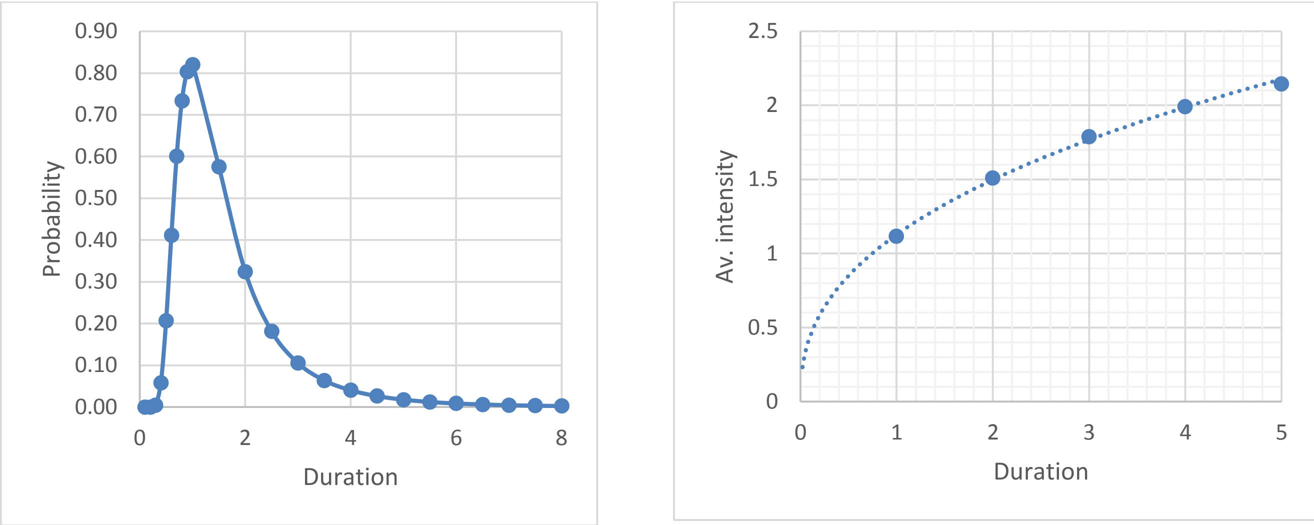

Figure 75: Variation of probability of rainfall and average intensity over duration at Dwa estate

Figure 76 shows the variations of rainfall probability and the average intensity at equinox horticulture. The peak duration is 0.8 hours/ 48 minutes at an average intensity of 1.7mm/hr.

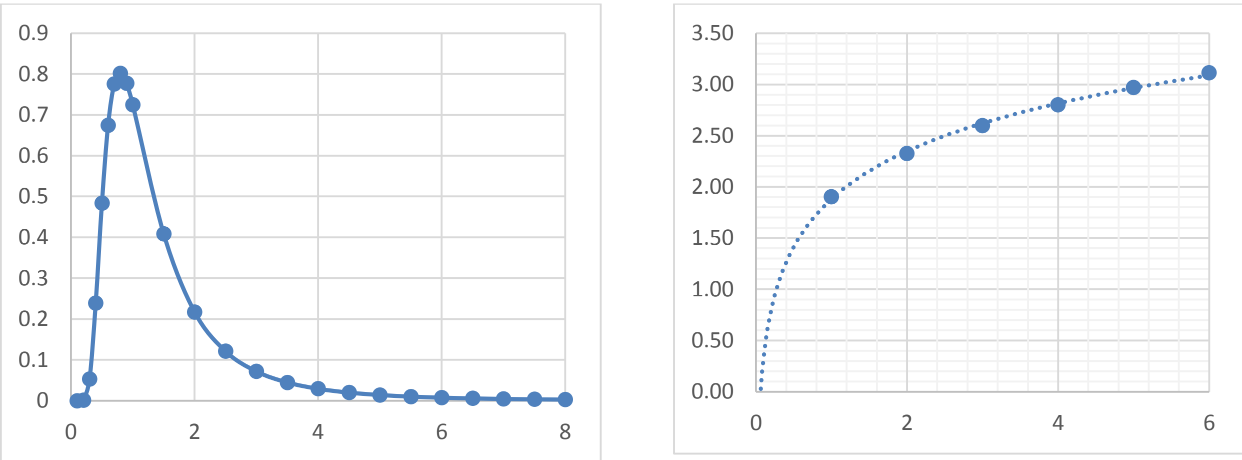

Figure 76: Variation of probability of rainfall and average intensity over duration at Equinox horticulture

4.5 IDF curves in Kenya

To plot the IDF curves, partial duration series analysis was used to select several maximum rain days. For every stations 10-20 maximum independent rainy days events were selected. The cumulative rainfall totals for 1 to 8 hours were obtained from these data sets. Then the data sets were converted to annual series by using the Chow (1964) conversion formula. Gumbels' extreme value analysis was then used for the IDF analysis. The intensities of rainfall for different durations and return periods were calculated and entered into the IDF tables, then plotted as shown in the results below.

Table 3 shows the IDF distribution for Dwa estate. An extreme rainfall event of 312mm/hr for a duration of 1 hour is likely to be experienced once in10, 000 years with as high as 170 mm/hr return period. Extreme events are expected to range from 97mm/hr to 312mm/hr. Figure 77 shows the distribution of IDF curves at Dwa estate.

Table 3: IDF table for Dwa estate

Duration (Hours)	**RETURN PERIOD (YEARS) FOR DWA ESTATE**						
	10	**25**	**50**	**100**	**500**	**1000**	**10000**
1	97.8	127.0	148.7	170.3	220.1	241.5	312.6
2	95.5	124.2	145.5	166.7	215.5	236.5	306.2
3	94.3	122.6	143.6	164.4	212.6	233.3	302.0
4	92.8	120.5	141.0	161.4	208.5	228.8	296.0
5	91.5	118.6	138.7	158.7	204.9	224.7	290.6
6	90.4	117.2	137.1	156.8	202.5	222.1	287.3
7	89.6	116.2	136.0	155.6	200.9	220.4	285.1
8	89.0	115.5	135.1	154.7	199.8	219.2	283.5

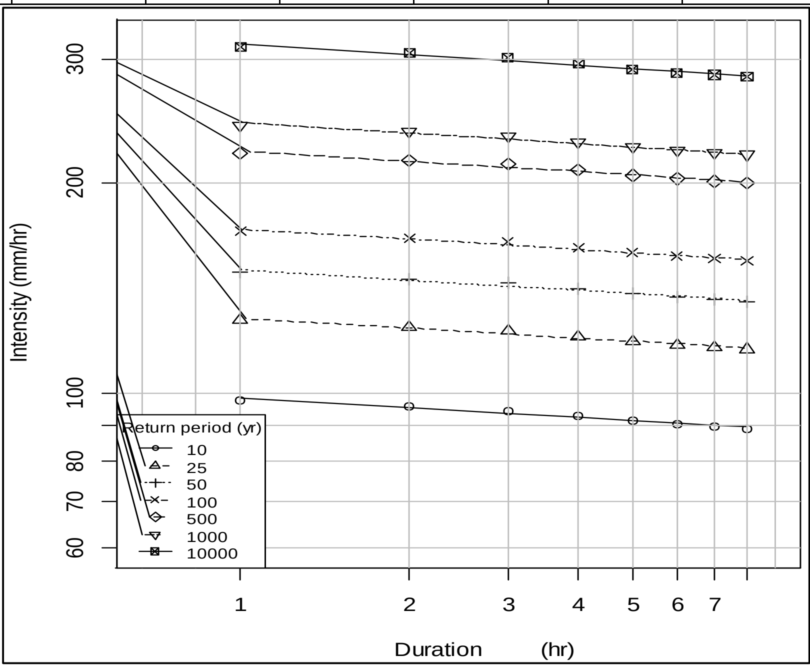

Figure 77: IDF curves for Dwa estate

Table 4 shows the intensities for different return periods and durations for equinox horticulture. These were used to plot the IDF curves for equinox horticulture. Extreme events of up to 850 mm/hr are possible in 10000 years return period. Figure 78 shows the IDF curves for equinox horticulture.

Table 4: IDF table for equinox horticulture

Duration (Hours)	**RETURN PERIOD (YEARS) FOR EQUINOX HORTICULTURE**						
	10	**25**	**50**	**100**	**500**	**1000**	**10000**
1	258.5	337.8	396.6	455.0	589.9	648.0	840.5
2	257.9	337.5	396.5	455.1	590.5	648.8	842.0
3	257.3	337.2	396.4	455.2	591.1	649.5	843.4
4	256.2	336.2	395.6	454.5	590.6	649.1	843.4
5	255.6	335.8	395.2	454.2	590.5	649.1	843.7
6	254.9	335.2	394.7	453.9	590.5	649.3	844.3
7	253.7	334.4	394.2	453.6	590.9	649.9	845.8
8	252.4	333.8	394.1	454.0	592.5	652.0	849.6

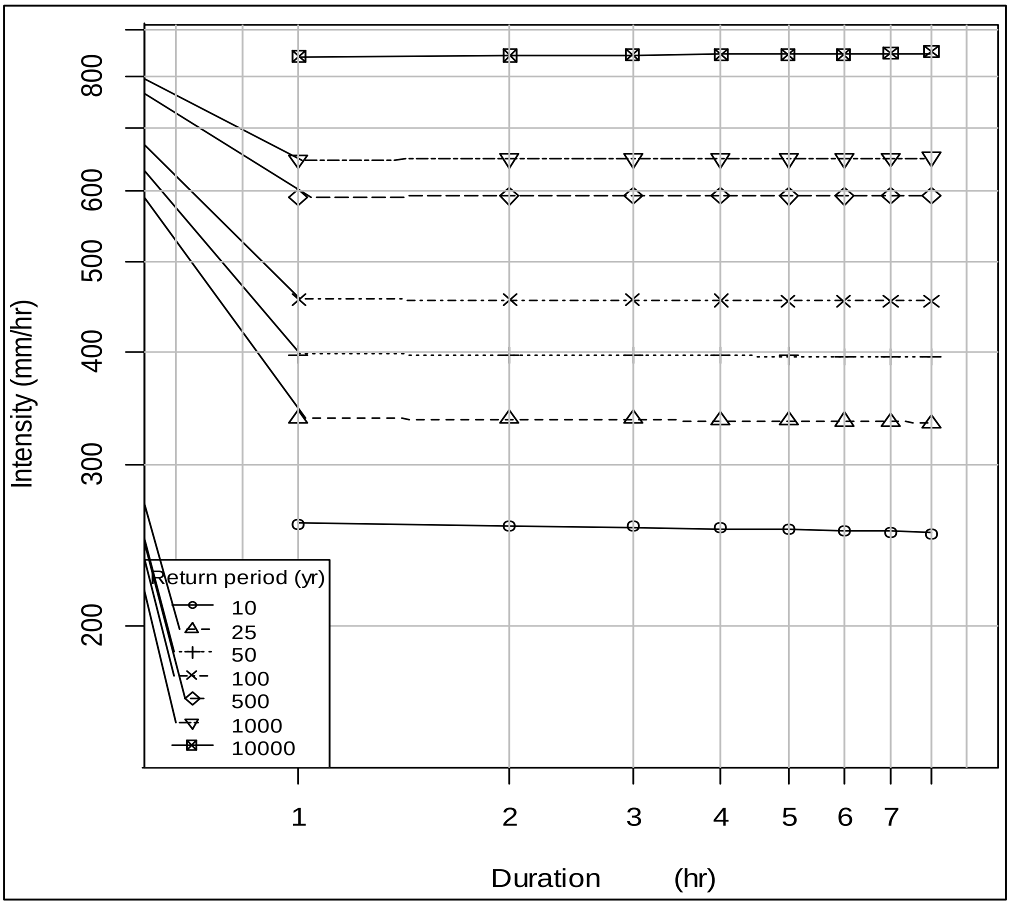

Figure 78: IDF curves for Equinox horticulture

Table 5 is the IDF table for Ganze boys, the maximum probable precipitation is an extreme rainfall event of 168.5 mm/hr in 10, 000 years. Figure 79 shows the IDF curves for Ganze boys.

Table 5: IDF table for Ganze boys

Duration (Hours)	**RETURN PERIOD (YEARS) FOR GANZE BOYS**						
	10	**25**	**50**	**100**	**500**	**1000**	**10000**
1	67.6	81.4	91.5	101.6	125.0	135.1	168.5
2	51.1	62.9	71.6	80.2	100.2	108.8	137.4
3	50.7	62.5	71.2	79.9	100.1	108.7	137.4
4	50.1	61.9	70.7	79.5	99.7	108.4	137.3
5	49.6	61.5	70.4	79.2	99.6	108.4	137.5
6	49.1	61.1	70.0	78.9	99.4	108.2	137.5
7	48.5	60.6	69.6	78.5	99.1	108.0	137.5
8	47.8	59.9	68.9	77.9	98.5	107.4	136.9

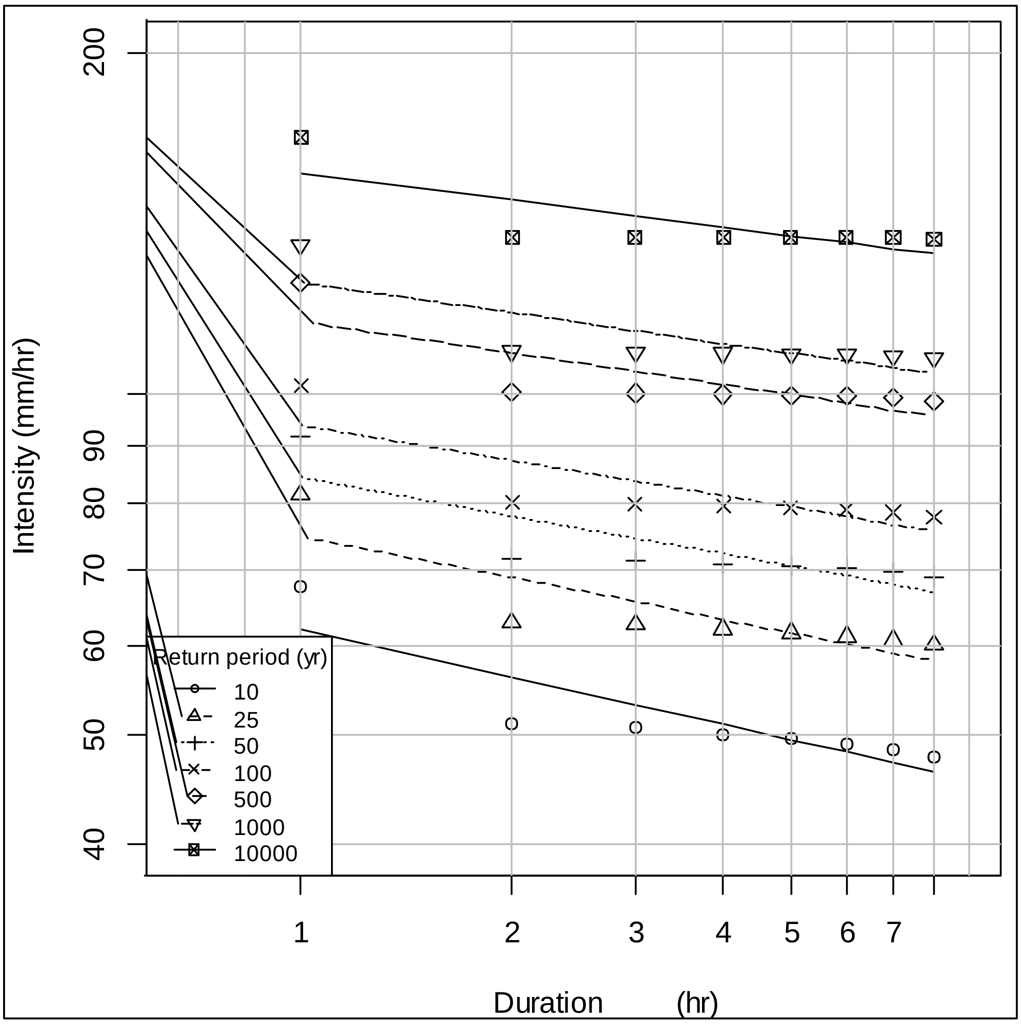

Figure 79: IDF curves for Ganze boys

Table 6 shows is the IDF table for Habasweni DC offices, the extreme rainfall events likely to occur range from 30.2 mm/hr in one hour after a return period of 10 years to 96.0 mm/hr in one hour with a return period of 10000 years. Figure 80 shows the IDF curves for Habasweni.

Table 6: IDF table for Habasweni DC office

Duration (Hours)	**RETURN PERIOD (YEARS) FOR HABASWENI**						
	10	**25**	**50**	**100**	**500**	**1000**	**10000**
1	30.2	39.1	45.8	52.4	67.6	74.2	96.0
2	28.1	36.2	42.2	48.1	61.9	67.8	87.5
3	24.2	30.7	35.5	40.3	51.4	56.1	71.9
4	21.4	26.7	30.7	34.6	43.7	47.6	60.6
5	19.4	24.0	27.5	30.9	38.8	42.2	53.5
6	19.1	23.3	26.4	29.5	36.6	39.6	49.8
7	16.4	20.0	22.6	25.3	31.3	34.0	42.6
8	15.4	18.6	21.0	23.4	28.9	31.3	39.2

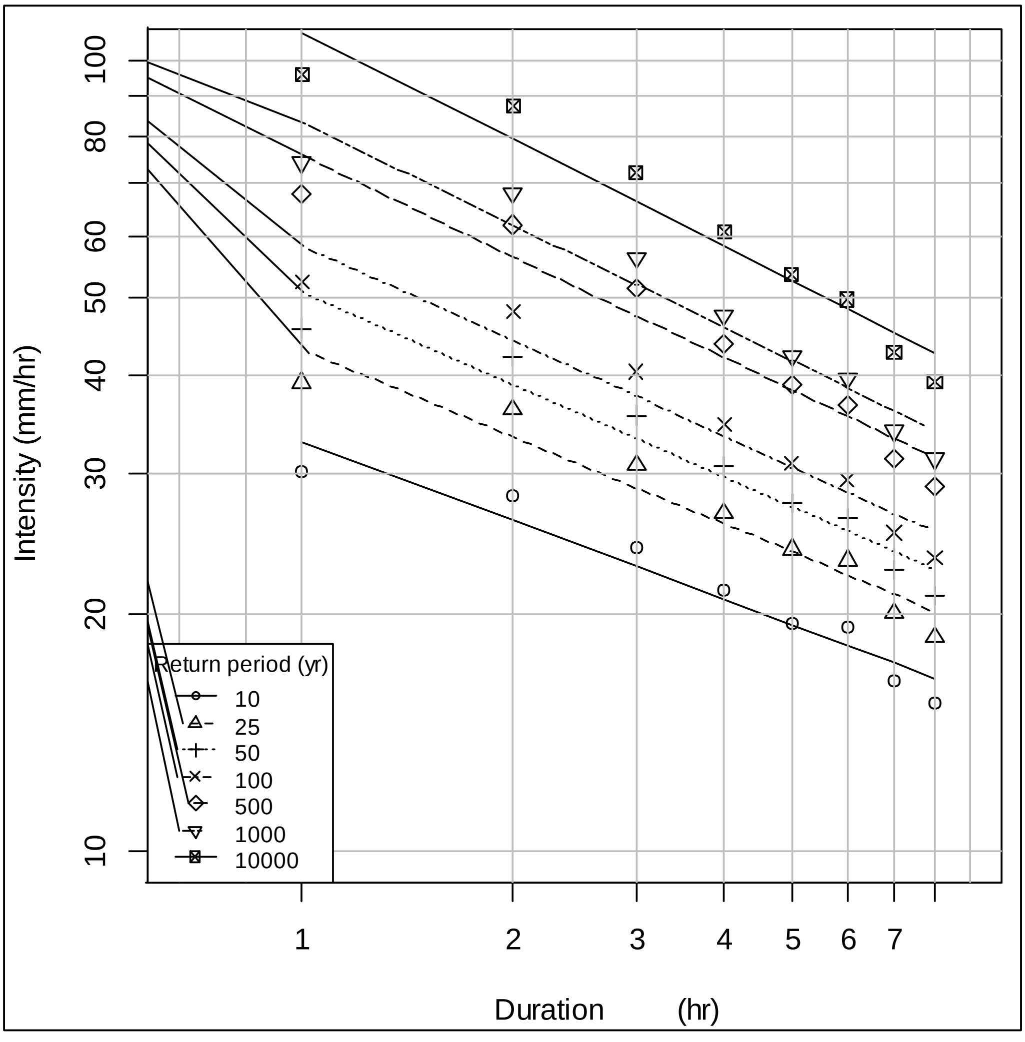

Figure 80: IDF curves for Habasweni

Table 7 shows the IDF table for Kaaga boys high school. An extreme rainfall events of 52.2 mm/hr in one hour is likely to be experienced with a return period of 10 years , while 93.9 mm/hr in one hour is likely to be experienced every 10000 years. Figure 81 shows the IDF curves for Kaaga boys.

Table 7: IDF table for Kaaga boys

Duration (Hours)	**RETURN PERIOD (YEARS) FOR KAAGA BOYS**						
	10	**25**	**50**	**100**	**500**	**1000**	**10,000**
1	52.2	57.9	62.1	66.3	76.0	80.1	93.9
2	50.5	56.4	60.7	65.1	75.0	79.3	93.6
3	49.4	56.1	61.0	65.8	77.1	81.9	98.
4	48.9	56.4	62.0	67.6	80.5	86.0	104.3
5	38.9	45.0	49.5	54.0	64.4	68.9	83.7
6	40.3	47.2	52.4	57.5	69.4	74.5	91.4
7	40.9	48.4	54.0	59.6	72.4	77.9	96.2
8	40.7	48.5	54.3	60.1	73.4	79.2	98.2

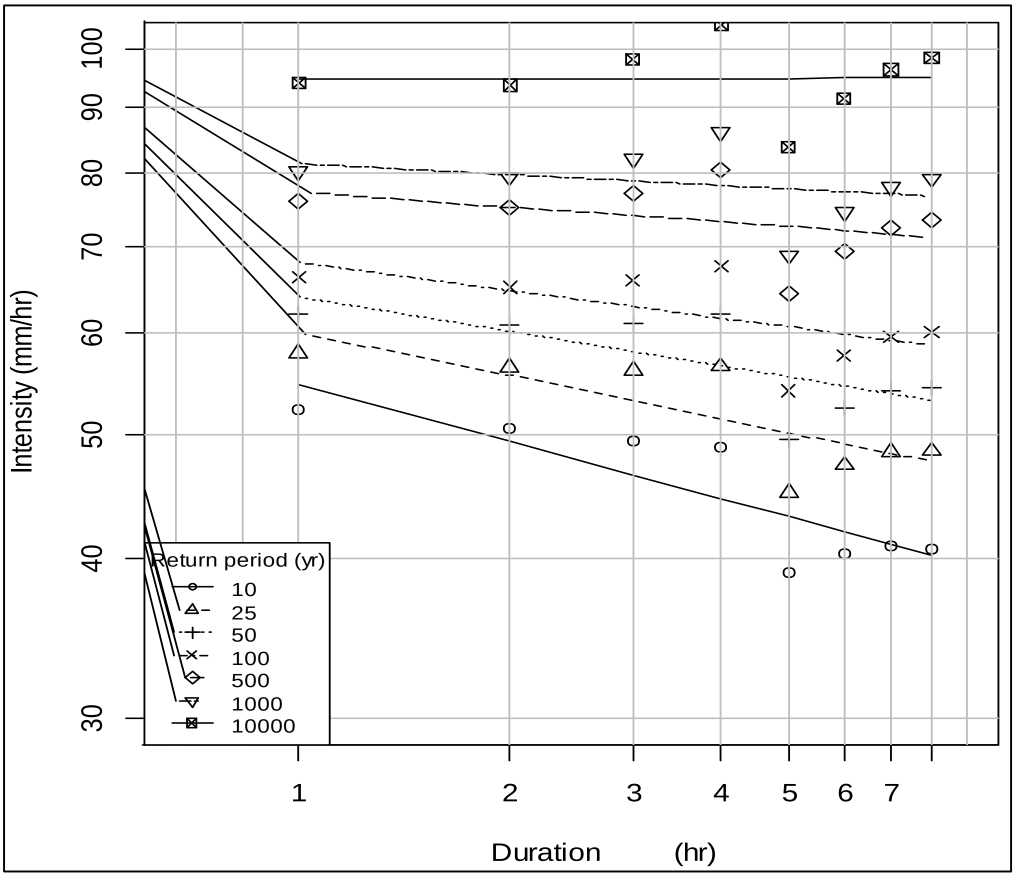

Figure 81: IDF curves for Kaaga boys

Table 8 shows the distribution intensities at Kamusinga friends' school for different return periods and durations, an extreme events of 79.8 mm/hr and 175.2 mm/hr are likely to occur every 10 years and 10,000 years respectively. The IDF curves are shown in figure 82.

Table 8: IDF table for Kamusinga friends' school

Duration (Hours)	**RETURN PERIOD (YEARS) FOR KAMUSINGA FRIENDS'**						
	10	**25**	**50**	**100**	**500**	**1000**	**10000**
1	79.8	92.8	102.5	112.0	134.2	143.7	175.2
2	68.4	79.4	87.5	95.6	114.2	122.2	148.7
3	67.7	78.6	86.6	94.5	113.0	120.9	147.1
4	67.3	78.1	86.1	94.0	112.3	120.1	146.3
5	67.0	77.7	85.7	93.6	111.8	119.6	145.7
6	66.8	77.4	85.4	93.2	111.4	119.2	145.2
7	66.4	77.0	84.9	92.7	110.7	118.5	144.2
8	66.2	76.7	84.5	92.2	110.1	117.8	143.3

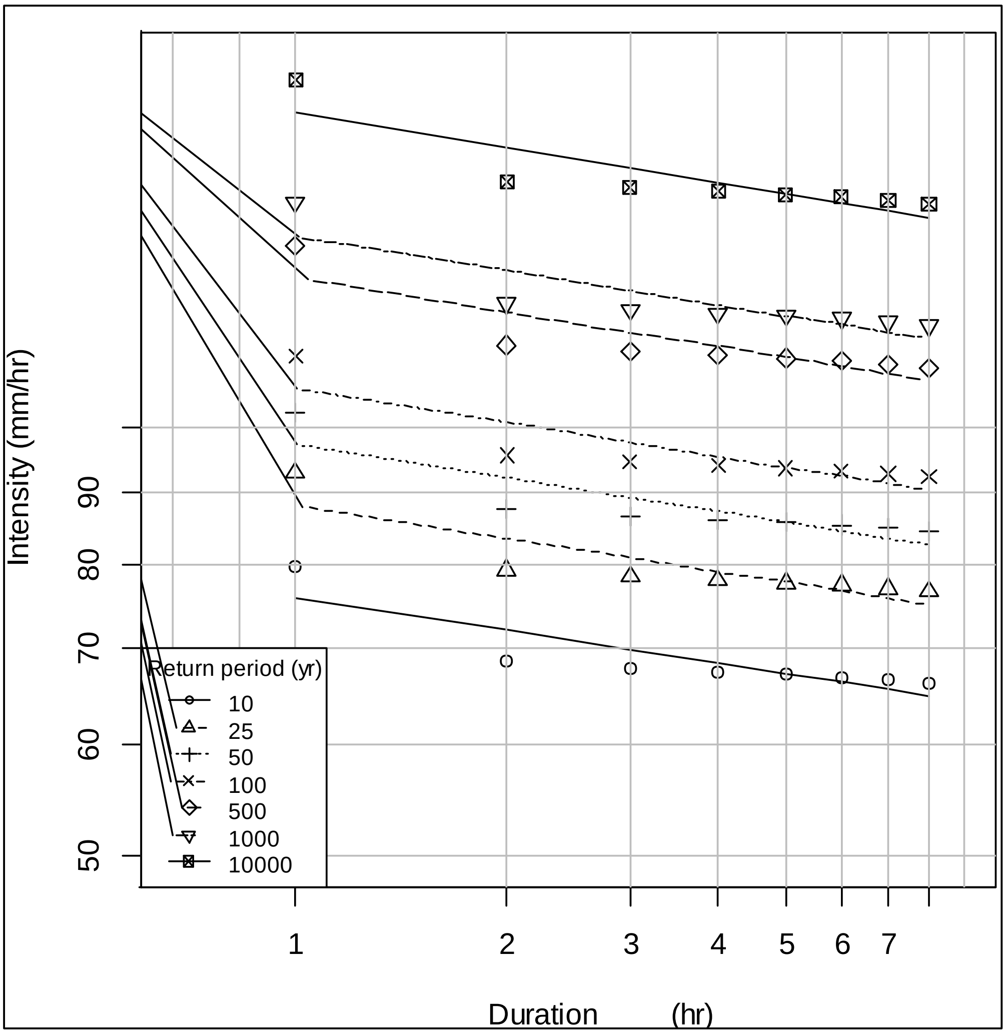

Figure 82: IDF curves for Kamusinga friends' school

Table 9 shows the IDF table at Karima girls' high school, extreme rainfall events of 63.5mm/hr and 118.2mm/hr are likely to be experienced in 10 years and 10,000 years return periods respectively. Figure 83 shows the IDF curves for Karima girls' school.

Table 9: IDF table for Karima girls' high school

Duration (Hours)	**RETURN PERIOD (YEARS) FOR KARIMA GIRLS**						
	10	**25**	**50**	**100**	**500**	**1000**	**10000**
1	63.5	71.0	76.5	82.0	94.7	100.1	118.2
2	56.4	63.7	69.1	74.4	86.8	92.1	109.7
3	56.3	63.5	68.9	74.2	86.6	91.9	109.5
4	56.2	63.4	68.8	74.1	86.4	91.7	109.3
5	56.0	63.3	68.6	73.9	86.2	91.5	109.1
6	55.9	63.1	68.4	73.7	86.0	91.3	108.8
7	55.7	62.9	68.3	73.6	85.9	91.2	108.7
8	55.6	62.9	68.2	73.5	85.9	91.2	108.7

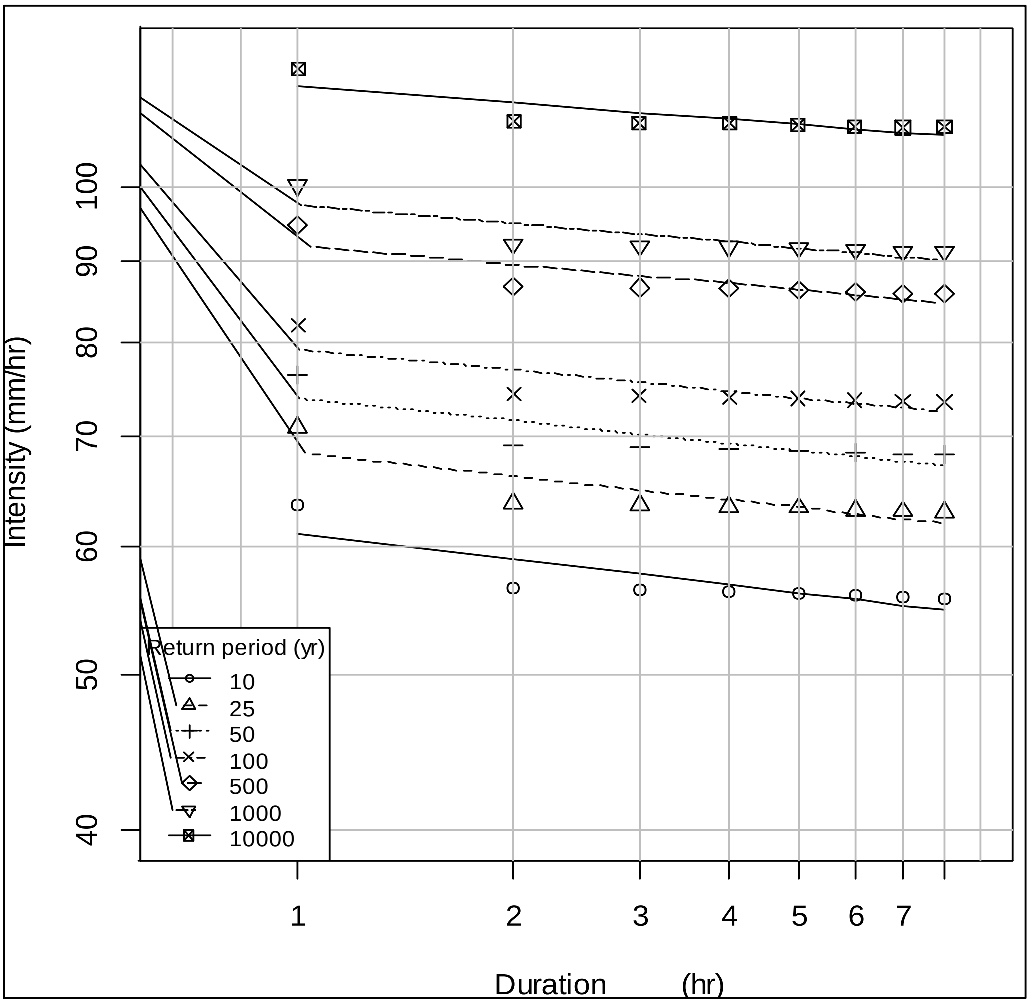

Figure 83: IDF Curves for Karima girls

Table 10 shows the IDF table for Kisoko girls. This region is likely to experience extreme rainfall events of 48.4 mm/hr every 10 years and 93.9 mm/hr every 10000 years. Figure 84 shows the IDF table for Kisoko girls'.

Table 10: IDF table for Kisoko girls

Duration (Hours)	**RETURN PERIOD (YEARS) FOR KISOKO GIRLS**						
	10	**25**	**50**	**100**	**500**	**1000**	**10000**
1	48.4	54.6	59.2	63.7	74.3	78.8	93.9
2	48.1	54.3	58.9	63.4	73.9	78.4	93.4
3	47.4	53.5	58.0	62.4	72.7	77.1	91.7
4	46.8	52.7	57.2	61.5	71.7	76.0	90.5
5	46.5	52.5	57.0	61.5	71.7	76.2	90.8
6	46.5	52.7	57.3	61.8	72.4	77.0	92.0
7	46.6	53.0	57.7	62.5	73.4	78.1	93.7
8	46.7	53.3	58.3	63.2	74.4	79.3	95.4

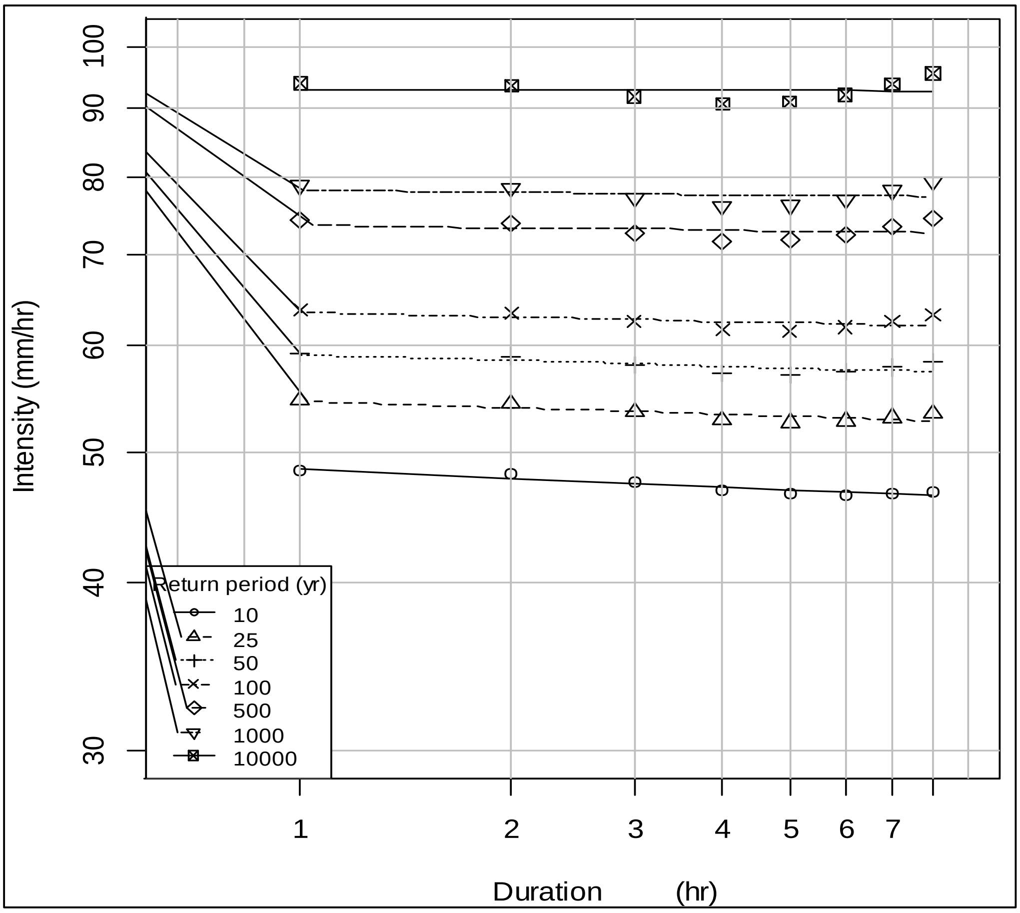

Figure 84: IDF curves for Kisoko girls

Table 11 represents the IDF table for Makueni Boys high school. This area is likely to experience an extreme rainfall events of 58.5 mm/hr every 10 years and 120.5 mm/hr every 120.5 years. Figure 85 shows the IDF curves for Makueni boys.

Table 11: IDF table for Makueni boys

DURATION (HOURS)	RETURN PERIOD (YEARS) FOR MAKUENI						
	10	**25**	**50**	**100**	**500**	**1000**	**10000**
1	58.5	67.0	73.2	79.4	93.8	100.0	120.5
2	57.5	66.3	72.9	79.4	94.4	100.9	122.3
3	56.4	65.7	72.5	79.3	95.0	101.8	124.2
4	55.3	64.8	71.9	78.9	95.1	102.0	125.1
5	53.2	62.4	69.3	76.1	91.8	98.6	121.1
6	51.4	60.4	67.2	73.8	89.2	95.8	117.8
7	50.3	59.3	66.0	72.6	88.0	94.5	116.4
8	49.4	58.4	65.1	71.7	87.0	93.6	115.4

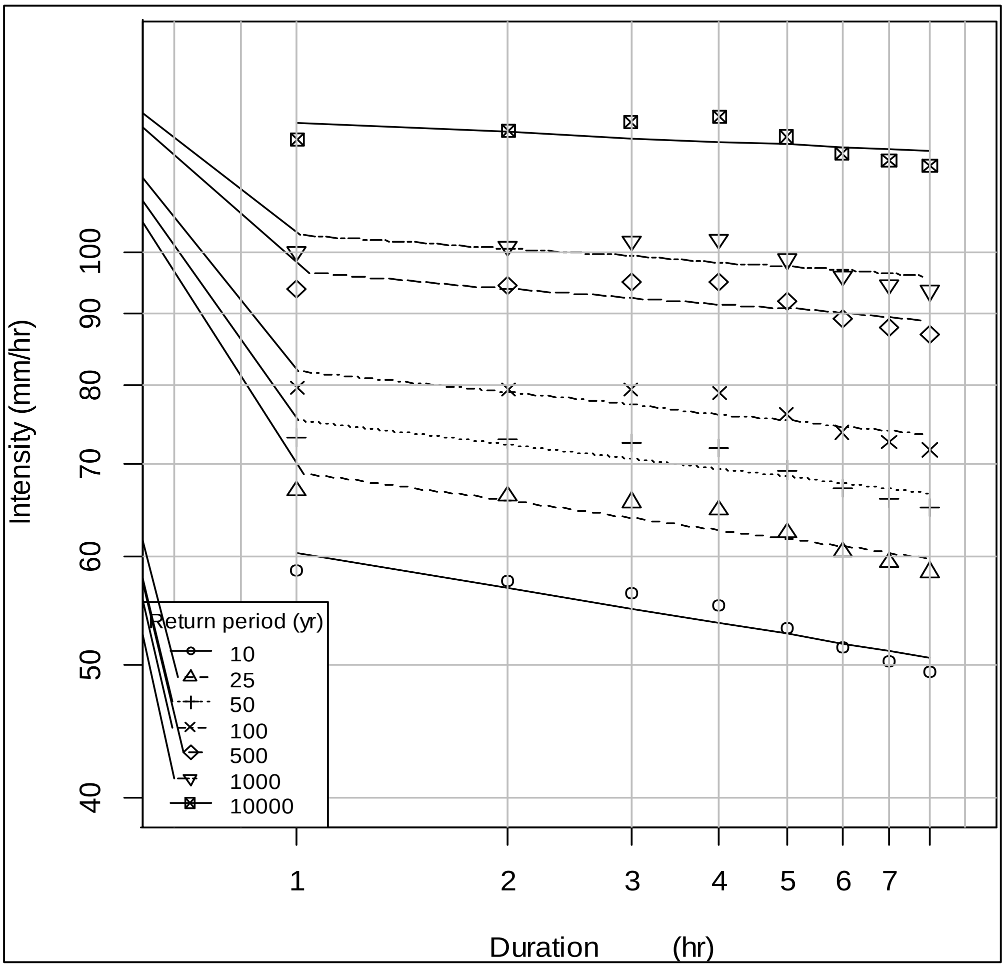

Figure 85: IDF Curves for Makueni boys

Table 12 shows the IDF table for Mkunubi secondary school. This area is likely to experience an extreme event of 67.8mm/hr every 10 years and 189.9 mm/hr every 10,000 years. Figure 86 shows the IDF curves for Mkunubi.

Table 12: IDF table for Mkunubi secondary school

DURATION (HOURS)	**RETURN PERIOD FOR MKUNUBI**						
	10	**25**	**50**	**100**	**500**	**100**	**10000**
1	67.8	84.4	96.8	109.0	137.3	149.5	189.9
2	67.6	84.3	96.7	109.1	137.5	149.8	190.4
3	67.1	83.9	96.4	108.7	137.3	149.6	190.4
4	65.3	81.5	93.5	105.4	133.0	144.8	184.2
5	63.5	79.2	90.9	102.5	129.2	140.8	179.0
6	61.9	77.4	88.8	100.2	126.4	137.7	175.2
7	60.1	75.2	86.4	97.5	123.2	134.2	170.9
8	58.4	73.2	84.3	95.3	120.6	131.5	167.7

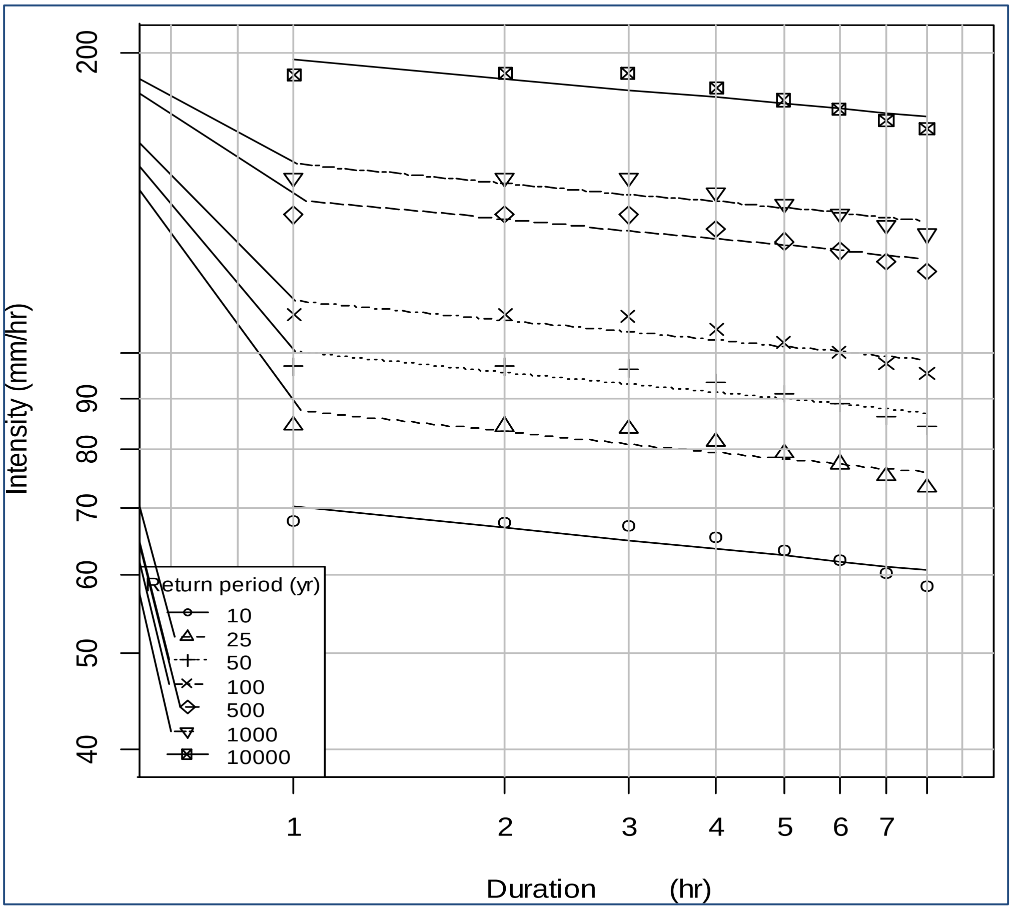

Figure 86: IDF Curves for Mkunubi Secondary

Table 13 shows the intensities for different return periods and durations at Musaria secondary school. This region is likely to experience extreme events of 70.2 mm/hr every 10 years and

182.1 mm/hr every 10,000 years. Extere Figure 87 shows the IDF curves for Musaria secondary school.

***Table 13*: IDF table for Musaria secondary school**

Duration (Hours)	**RETURN PERIOD (YEARS) FOR MUSARIA**						
	10	**25**	**50**	**100**	**500**	**1000**	**10000**
1	70.2	85.4	96.7	108.0	133.9	145.1	182.1
2	70.2	85.4	96.8	108.0	134.0	145.2	182.3
3	70.1	85.4	96.8	108.0	134.1	145.2	182.4
4	70.1	85.4	96.8	108.0	134.1	145.3	182.5
5	69.3	84.4	95.6	106.6	132.3	143.3	179.8
6	68.1	82.8	93.7	104.5	129.5	140.3	175.9
7	67.2	81.7	92.5	103.1	127.8	138.4	173.5
8	66.7	81.2	91.8	102.5	127.0	137.5	172.5

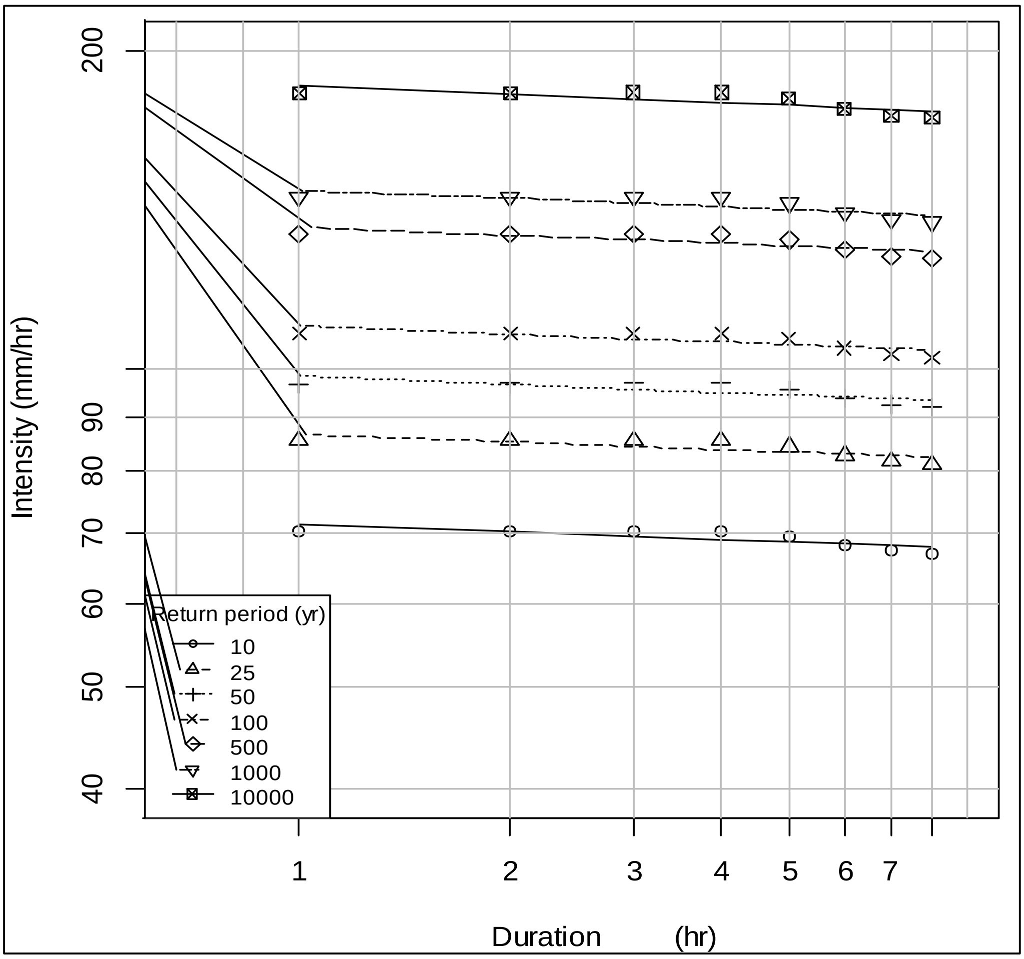

Figure 87: IDF curves for Musaria secondary

Table 14 shows the intensities for different return periods and durations for Namanga secondary school. This region is likely to experience extreme events of 55.8 mm/hr in 10 years and 169.8 mm/hr in 100 years. Figure 88 shows the IDF curves for Namanga secondary school.

Table 14: IDF table for Namanga

DURATION (HOURS)	**RETURN PERIOD (YEARS) FOR NAMANGA**						
	10	**25**	**50**	**100**	**500**	**1,000**	**10,000**
1	55.8	71.3	82.9	94.3	120.7	132.1	169.8
2	55.5	71.1	82.7	94.2	120.8	132.2	170.1
3	55.2	70.9	82.6	94.1	120.9	132.3	170.5
4	52.9	68.1	79.3	90.5	116.4	127.5	164.3
5	51.7	66.8	78.0	89.1	114.7	125.7	162.3
6	51.1	66.1	77.3	88.4	114.0	125.1	161.7
7	50.6	65.8	77.0	88.1	113.9	124.9	161.7

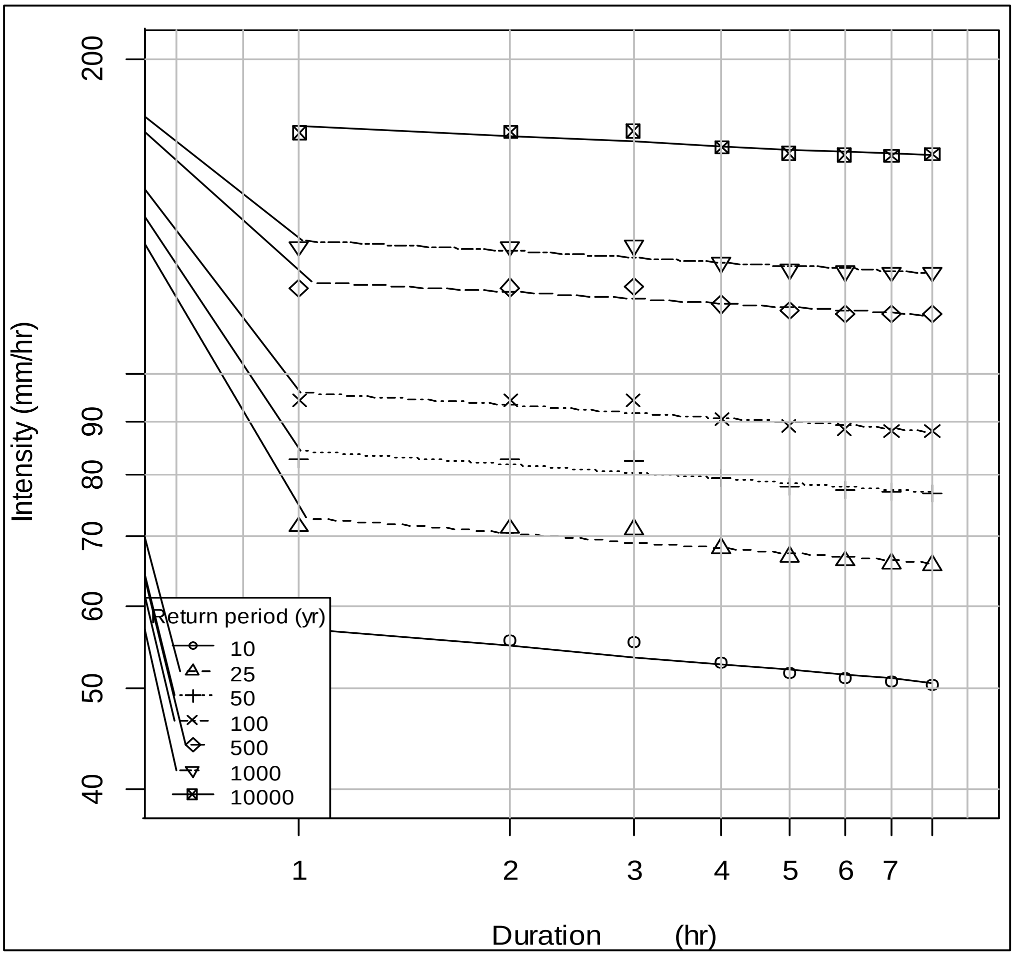

Figure 88: IDF curves for Namanga

Table 15 shows the IDF curves for University of Nairobi Chiromo campus. This area is likely to experience an extreme event of 25.5 mm/hr every 10 years and 62.5 mm/hr every 10,000 years for 1 hour durations. Figure 89 shows the IDF curves for UON Chiromo.

Table 15: IDF table for UON Chiromo

Duration (Hours)	RETURN PERIOD (YEARS) FOR UON CHIROMO						
	10	**25**	**50**	**100**	**500**	**1000**	**10000**
1	25.5	30.5	34.3	38.0	46.6	50.3	62.5
2	25.3	30.4	34.2	38.0	46.8	50.6	63.2
3	25.1	30.4	34.3	38.2	47.3	51.1	64.1
4	23.7	28.7	32.4	36.2	44.8	48.5	60.8
5	23.1	28.1	31.9	35.6	44.2	48.0	60.3
6	22.7	27.9	31.7	35.5	44.3	48.1	60.7
7	22.3	27.5	31.4	35.2	44.1	48.0	60.5
8	21.8	27.1	31.0	34.8	43.8	47.7	62.5

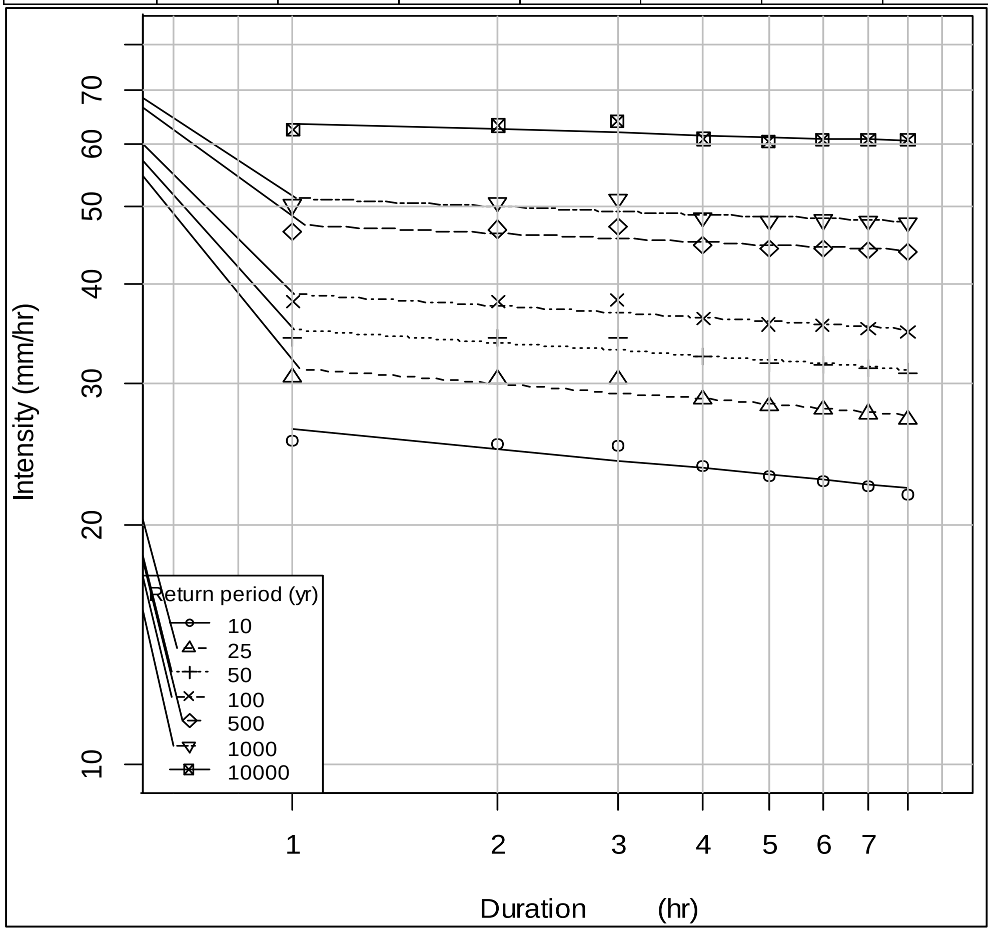

Figure 89: IDF Curves for UON Chiromo

Table 16 is the IDF table for Talent high school, extreme rainfall events of 51.5 mm/hr and 150.5 mm/hr are likely to be experienced for durations of 1 hour and return periods of 10 years and 10,000 years respectively. Figure 90 shows the IDF curves for Talent high school.

Table 16: IDF table for Talent high school

DURATION (HOURS)	RETURN PERIOD (YEARS) FOR TALENT HIGH SCHOOL						
	10	**25**	**50**	**100**	**500**	**1000**	**10 000**
1	51.5	65.0	75.0	84.9	107.9	117.76	150.5
2	50.7	64.1	74.0	83.8	106.5	116.3	148.8
3	47.5	59.9	69.1	78.3	99.4	108.5	138.7
4	45.4	57.3	66.2	75.0	95.4	104.2	133.3
5	43.4	55.0	63.7	72.2	92.0	100.4	128.6
6	41.9	53.2	61.6	69.9	89.1	97.4	124.8
7	40.4	51.5	59.7	67.8	86.6	94.7	121.5
8	38.3	48.8	56.6	64.4	82.3	90.1	115.7

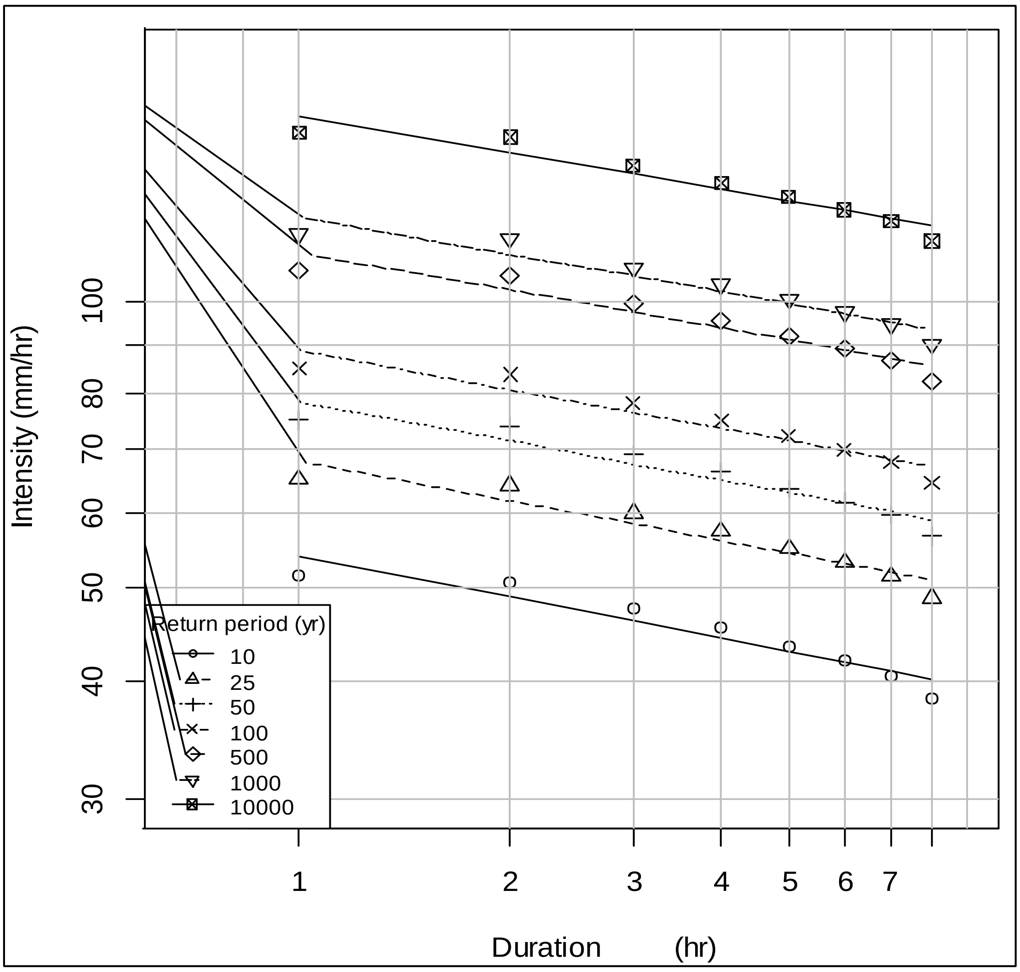

Figure 85: IDF curves for Talent high school

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

This section highlights the different conclusions and recommendations derived from this study.

5.1 Conclusion

Rainfall is very important in Kenya for replenishing our fresh water resources. However extreme rainfall events lead to loss of infrastructure and flooding which is detrimental to our economy. Therefore it is important to study the spatial and temporal characteristics of our rainfall events so that we can build infrastructure which can withstand these events.

5.1.1 Duration of rainfall events in Kenya

This study analysed the durations of rainfall events in Kenya. The results show that 82% of the recorded rainfall events in Kenya last one to two hours. Whereas only 5% of the events lasted between 4-8 hours. This shows that most of the rainfall events in Kenya are formed through convection. Kenya being a country in the tropical region there is a lot of insolation, where the ground if heated, it heats the air near the ground and the air raises, if air is moist enough it condenses and rainfall forms. Rainfall from convection last shorter duration.

Three to eight hour events were also observed totalling to 5% of all recorded events. These could be associated with the cooling of the atmosphere at night, as the temperatures come down the air becomes saturated yielding to low intensity events lasting longer durations such as drizzles.

5.1.2 Intensity of rainfall events in Kenya

This study analysed the intensity of rainfall events for all the stations around Kenya. The results show that the intensity of rainfall events vary from station to station. However low intensity rainfall events are the most common ones. These include drizzles, light and moderate rainfall events. However significant number of heavy and very heavy rainfall events were also

This study has showed that lower intensity rainfall events are the most common in Kenya, however it was also established that high intensity (>20 mm/hr) events also occur. These are of interest because they're responsible for flash floods and destruction of infrastructure.

5.1.3 Rainfall thresholds in Kenya

Rainfall threshold defines the average rainfall intensity received during the peak duration of rainfall. The peak duration of rainfall varies for different regions of the country, varying from 0.7 hours (42 minutes) to 1.5 hours (90 minutes). Regions with high rainfall thresholds and lower peak durations experience rainfall in short torrential storms which means that these areas are most likely to experience flash floods after rainfall events.

The North eastern parts of the country and the southern counties of Kajiado and Narok are most prone to flash floods. Even though these regions may not report the highest annual amounts of rainfall, the rainfall events are very significant because high intensities of rainfall are received within very short durations.

The highland regions in the central part of Kenya have the lowest thresholds. This is because the rainfall here is formed through orographic lifting as moist air is lifted by Kenya's terrain, resulting in rainfall events of lower intensity lasting a longer duration.

5.1.4 Intensity-duration-frequency distribution of rainfall in Kenya

IDF curves in Kenya are an accurate way of establishing the expected design rainfall events over given return periods and durations. From this study, these have also been shown to vary from place to place.

5.2 Recommendation

This study recommends for more research on rainfall events using longer data sets and different methods to provide more insights on rainfall threshold, intensity, duration, frequency of rainfall in Kenya.

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